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Persistent Organic Pollutants in Sediments from Sai Gon–Dong Nai River Basin, Vietnam: Levels and Temporal Trends

Nguyen Hung Minh,[1] Tu Binh Minh,[1] Hisato Iwata,[1] Natsuko Kajiwara,[1] Tatsuya Kunisue,[1] Shin Takahashi,[1] Pham Hung Viet,[2] Bui Cach Tuyen,[3] Shinsuke Tanabe[1]

[1] Center for Marine Environmental Studies, Ehime University, Bunkyo-cho 2-5, Matsuyama 790-8577, Japan
[2] Hanoi National University, 334 Nguyen Trai Street, Thanh Xuan District, Hanoi, Vietnam
[3] Nong Lam University, Thu Duc District, Hochiminh City, Vietnam

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Abstract. Surficial sediment samples were collected from Hochiminh City canals, the Sai Gon–Dong Nai River, and its estuary, one of the most predominant industrial areas in Hochiminh City, southern Vietnam, for determination of selected persistent organic pollutants (POPs). Contamination pattern was as follows: PCBs ≥ DDTs > HCB > CHLs > HCHs. Concentrations of PCBs and DDTs ranged from 0.50–150 ng/g and 0.15–72 ng/g dry wt, respectively. On the other hand, concentrations of CHLs, HCHs, and HCB were mostly <2 ng/g dry wt. Levels of the all organochlorines (OCs) in Hochiminh City canals were significantly higher than those in the other areas, indicating the urban areas as major pollution sources to the aquatic environment. The contamination pattern was PCBs > DDTs in the city canals but PCBs < DDTs in the downstream and the estuary, suggesting particularly high contamination by PCBs in the city. Examination of DDTs composition and their ratios demonstrated continuous input of this pesticide to the city canals. However, the combination of our data and those from available literature implies a decreasing trend of PCBs and DDTs in the environment. DDTs concentrations have been reduced 50% after approximately 5 years. Composition of CHLs in the sediment from Hochiminh City canals was comparable to those of common technical mixtures, suggesting continuous input of CHLs to the environment. CHLs might be in use for purposes like termite control, wood preservation, and protection of underground cables. Hazard assessment implies high toxic potential of DDTs for sediments from Hochiminh City canals and suggests the need for better management of municipal discharges.

Key words: Persistent organochlorine—Sediment—Temporal trend—Vietnam

Correspondence to: Shinsuke Tanabe; *email:* shinsuke@agr.ehime-u.ac.jp

The Sai Gon - Dong Nai (SG-DN) River in Southern Vietnam has an important role in social and economic development in Vietnam since this basin encompasses the Southern Principal Economic Zone including Hochiminh City (HCMC), Binh Duong, Dong Nai, and Ba Ria Vung Tau Provinces. These provinces are the most predominant industrial areas in Vietnam with a high rate of economic growth. The river is one of the important sources of water for almost 7 million people living in the catchment areas. Rapid development in this region, however, has raised concerns about the local environment and ecological integrity (Anh et al. 2003). Large amounts of untreated municipal and industrial wastewater as well as accidental spills are released directly into the canal systems of the river. Besides, municipal solid wastes are dumped in open areas with poor management and, therefore, runoff from flood and rain events carry various toxic contaminants from these sites to the surface waters. Protection and remediation of the river from various pollutions caused by toxic discharges have become important tasks for sustainable development in this region, especially when demand for water supply has been increasing rapidly.

In Vietnam, persistent organic pollutants (POPs) such as dichlorodiphenyltrichloroethane (DDTs), chlordane compounds (CHLs), hexachlorocyclohexane (HCHs), and hexachlorobenzene (HCB) were largely used for over the last 30 years for various purposes like agriculture, industries, and malaria control. Sinh et al. (1999) reported that before 1985, about 6,000 to 9,000 tons per year of organochlorine (OC) pesticides were used in agriculture. Besides, usage of DDT for vector control was continued until 1995, when its application was officially banned. Despite this fact, several studies have indicated that contamination by OC pollutants in Vietnam has continued until recently (Kannan et al. 1992, Nhan et al. 2001, Minh et al. 2002, 2004, 2006).

