Chapter 8

Contamination of Selected Persistent Organic Pollutants (POPs) in Sediment of Some Areas in Vietnam

Vu Duc Toan and Ngo Tra Mai

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.70425

Abstract

This chapter evaluates the contamination of selected persistent organic pollutants (S-POPs) in the sediment of some typical areas in Vietnam. S-POPs are composed of dichlorodiphenyltrichloroethanes (DDTs), hexachlorocyclohexanes (HCHs), polychlorinated biphenyl (PCBs), and polybrominated diphenyl ethers (PBDEs). The collected data and analyzed results indicated the wide occurrence of significant S-POPs residues in studied areas. The main sources of S-POPs are discussed by using composition analyses and diagnostic ratios of S-POPs indicator. Ecotoxicological risk of S-POPs is assessed. The obtained results have contributed to the assessment of S-POPs fate in the environmental sediment in Vietnam.

Keywords: sediment, persistent organic pollutants, residues, ecological risk assessment

1. Introduction

Persistent organic pollutants (POPs) have low solubility in water and dissolve well in non-polar solvents. Therefore, when penetrating into the river, POPs tend to accumulate in creatures in the river (such as fish, shellfish…), suspended solids, and sediment. In sediment, most POPs accumulate in organic phases and persist for a long time. A part of POPs is transformed through chemical reactions, decomposed, and diffused back into the rivers. Flowing from the river to the sea, POPs are transmitted along with suspended solids and creatures. POPs distribution in the river water-sediment is a continuous process, which is considered to be important for detailed valuation in studies about POPs in the environment; it can be simulated using the modeling method.

Studies about POPs residue in sediment are mostly about the surface layer. The selected depths of sampling in the surface layer vary depending on the viewpoint of research groups in the world (usually 2, 3, and 10 cm in depth). Several studies also evaluate POPs residue according to depth and carry analysis for numerous segments (which can be tens of centimeters, depending on the substance in POP group and characteristics of the waste source). However, in many cases, it is very difficult to compare the obtained results of studies because of the difference in the quantity of POPs used for analysis. For example, total polychlorinated biphenyl (PCB) residue can consist of 6, 7, 10, or 13 PCBs congeners, depending on the research conditions of standard substances, equipment, procedures, and capability of the research group. Still, within its research conditions and obtained results, each study about POPs residue in sediment contributes to the overall picture of POPs in the environment.

Among POPs, dichlorodiphenyltrichloro-ethane (DDTs), hexachlorocyclohexane (HCHs), polychlorinated biphenyl (PCBs), and polybrominated diphenyl ethers (PBDEs) are found in sediment from big cities to remote areas. This chapter will focus on contamination status, composition analyses, and ecological risk assessment of these selected POPs (S-POPs).

2. PCBs in sediment in Vietnam

2.1. General characteristics of PCBs

PCBs are industrial products, which constitute a global environmental health hazard of solely anthropogenic origin. Theoretically, there are 209 PCB isomers and congeners with 1–10 chlorine atoms attached to the biphenyl molecule.

The term “PCBs homolog” is used to refer to all PCBs with the same number of chlorines. Homolog with different substitution patterns is referred to as isomer. The numbering system for the PCBs is shown above. Positions 2, 2′, 6, and 6′ are called ortho positions, positions 3, 3′, 5, and 5′ are called meta positions, and positions 4 and 4′ are called para positions. The benzene rings can rotate around the bond connecting them. The two extreme configurations are planar and the nonplanar in which the benzene rings are at a 90° angle to each other [1]. The benzene rings of non-ortho substituted PCBs, as well as monoortho substituted PCBs, may assume a planar configuration and are referred to as planar or coplanar congeners. The PCBs congeners are arranged in ascending numerical order using a numbering system that follow the IUPAC rules.

2.2. Contamination status of PCBs

Monitoring surveys of PCBs residue in sediment have been conducted during the early 1994s. In the northern Vietnam, PCBs were found in environmental sediment of Thaibinh province (Ba Lat Estuary, coast lines of Thai Binh province), Quangninh province (Halong Bay), and Hanoi city (Set, Kim Nguu, CauBay River, Yen So Lake). PCBs penetrated into the estuaries, urban rivers, lakes, and coastal areas. High PCB concentrations were found in sediment of Kim Nguu River (328 ng/g) and Yen So Lake of Hanoi city (384 ng/g) in 2006 [2]. Hoai et al. [2]

reported that the sediment levels of PCBs measured in their study in 2006 revealed a clear increase compared to 0.79–40 ng/g (mean 13 ng/g) in 1997 and 15–120 ng/g (mean 45 ng/g) in 1999 [3, 4]. Until 2015, sediment levels of PCBs decreased compared to 31.72–167.32 ng/g [5]. Toan et al. reported that the main source of contamination in Hanoi city could originate from the dielectric oil used in old hanging transformers and capacitors [6]. From such equipment, PCBs could penetrate into the environment by re-filling of dielectric oil, mechanical damage, electrical accident, and fire. Statistics until 2006 show that the total amount of dielectric oil containing PCBs in the entire country is approximately 19,000 tons [7]. This clearly indicates a huge contamination source of PCBs in the environment in Vietnam. In central Vietnam, PCBs were found in the environmental sediment of Hue city (Phu Da, A Luoi, and Tam Giang-Cau Hai Lagoon), Quy Nhon city (Thi Nai Lagoon). PCBs penetrated into the lagoons and canals near paddy fields or municipal sewage at low levels (<25 ng/g). In southern Vietnam, PCBs were also found in Mekong River Delta (Tra Vinh), Can Tho city, and Hochiminh city. PCBs were distributed in wide spaces such as drainage from rice fields, rivers near ferry harbors, river near the mouth of Mekong, shrimp farming areas, and canals in the densely populated areas. Highest PCBs concentrations were found in sediment of Saigon River, Hochiminh city (590.5 ng/g) [8]. According to typical data about PCB residues in sediment in Vietnam in **Table 1**, we can draw a number of general conclusions about studies of PCB residues in sediment in Vietnam (**Figures 1** and **2**):

- Within 23 years (1994–2016), about 143 typical sediment samples in several areas of Vietnam were analyzed. Obtained results had a great effort to show the PCB residues level in a number of studied areas. However, the database of PCBs is still limited and further assessment is required in the future.
- Studies about total PCBs are quantified according to various PCBs standards. Several studies do not report the depth of sediment sampling, and the component of total PCBs is not the same (total PCBs can be the sum of 6, 7, 22, 53, 93, or even more than 100 PCBs isomers and congeners). Therefore, the comparisons of total PCBs of different studies are relative and are not precise. This calls for a unified standard about PCBs research for application and further study in the future. We recommend that the researchers can analyze only six indicator congeners (PCB 28, 52, 101, 138, 180). After, the sum of six PCBs can be multiplied by five relatively to get the value of total PCBs. This recommendation is in good agreement with Kohler et al. [16].
- Published studies about PCBs in sediment only provide an initial evaluation about the residue in a point in time without assessments about the time trend variation or in-depth studies about the consequences of PCBs residue in the studied areas. These problems can be additional research directions for PCBs in Vietnam in the future.

2.3. Composition analyses of PCBs

Concerning the PCB congeners, PCBs could be detected from tri-CB to octa-CB in the collected sediment samples. The mean percentages of six selected PCB indicators in the collected sediment samples from several studies (**Table 1**) followed the order PCB138 > PCB153 > PCB101 > PCB52 > PCB180 > PCB28. This order can be explained by physical and chemical properties of PCBs.