Understanding contamination by OCs as well as their sources and potential toxic effects on the SG-DN River is an important task in order to protect the environment and the ecological systems. Because OCs have a very long half life in sediment, examining their levels in sediment may give basic information on the contamination status, sources, and

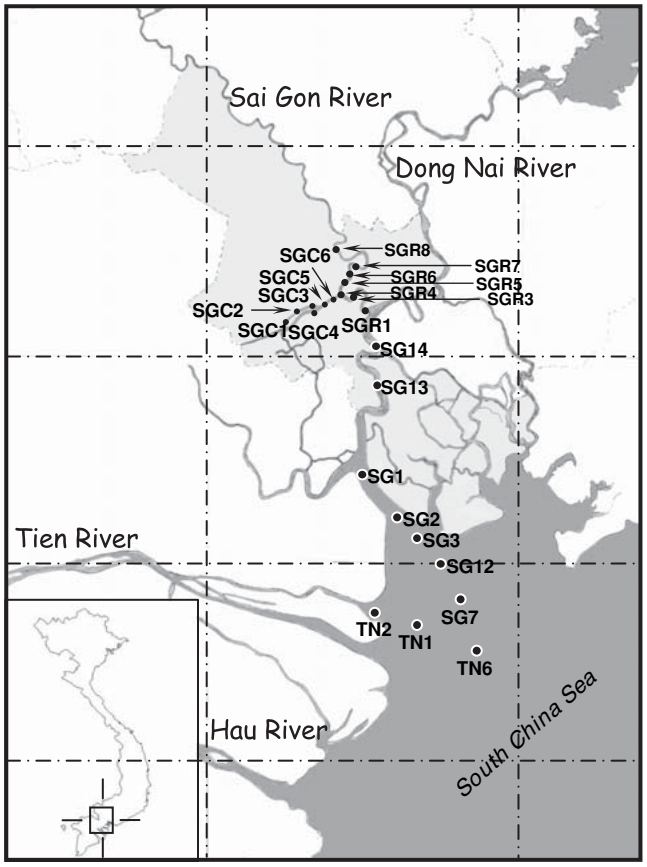

Fig. 1. Map showing sediment sampling sites in May 2004

ecological risk assessment. In this study, sediment samples were collected along the river for analysis of OCs. The results are expected to provide information for public and environmental authorities on the contamination in the region.

Materials and Methods

Samples

Twenty-one surface sediment samples were collected in May 2004 from areas of HCMC using stainless-steel grabs (Fig. 1). Sediments were collected from 0–5 cm depth. Sediment samples were divided into three categories: (1) sediments from internal canal systems of HCMC (SGC 1–SGC 6); (2) sediments from the SG-DN River (SGR 1–SGR 8, GS 13, GS 14), and (3) sediments from the SG-DN River estuary (SG 1, 2, 3, 7, and TN 1, 2, 6; hereafter cited as the estuary samples). Sediment samples were stored in clean polyethylene bags and transported to our laboratory in boxes packed with dry ice. In the laboratory, the sediment samples were kept at −20°C until analysis. Moisture content of sediment was determined by gravimetric method by heating about 2 g of wet sediment at 130°C for 12 hours. For TOC analysis, about 2–3 g of dry sediment were treated with hydrochloric acid 6N to remove carbon in the inorganic carbonate form. The sample was then washed 3 times by water and dried again in oven at 110°C for 12 hours. The dry sample was grounded and subjected for TOC analysis using CHN coder (MT-5; Yanaco, Kyoto, Japan).

Chemical Analysis

Organochlorines were analyzed following the method described by Iwata et al. (1994) with some modifications. Approximately 20 g of wet sediment sample was placed in a conical flask and 100 ml acetone was added before the flask was shaken vigorously for 60 minutes in an electric shaker (SR-2W model, Taitec Co. Ltd.). The solution was filtered into a separatory funnel containing 600 ml of hexane-washed water and 100 ml of hexane. The funnel was shaken vigorously for 15 minutes and then kept for at least 8 hours to separate the aqueous and hexane layers. The aqueous layer was discarded and the hexane layer was washed three times with 100 of ml water. The volume of hexane in the final solution was measured for calculating the volume recovery from an initial 100 ml (this value was used as a correction factor when calculating the final result). The solution was concentrated to about 10 ml in a Kuderna-Danish apparatus and further to 5 ml by a gentle stream of nitrogen. An equal volume of concentrated H_2SO_4 was added to this solution to remove pigment, humic acids, and other organic interferences. This step was repeated several times until the hexane layer became transparent. The solution was further washed by hexane-washed water for 3 times. Then 4 ml of the remaining solution was subjected to cleaning up by a gel permeation chromatography system (GPC), separated by Florisil column chromatography, and treated with activated copper to remove sulfur-containing substances. A final solution was further concentrated to about 20–40 times the original volume, prior to analysis by gas chromatography with election capture detection (GC/ECD). The details of quantification using GC/ECD were similar to those previously described (Minh et al. 2006). A procedural blank was run for every batch of five samples for cross-verification. Recovery rates obtained by this procedure were as follows: HCHs, 85–91 %; HCB, 91%; PCBs, 108%; CHLs, 87–98%, and DDTs, 82–103%. The reported concentrations were not corrected with recovery values.

Statistical Analysis

The statistical analysis was performed using StatView software (SAS Institute Inc., V.5, 1998). The Mann-Whitney U test was used to examine statistical differences between groups ($p < 0.05$). Spearman's rank correlation test was used to examine significance of correlations among residue levels of the contaminants.

Results and Discussion

Residue Levels and Contamination Pattern

In general, mean concentration of OCs for all three categories of sediments (including HCMC canals, SG-DN River, and SG-DN estuary) followed the order: PCBs > DDTs > HCB > CHLs > HCHs (Table 1). However, this contamination pattern was different, particularly for PCBs and DDTs, if three subcategories were examined separately. For instance, in the SG-DN River and in the HCMC canals, PCBs are one to three times higher than DDTs. On the other hand, in the SG-DN estuary, DDTs are more abundant than PCBs. This implies the high contamination by PCBs in HCMC. Spatial distribution of OCs demonstrates significantly higher concentrations of PCBs, DDTs, CHLs, and HCB in HCMC canals, compared to the SG-DN River as well as the SG-DN River compared to the estuary ($p<0.05$; Table 1). Such spatial differences in OC concentrations remained unaffected when the concentrations

Table 1. Concentration (ng/g dry wt.) of Ocs in sediments from Hochiminh city, Vietnam

	Sampling location							
Sample ID	Latitude	Longitude	TOC(%)	PCBs	DDTs	CHLs	HCHs	HCB
Hochiminh city canals								
SGC 1	N10°45′02.0″	E106°41′01.1″	3.2	47	12	2.0	<0.05	18
SGC 2	N10°45′05.2″	E106°41′00.9″	3.8	65	39	4.5	<0.05	3.5
SGC 3	N10°44′58.5″	E106°40′15.1″	4.2	100	41	2.9	<0.05	<0.1
SGC 4	N10°44′37.0″	E106°39′04.0″	4.9	150	72	1.1	<0.05	5.6
SGC 5	N10°45′39.5″	E106°41′47.6″	3.2	46	21	0.58	<0.05	4.4
SGC 6	N10°45′49.7″	E106°41′56.2″	4.6	76	37	0.89	<0.05	7.3
Mean			4.0	81	37	2.0	-	6.6
Sai Gon-Dong Nai River								
SGR 1	N10°44′29.2″	E106°44′44.1″	2.0	1.8	1.9	0.071	<0.01	0.043
SGR 3	N10°46′06.6″	E106°45′12.3″	1.9	8.5	4.7	0.20	<0.01	0.20
SGR 4	N10°45′34.7″	E106°43′39.9″	2.2	5.4	5.3	0.53	0.030	0.22
SGR 5	N10°45′55.5″	E106°42′42.6″	3.8	22	23	1.0	<0.01	0.61
SGR 6	N10°46′40.9″	E106°42′32.5″	2.4	9.5	6.3	0.33	<0.01	0.30
SGR 7	N10°47′55.0″	E106°43′34.0″	2.8	3.8	1.1	0.063	<0.01	<0.001
SGR 8	N10°48′38.0″	E106°43′17.0″	3.1	8.8	5.5	0.24	<0.01	0.53
SG 13	N10°50′21.9″	E106°42′15.6″	2.1	0.33	0.21	0.016	<0.01	0.0057
SG 14	N10°36′91.8″	E106°46′51.0″	1.5	1.6	1.8	0.040	<0.01	0.0075
Mean	N10°41′70.6″	E106°45′60.6″	2.4	6.8	5.6	0.28	0.011	0.24
Sai Gon-Dong Nai River estuary								
SG 1	N10°27′36.7″	E106°46′11.4″	1.6	0.53	0.52	0.030	<0.005	0.0061
SG 2	N10°23′66.6″	E106°49′47.1″	1.3	1.2	0.82	0.036	<0.005	0.0077
SG 3	N10°22′57.0″	E106°49′34.0″	2.1	2.4	5.4	0.062	<0.005	<0.001
SG 7	N10°14′97.7″	E106°55′29.7″	1.5	0.49	0.43	0.012	<0.005	<0.001
TN 1	N10°13′24.4″	E106°50′65.3″	0.44	0.49	0.90	0.037	0.022	0.087
TN 2	N10°15′26.0″	E106°45′53.9″	0.91	0.51	0.15	0.010	0.021	<0.001
TN 6	N10°07′18.2″	E106°57′80.4″	0.49	0.73	0.39	0.014	0.022	0.11
Mean			1.2	0.90	1.2	0.029	0.012	0.031