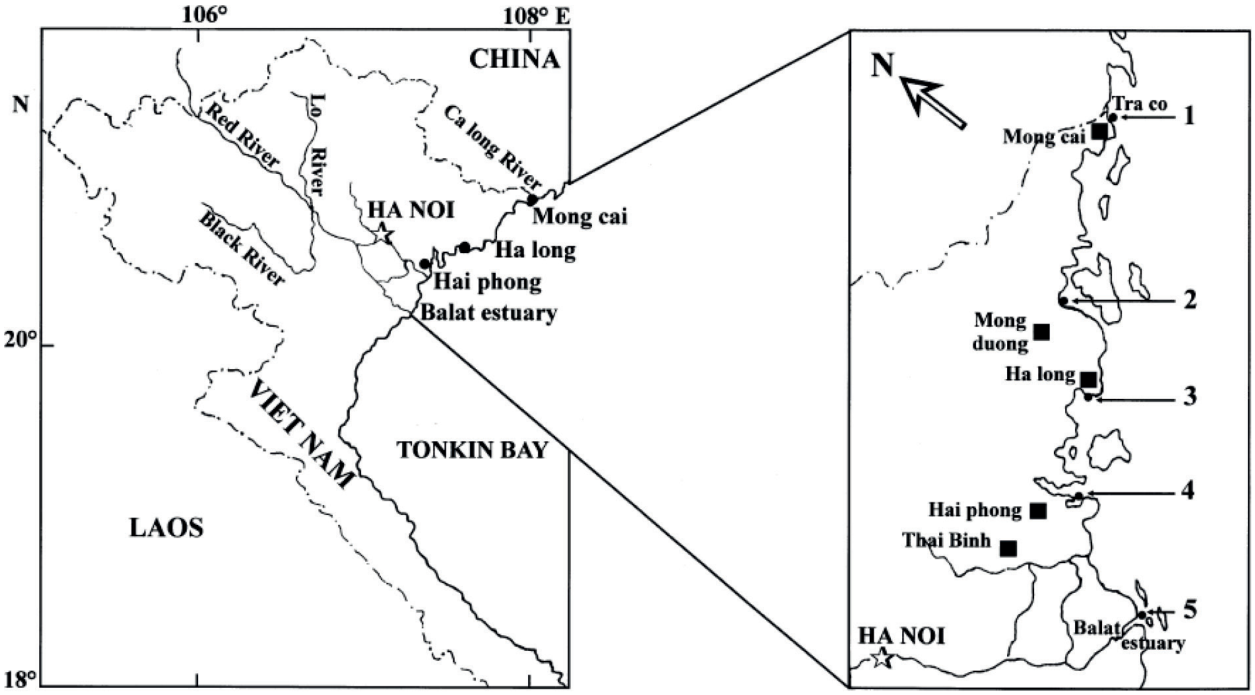

Figure 1. The five sampling stations along the coast of northern Vietnam [3].