DDTs = *p,p′*-DDE + *p,p′*-DDD + *p,p′*-DDT; HCHs = α-HCH + β-HCH + γ-HCH; CHLs = *trans* –chlordane + *cis* –chlordane + *trans* –nonachlor + *cis* –nonachlor when results were less than quanitification limits, the limits were inserted to calculate means.

were normalized to total organic carbon content. However, it should be noted that TOC of sediments from HCMC canals (mean 4%) were higher than those in estuary sediments (mean 1.2%). This clearly suggests that the urban areas of HCMC act as emission sources of OCs to the aquatic ecosystem of the SG-DN River and nearby coastal areas.

The present contamination pattern agrees well with those observed in sediments collected from HCMC canals in 1996 that showed a higher contamination of PCBs than DDTs (Phuong et al. 1998). However, a different pattern was found in human breast milk collected from the same city in 2001 (Minh et al. 2004). Since PCBs and DDTs have relatively comparable bioaccumulation factors in aquatic food webs (Hoekstra et al. 2003), different patterns of PCBs and DDTs in sediment and human breast milk may indicate that exposure to PCBs derived from HCMC canal sediment through the food chain is not significant to the HCMC population. In fact, we did not find aquaculture along the HCMC canals during our sampling. Nevertheless, transport of elevated residues of persistent organic pollutants (POPs) from the city canals to the SG-DN River may result in contamination of much larger areas of the estuary and coastal areas.

PCB residue levels varied from 12 to 72 ng/g dry wt. in HCMC canals, 0.33–22 ng/g in the SG-DN River, and 0.49–2.4 ng/g in the SG-DN estuary. These levels are about 3 to 6 times lower compared to previous results reported in the early 1990s (Table 2; Phuong et al. 1998; Iwata et al. 1994). This finding demonstrates decreasing levels of PCBs in the aquatic environment of the SG-DN River system. Studies in various environmental matrices as well as in Vietnamese human tissues consistently found high PCB levels compared to other Asian developing countries, suggesting additional releases from heavy weapons used during the Indochina War (Kannan et al. 1992, Thao et al. 1993).

Table 2. Correlation among concentrations of PCBs, DDTs, CHLs and total organic carbon content (TOC)

	TOC	PCBs	DDTs	CHLs
TOC	1			
PCBs	0.82**	1		
DDTs	0.85**	0.97**	1	
CHLs	0.62*	0.63*	0.64*	1

*$p < 0.05$, **$p < 0.0001$.

In general, DDTs are the most abundant OC contaminants found in the environment of Vietnam. Although, the prohibition of DDTs has been implemented in Vietnam since 1995, this chemical perhaps is continuously used until recent years. Moreover, consistent spatial pattern showing their higher levels in urban sites compared to agricultural areas suggests sources from the usage for vector control and hygienic purposes (Minh et al. 2002, 2004, 2006, Monirith et al. 2003, Nhan et al. 2001). In the present study, the fact that DDTs