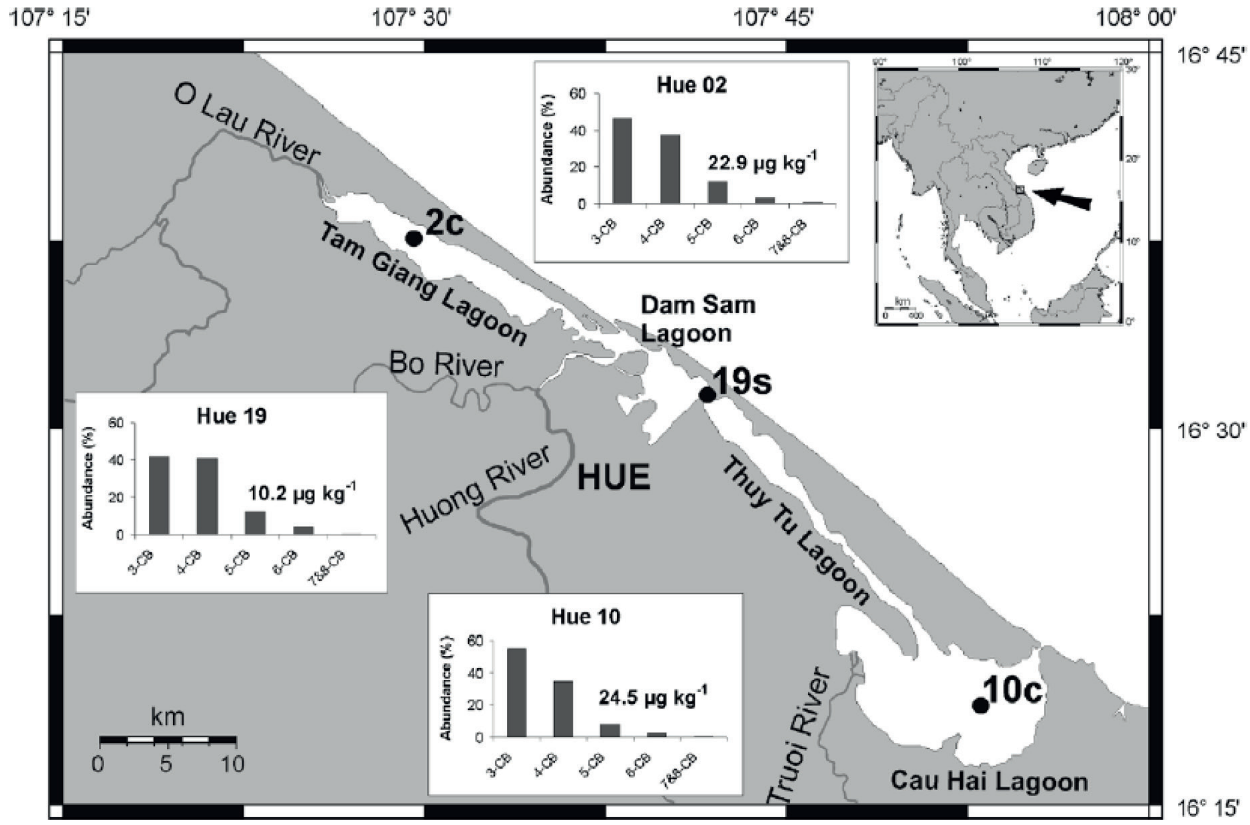

Figure 2. The sampling stations along the Tam Giang-Cau Hai Lagoon, Central Vietnam [12].

According to Toan et al., lightly chlorinated PCBs are less persistent, have lower log K_{ow}, and are more volatile than heavily chlorinated PCBs. Therefore, heavily chlorinated PCBs are more accumulative in the sediment, whereas lightly chlorinated PCBs are degraded and volatilized faster [6].