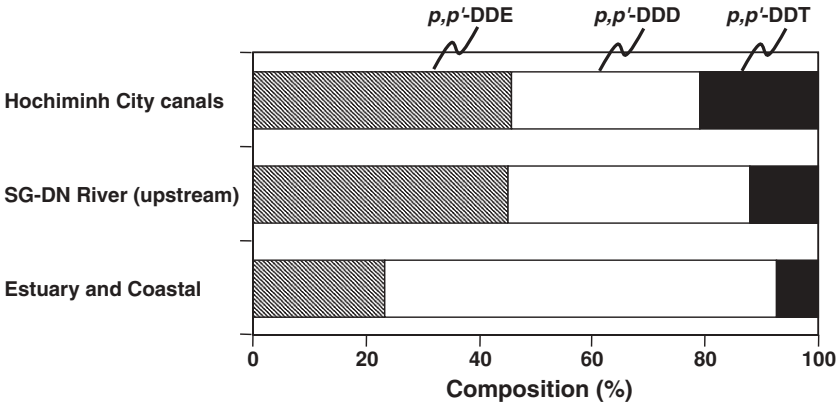

Fig. 2. Composition of DDT compounds in sediment collected from Hochiminh City, the Sai Gon–Dong Nai River and its estuary

levels in HCMC urban areas are about 7–10 times higher than those in other locations (Table 1) may support the hypothesis. Besides, usage of the insecticide dicofol, which contains DDTs as byproducts, can also be suggested as a pollution source of DDTs. In China, about 8800 tons of DDT were estimated to enter the environment from 1988–2002 through usage of dicofol (Qiu et al. 2005). Accurate data of usage of dicofol in Vietnam are not available, although Minh et al. (2006) suggested that this chemical might be have been used in Vietnam in recent years. Perhaps further studies regarding the characterization of DDT pollution in Vietnam is necessary.

Contamination by CHLs in Vietnam was scarcely investigated compared to PCBs and DDTs. Available data in human breast milk and sediment (Minh et al. 2004, Iwata et al. 1994) demonstrate slightly higher levels of CHLs in South Vietnam compared to other areas. In the sediment survey in 1990, Iwata et al. (1994) reported CHL levels of about 8.8–20 ng/g dry wt. in HCMC urban areas and 0.14–0.79 ng/g in estuarine and coastal areas. These levels are approximately an order of magnitude higher compared to that of the present study (Table 1), suggesting decreasing contamination by CHLs in the environment. Interestingly, similar spatial distribution showing higher CHL levels in urban areas than in suburban and rural areas is observed in the present survey as well as that in 1990 (Iwata et al. 1994) and 1997 (Monirith et al. 2003). This fact suggests that the major usage and emission of CHLs are in urban areas of Vietnam. CHLs might have been used for termite control, wood preservation (Monirith et al. 2003), and protective treatment for underground cables (ATSDR 1995).

Composition and Correlation of Pollutants

Composition of DDT compounds demonstrates differences in *p,p*'-DDT proportion among the three subgroups, showing a decreasing gradient from the city canals to the SG-DN River and the estuary (Fig. 2). It is well known that a higher proportion of *p,p*'-DDT indicates more recent residues of DDT in the environment and biota. Hence, the above result perhaps suggests more recent input of DDT to the urban aquatic environment. In fact, use of DDT was officially prohibited in Vietnam in 1995. However, continuous input of DDT and its metabolites to the environment as well as their elevated concentration in humans and wildlife have been recorded

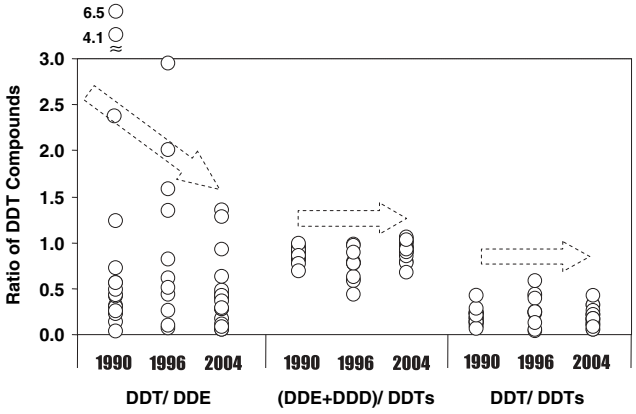

Fig. 3. Ratios of DDT compounds in sediments collected in Hochiminh City region in 1990 (Iwata et al. 1994), 1996 (Phuong et al. 1998), and 2004 (the present study)

throughout the country (Phuong et al. 1998, Nhan et al. 2001, Monirith et al. 2003, Minh et al. 2002, 2004).