Location	Year of sampling	Number of samples	Depth of sampling (cm)	Component of analyzed PCBs/PCBs standards	Total PCBs (ng/g)	Reference	Remark
A. Northern Vietnam							
Ba Lat Estuary, coast lines of Thai Binh province	1995/1996	1	0–5	Aroclor 1254, Aroclor 1260[b]	1.1/0.7[a]	[9]	Sediment, intertidal mudflat areas
	2003–2004	10	–[c]	8, 18, 28, 29, 44, 52, 66, 87, 101, 105, 110, 118, 128, 138, 153, 170, 180, 187, 195, 200, 206, 209	0.04–0.26	[10]	Sediment, intertidal mudflat areas
Ha Long Bay, Quang Ninh province	1997	1	0–5	Aroclor 1254, Aroclor 1260	11	[9]	Marine sediment
	1998	1	–	Aroclor 1254, Aroclor 1260	37	[4]	Estuary sediment
	2003–2004	16	–	8, 18, 28, 29, 44, 52, 66, 87, 101, 105, 110, 118, 128, 138, 153, 170, 180, 187, 195, 200, 206, 209	0.11–10.1	[10]	Surface sediment
Nhue River, suburb of Hanoi city	1997	2	0–5	Aroclor 1254, Aroclor 1260	1.7 (0.97–2.51)[d]	[3]	Sediment, canal, densely populated
	1997	1	0–5	Aroclor 1254, Aroclor 1260	0.74	[3]	Sediment, canal, rural area
	2006	2	–	28, 52, 101, 118, 138, 153, 180	22–153	[2]	Sediment, river
Set River, Hanoi city	2006	2	–	28, 52, 101, 118, 138, 153, 180	36–139	[2]	Sediment, river
Kim Nguu River, Hanoi city	2006	2	–	28, 52, 101, 118, 138, 153, 180	237–328	[2]	Sediment, river
Yen So Lake, Hanoi city	2006	6	–	28, 52, 101, 118, 138, 153, 180	20–384	[2]	Sediment, lake
CauBay River, Hanoi city	2015	10	–	4, 5, 6, 7, 8, 9, 10, 12, 13, 15, 16, 17, 19, 21, 22, 26, 28, 31, 32, 37, 41, 42, 44, 45, 47, 48, 49, 52, 53, 56, 60, 61, 64, 66, 70, 71, 74, 77, 81, 83, 84, 85, 86, 87, 89, 91, 92, 95, 99, 100, 101, 105, 110, 114, 118, 119, 123, 126, 128, 131, 132, 135, 138, 144, 149, 153, 156, 157, 163, 167, 169, 170, 171, 172, 174, 180, 189, 194, 199, 200, 202, 205, 206, 207	31.72–167.32	[5]	Sediment, river
B. Central Vietnam							
Phu Da, Hue city	1990	1	No data	KC-300, KC-400, KC-500, KC-600[e]	0.65	[11]	Sediment, near paddy field

Location	Year of sampling	Number of samples	Depth of sampling (cm)	Component of analyzed PCBs/PCBs standards	Total PCBs (ng/g)	Reference	Remark
A Luoi, Hue city	1990	1	No data	KC-300, KC-400, KC-500, KC-600	0.18	[11]	Sediment, municipal sewage
Tam Giang, Hue city	2002	10	0–2; 2–4; 8–10; 20–23; 23–26; 32–35; 38–41; 47–50	53 congener (no data in detail)	2.03–24.7	[12]	Sediment, Tam Giang-Cau Hai Lagoon
Thi Nai Lagoon, Quy Nhon city	2010	18	–	11, 16, 19, 18, 17, 24, 27, 16, 32, 34, 29, 26, 25, 31, 28, 20, 33, 22, 20, 45, 46, 52, 49, 47, 48, 44, 42, 59, 41, 64, 71, 40, 67, 63, 74, 70, 66, 56, 60, 104, 93, 95, 91, 92, 84, 90, 101, 99, 97, 87, 115, 85, 110, 82, 107, 123, 118, 105, 136, 151, 135, 144, 147, 149, 146, 153, 132, 141, 138, 164, 158, 128, 167, 156, 157, 169, 13, 179, 176, 178, 187, 183, 174, 177, 171, 172, 180, 193, 170, 190, 199, 196, 203, 194, 208, 209	0.47–6.40	[13]	Surficial sediment, lagoon
C. Southern Vietnam							
Tra Vinh, Mekong River Delta	1998	1	–	44, 49, 52, 101, 105, 118, 128, 138, 149, 153, 170, 180, 200	0.985	[14]	Sediment, canal
Can Tho city, Mekong River delta	2003–2004	4	No data	KC-300, KC-400, KC-500, KC-600	1.8 (0.12–3.7)	[11]	Sediment, canals in Cantho city
Hau River, Mekong River delta	2003–2004	7	No data	KC-300, KC-400, KC-500, KC-600	0.21 (0.12–0.54)	[11]	Sediment, river
Saigon River, Hochiminh city	2004	5	No data	No data	81	[15]	Canals, densely populated areas
	1996	11	–	28, 52, 101, 138, 153, 180	N.D – 590.5[f]	[8]	Canals, densely populated areas

[a]Dry season/rainy season.
[b]PCB mixture from the US; Aroclor 1254 and Aroclor 1260 contain more than 100 PCBs isomers and congeners.
[c]Not reported.
[d]Mean (range).
[e]PCB mixture from Japan. KC-300, KC-400, KC-500, and KC-600 contain more than 100 PCBs isomers and congeners.
[f]Not detected.