Ratios of the three major compounds, DDT, DDE, and DDD, can be assessed in order to understand the chronology of input of DDT residues in the environment. Strandberg et al. (1998) suggested that ratios of DDT/DDE in sediments higher than 0.5 may indicate recent input of DDT. In contrast, the ratios less than 0.3 suggest past input of DDT. In addition, ratio of (DDE + DDD)/ΣDDTs was used for similar assessment (Hong et al. 1999, Zhang et al. 1999). The (DDE + DDD)/ΣDDTs ratio higher than 0.5 may indicate old DDTs residues while those less than 0.5 imply recent input. In this study, we attempted to use both of the approaches for assessing input of DDT in the HCMC region. Published data regarding DDTs in sediment from the HCMC region (Iwata et al. 1994; Phuong et al. 1998) were also gathered to provide a better evaluation. Despite the fact that DDT/DDE values seem to have decreased from 1990 to 2004, the ratio in some sediment samples collected in 2004 is still higher than 0.5 (Fig. 3), suggesting recent input of DDT to the environment. Alternatively, the ratio of (DDE + DDD)/ ΣDDTs appears to show no clear trend during this period. Moreover, this ratio in most of the sediment samples is higher than 0.5, which is the criteria of the later approach, indicating past residues of DDT compounds. Considering the fact that DDT was used in Vietnam officially until 1995 (Sinh et al. 1999), this assessment may not

Table 3. Comparison of organochlorines in surface sediments from various locations in the world [a]

Country	Year	*n*	PCBs	DDTs	Reference
Vietnam					
Duyen Hai (Mangroves)	1990	9	5.2	8.5	Iwata et al. (1994)
Hanoi (Urban areas)	1997	12	11	30	Nhan et al. (2001)
Hanoi (Outskirt)	1995–1996	2	5.5[b]	10	Nhan et al. (1998)
Hochiminh city canal	2004	6	81	37	This study
Hochiminh city canal	1996	10	220	80	Phuong et al. (1998)
Hochiminh (Urban areas)	1990	4	310	240	Iwata et al. (1994)
Hochiminh (Outskirt)	1990	5	5.9	10	Iwata et al. (1994)
North coast	1995–1996	4	1.7[b]	5.5	Nhan et al. (1998)
Sai Gon-Dong Nai River	2004	9	6.8	5.6	This study
Sai Gon-Dong Nai Estuary	2004	7	0.90	1.2	This study
World					
China (Pearl River Estuary)	1996–1997	20	0.7	2.8	Hong et al. (1999)
China (Minjiang River)	1999	9	35	6.7	Zhang et al. (2003)
China (Daya Bay)	1999	14	8.8	2.7	Zhou et al. (2001)
China (Lingding Bay)	1997	6	10–12[d]	2.6–115	Kang et al. (2000)
China (Macao Harbor)	1997	1	340	1630	Kang et al. (2000)
Korea (Ulsan Bay)	2001	32	—	3.3	Khim et al. (2001)
Korea (Masan Bay)	1997	20	15	13.6	Hong et al. (2003)
Taiwan (Wu-Shi-River)	1997–1998	19	—	2.5	Doong et al. (2002a)
Taiwan (Da-han River)	1997–1998	20	—	0.90	Doong et al. (2002b)
Taiwan (Erh-Jen River)	1997–1999	20	—	0.72	Doong et al. (2002b)
Egypt (Alexandria harbor)	1998	23	260[c]	87[c]	Barakat et al. (2002)
Russia (Lake Baikal)	1992	6	6.1	2.7	Iwata et al. (1995)
Ukraine (Black Sea)	1995	2	5.7–6.8[d]	35–65	Fillmann et al. (2002)
Ukarine (Coastline)	1995	2	nd–0.4	0.06–0.6	Fillmann et al. (2002)
Ukarine (Danube River)	1995	2	1.4–2.7	9.2–43	Fillmann et al. (2002)
Brazil (Amazon region)	1997	7	—	24	Torres et al. (2002)
Canada (6 lakes)	1992–1995	7	15	1.3	Rawn et al. (2001)

[a] Mean concentration in ng/g dry wt.
[b] Quantified using Arochlor 1254 mixture.
[c] Median value.
[d] Range is given when mean value is not available.

be appropriate. Perhaps in this particular situation, the earlier approach might provide more reliable assessment, which suggests recent DDT input to the aquatic environment of the HCMC region. The recent inputs of DDTs into the environment might have come from illegal usage of DDT as well as dicofol, the pesticides that contains DDTs as byproducts. Commercial dicofol contains *o,p*'-DDT, *p,p*'-Cl-DDT, *o,p*'-DDE, and *p,p*'-DDT as major impurities with a relatively small proportion of *p,p*'-DDT (Qiu et al. 2005). The use of dicofol may contribute as an additional proportion of *p,p*'-DDT. In addition, the degradation of DDT to DDD by microflora under anaerobic conditions cannot be ruled out. In fact, our results showed relatively high proportions of *p,p*'-DDD in sediments from estuary and coastal areas (Fig. 2).