Table 1. Concentrations of PCBs (ng/g) in sediment from Vietnam.

Another explanation could be related to the compositions of PCB mixtures that probably escaped from the dielectric oil. Up to April 1998, 48.3% of the total quantity of dielectric oils in Vietnam was imported from the Soviet Union. Japan and China contributed with smaller percentages of 7.5 and 3.6%, respectively [6, 17]. According to Falandysz et al., the percentages of PCB138, PCB153, PCB101 (along with PCB90), PCB52, PCB180, and PCB28 (along with PCB31) in Sovol (trade name of Soviet Union dielectric oil) were 11.4, 7.0, 6.5, 3.6, 0.4, and 0.8%, respectively [18]. It seems that the predominance of heavily chlorinated PCBs, PCB138, and PCB153, still remained when they penetrated the sediment. In general, low percentages of lightly chlorinated PCBs and a high percentage of heavily chlorinated PCBs in the analyzed sediment samples reflect their long-time release **Figure 3** [6].

2.4. Ecological risk assessment of PCBs

To evaluate the ecotoxicological significance of PCBs contamination, total PCBs in collected sediments were compared with the NOAA sediment quality guideline (SQG) [19]. This guideline specifies the "effects range low" (ERL) and the "effects range median" (ERM). The ERL represents the chemical concentration below which an adverse effect would rarely be observed. The ERM represents the concentration above which adverse effect would frequently occur [20]. Only total PCBs of sediment samples in two big cities (Hanoi and Ho Chi Minh cities) exceeded ERM levels (ERM of total PCBs is 180 ng/g). The other sediment samples listed in **Table 1** that were collected from the estuaries, coastal areas, lagoons, canals near paddy field or municipal sewage, drainage from rice fields, rivers near ferry harbors, river near the mouth of Mekong, shrimp-farming areas, were lower than ERL levels (ERL of total PCBs is 22.7 ng/g). This finding raises the concern on PCBs impact in the two big cities of Vietnam. Thus, further investigation is required in Hanoi and Hochiminh cities to assess possible toxic effects on human health and ecological system.

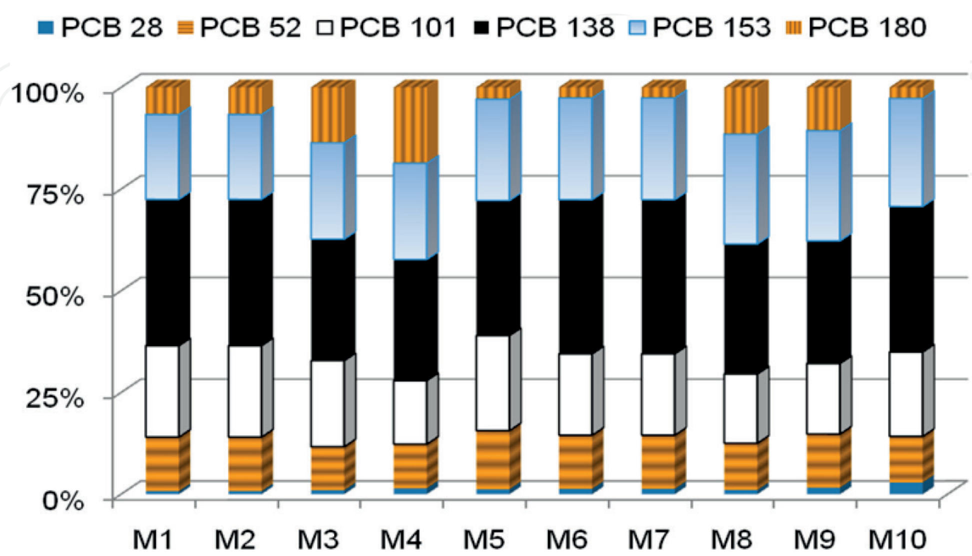

Figure 3. Mean percentages of PCB congeners in sediment samples in CauBay River [5].

3. PBDEs in sediment in Vietnam

3.1. General characteristics of PBDEs

Polybrominated diphenyl ethers (PBDEs) are used commercially as additives in plastics and textiles, building materials, carpets, and vehicles and aircraft with half-lives in the order of 2–10 years. In computers, these compounds are commonly used in printed circuit boards, components such as connectors, cables, plastic covers, and parts of keyboards and monitors. Theoretically, there are 209 PBDEs isomers and congeners with 1–10 bromine atoms attached to the biphenyl molecule.

PBDEs are highly resistant to heat, light, oxidizing, and reducing compounds. Thus, PBDEs are extremely persistent when released into the environment. The use of PBDEs has increased over the last 30 years with production estimated to be about 3000–5000 tons in Europe. Deca-BDE is the largest mix on the market and makes up over 80% of the total PBDE production, whereas penta-BDE and octa-BDE products constitute about 12 and 6%, respectively, of the total PBDE production [21]. The presence of high levels of these compounds in samples from remote areas suggests that they may now have been distributed worldwide as a result of long-range atmospheric transport. PBDEs have been associated with endocrine disruption, neurotoxicity, and cancer. Sediments are major sinks for these contaminants in aquatic environments, and their study is an important step in mapping possible pollution sources and exposure pathways that facilitate PBDE bioavailability to sediment-dwelling organisms [21].

3.2. Contamination status of PBDEs

From the north to the south of Vietnam, PBDEs was found in environmental sediment of Hanoi city (CauBay river), Quy Nhon city (Thi Nai Lagoon), Hochiminh city (canals), and Saigon-Dongnai River. PBDEs penetrated in the environmental sediment of rivers, lagoon urban canals, urban sewer systems, and estuary. Data about PBDE residue in sediment in these areas of Vietnam are presented in **Table 2**.

A number of general conclusions can be drawn from studies about PBDE in Vietnam:

- At present, there is a lack of studies about PBDE in Vietnam. In three representative studies presented in **Table 2**, the numbers of samples and research areas are not enough to represent PBDE residue in sediment in Vietnam. Published studies do not report the depth of sampling. There are also different viewpoints about the total PBDE value. Components of total PBDE can be the sum of 7, 9, or 11 PBDEs. Therefore, it is difficult to compare research results.
- Published studies about PBDE in sediment are mainly about initial evaluation of residue in a point in time. There is no assessment about the change in trend or in-depth research about the consequences of PBDE residue in the studied areas. Further studies about PBDE residue and its impact on the environment are necessary.

When compared with other regions in the world, the residues of total PBDEs in Hanoi and Hochiminh are lower than those in Dianchi lake, China and and higher than residues found in Hongfeng and Chenghai lake, China [23].