CHLs in the sediment contain four major compounds (data not shown): *trans*-chlordane (t-ca), *cis*-chlordane (c-ca), *trans*-nonachlor (t-nona), and *cis*-nonachlor (c-nona). Oxychlordane could be detected but lowers the limit of quantification (0.005 ng/g dry wt). Interestingly, ratios of (t-ca)/(c-ca), (t-ca)/(t-nona), and (c-ca)/(t-nona) in the city canal sediments were 1.1, 1.2, and 1.3, which are comparable to those observed in two common technical mixtures: 1.0, 1.4, and 1.3 (Mattina et al. 1999). This result may suggest continuous input of CHLs to sediments of the HCMC canals. Despite the prohibition of CHL technical mixtures for use as common pesticides in many countries including Vietnam, they might have been used for termite control, wood preservation (Monirith et al. 2003), and protective treatment for underground cables (ATSDR 1995).

Total organic carbon content (TOC) in sediment varied from 3.2 to 4.9% in HCMC canals, which is relatively high compared to sediments from the SG-DN River and the estuary (0.44–3.8%; Table 1). Levels of TOC are an important factor altering the accumulation of OCs in sediment. Therefore, examination of the correlation between TOC and residue levels of OC may provide further understanding of their occurrence in sediments (Iwata et al. 1994). In the present study, a significant correlation was observed between TOC and PCBs, DDTs and CHLs (Table 2). This result depicts that higher amounts of OCs mainly occur in sediments with high TOC. Besides, significant correlation was also found among PCBs, DDTs, and CHLs, suggesting similar sources and accumulation characteristics in the sediments.

Geographical Comparison of OCs and Temporal Trend in HCMC

To understand the magnitude of contamination in sediments from southern Vietnam, residues levels of OCs in sediments from Vietnam in the present study were compared to those

reported previously as well as from other locations in the world (Table 3). Data for other countries were cited from recent studies (after 1995) to provide a more realistic comparison. DDT and PCB levels in sediment from the HCMC canals, the SG-DN River, and the SG-DN estuary belong to the high, middle, and low range, respectively (Table 3). Levels of PCBs and DDTs in HCMC are only lower than those in areas such as Macao harbor (China) and Alexandria harbor (Egypt). These results highlight elevated contamination by POPs in the aquatic environment of HCMC.

In order to clarify temporal trends of POPs in the environment, DDTs and PCBs in urban sediments of HCMC in the present study were compared with works previously carried out by Iwata et al. (1994) and Phuong et al. (1998) in similar areas. PCB levels decreased from 310 ng/g dry wt. in 1990 (Iwata et al. 1994), to 220 ng/g in 1996 (Phuong et al. 1998), and to 82 ng/g in the present study. In the same period, DDTs decreased from 240 ng/g dry wt. to 80 ng/g and 37 ng/g, respectively.

It is well known that a decrease of POPs residues in environmental matrices often follows first-order kinetics and thus their residue level data can be fitted in a simple log-linear regression for the examination of temporal trends (Bignert et al. 1998, Noren and Meironyte 2000). Using this approach, available data from the previous studies (Iwata et al. 1994, Phuong et al. 1998) were combined with the present data to estimate their half-life (defined as the time interval that is needed for a compound to decrease to half of its original concentration) of DDTs and PCBs in HCMC. The general estimated half-life is approximately 5 years for DDTs and 7 years for PCBs (Fig. 4). The half-life of DDTs in this study is in agreement with those observed in various environmental matrices from Northern Europe (Bignert et al. 1998) as well as those reported for human breast milk in HCMC (Minh et al. 2004). The estimation, however, gives a relatively lower half-life for PCBs in HCMC (7 years in this study compared to 11–17 years in the literature). Perhaps, a different method for the quantification of PCBs had led to the variation in total PCB concentrations, which caused a variation in the estimation of the half-life of PCBs. In fact, total PCB concentrations were estimated based on the mixture of KC300–KC600 in the earlier study by Iwata et al. (1994). On the other hand, Phuong et al. (1998) quantified six important congeners and then total PCBs concentrations were extrapolated by multiplying with the factor corresponding to their theoretical distribution in Arochlor 1254.

Hazard Assessment

In order to provide an overall view on the possible toxic effects caused by DDTs and PCBs, their concentration in sediments were compared with guidelines issued by The Canadian Council of Ministers of Environment (CCME 2003). For further consideration, it should be noted that a relatively comparable guideline for sediments is also provided by the Florida Department of Environmental Protection (FDEP 1994). According to CCME, the interim sediment quality guideline (ISQG) for DDE, DDD, and DDT in sediment is 1.42, 3.54, and 1.19 ng/g dry wt. In addition, the probable effect level (PEL) for DDE, DDD, and DDT is 6.75, 8.51 and 4.77 ng/g, respectively.

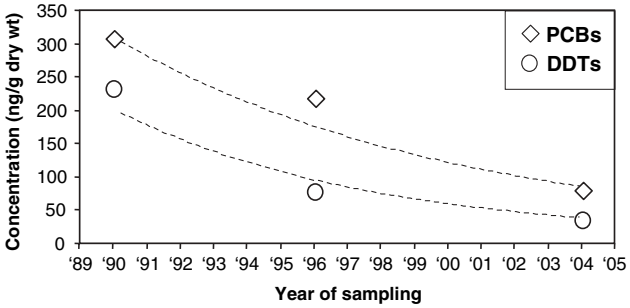

Fig. 4. Temporal trends of PCBs and DDTs in sediments collected from Hochiminh City during the last 14 years

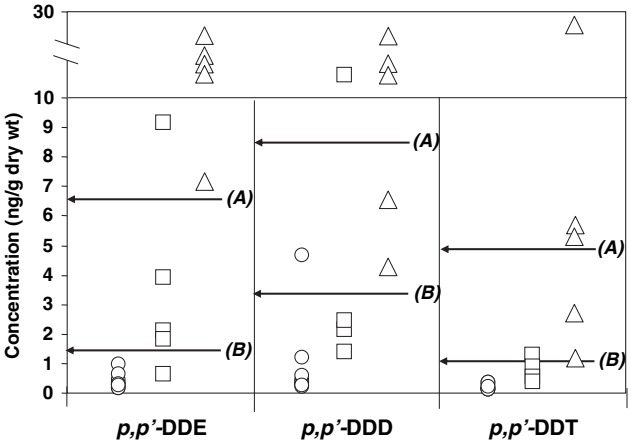

Fig. 5. Comparison of DDTs with the Canadian Environmental Quality Guideline for Sediment (Δ: HCMC canals; □: SG-DN River; ○: SG-DN estuary and coastal area). (A): the probable effect level; (B): interim sediment quality guideline. See text for more details

The results (Fig. 5) demonstrate that concentrations of DDTs in all sediment samples from HCMC canals are higher than ISQG and more than half of the samples exceeded PEL. Nearly half of the sediment samples from the SG-DN River had values above ISQG and 20% of the samples were above PEL. Only 10% of the estuarine and coastal samples showed values > ISQG and no samples > PEL. On the other hand, PCBs levels in all sediments were < PEL (277 ng/g dry wt.; data not shown) and only sediments from the HCMC canals contained PCB residues > ISQG (34 ng/g). Overall, the result implies high toxic potential of DDTs for sediments in the city canals and suggests a need for appropriate management.

Conclusions

Contamination by OCs in the environment of Vietnam is still one of the important environmental issues. In this study, the distribution pattern, the temporal trend, and the hazard assessment of OCs in sediments from the SG-DN River basin in Vietnam were comprehensively studied. Despite the prohibition on use of OCs since the mid of 1990s, relatively high residues of PCBs and DDTs were still found in sediments from

populated areas such as HCM City. Besides, a relatively high ratio of DDT/DDE was also observed in the sediments, suggesting recent input of this pesticide to the environment. Even though assessment of the temporal trend demonstrates decreasing levels of the predominant OCs such as PCBs and DDTs in the environment, the residue levels are higher than the proposed guidelines of Canada and the USA. Input of OCs to the aquatic environment is likely due to the discharge of untreated sewage from municipal areas and, thus, more efficient management would be needed to prevent discharge of anthropogenic toxic chemicals entering into the aquatic environment. Possible sources of illegal usage of DDT should also be identified for better management of this pesticide.

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