Location	Year of sampling	Number of samples	Depth of sampling (cm)	Component of analyzed PBDEs	Concentration PBDEs (ng/g)	Reference	Remark
A. Northern Vietnam							
CauBay River, Hanoi city	2014	10	–[a]	28, 47, 99, 100, 153, 154, 209	15.39–25.64	[21]	Sediment, river
B. Central Vietnam							
Thi Nai lagoon, Quy Nhon city	2010	18	–	17, 28, 47, 66, 100, 99, 85, 153, 183	N.D – 9.62[b]	[13]	Surficial sediment, lagoon
C. Southern Vietnam							
Hochiminh city canals	2004	5	0–5	28, 47, 99, 100, 153, 154, 183, 196, 197, 206, 207	54.5–119	[22]	Urban sediment, sewer system
Hochiminh city canals	2004	6	0–5	28, 47, 99, 100, 153, 154, 183, 196, 197, 206, 207	<0.2–10.63	[22]	Sub-urban sediments
Saigon-Dongnai estuary	2004	3	0–5	28, 47, 99, 100, 153, 154, 183, 196, 197, 206, 207	<0.02–0.065	[22]	Estuary sediment

[a]Not reported.

[b]Not detected.

Table 2. Concentrations of PBDEs (ng/g) in sediment from Vietnam.

3.3. Composition analyses of PBDEs

Concerning the composition analyses, PBDEs congeners could be detected from tri-BDE to deca-BDE in the collected sediment samples (**Table 2**). BDE-209 was a predominant congener in sediment samples. In the past, BDE-209 is the largest mix on the market and makes up over 8% of the total PBDE production, whereas penta-BDE and octa-BDE products constitute about 12 and 6%, respectively, of the total PBDE production [24]. This is one of important factors to explain the predominance of BDE-209.

The mean percentages of six PBDEs indicators in the collected sediment samples followed the order: BDE-47 > BDE-99 > BDE-100 > BDE-154 > BDE-153 > BDE-27. This order is in agreement with chemical properties of PBDEs as well as the percentages of PBDEs in the commercial mixtures.

3.4. Ecological risk assessment of PBDEs

It has been suggested that PBDEs biomagnified as they move along a food web. In addition, PBDEs can inhibit growth in colonies of algae as well as depress the reproduction of zooplankton. Based on the toxicity data of benthic organisms, the multiple species have no observed effect on the concentrations of ΣPBDEs which is 3.1 mg/kg of sediment

[21, 25]. Most of the collected sediment samples in **Table 2** had residues of PBDEs lower than 3.1 mg/kg. However, the values of PBDEs in the urban canals and urban sewer system of Hochiminh city are very high (maximal 119 ng/g). Due to the propensity of PBDEs to highly accumulate in various compartments of wildlife and human food webs, further evaluation of ecological risk assessment in Hochiminh city should be undertaken as a high priority.

4. DDT and HCH in sediment in Vietnam

4.1. General characteristics of DDTs and HCHs

4.1.1. General characteristics of DDTs

Chemical formula of DDT is $C_{14}H_9C_{15}$. Technical DDT is prepared by the Bayer condensation of chlorobenzene with trichloroacetaldehyde in oleum (fuming sulfuric acid), and the reaction is carried out with an excess of chlorobenzene (recommended molar ratio 3:1). Technical grade DDT is composed of up to 14 chemical compounds of which only 65–80% is the active ingredient, *p,p′*-DDT and included 15–21% of the nearly inactive *o,p′*-DDT. DDT is transformed by metabolism or by degradation in the environment [26]. The most common metabolites are DDE (1,1-dichloro-2,2-*bis*(*p*-chlorophenyl)ethylene) and DDD (1,1-dichloro-2,2-*bis*(*p*-chlorophenyl) ethane), which usually are found together with DDT in environmental samples. Thus, actually, people and animal are poisoned by these compounds at the same time. Each compound has three isomers and their primary isomers are *p,p′*-DDT; *p,p′*-DDE; *p,p′*-DDD [26]. Total concentration of DDTs can be evaluated by the sum of *p,p′*-DDT; *o,p′*-DDT; *p,p′*-DDE; *o,p′*-DDE; *p,p′*-DDD, and *o,p′*-DDD.

4.1.2. General characteristics of HCHs

1,2,3,4,5,6-Hexachlorocyclohexane (HCH), also called benzene hexachloride (BHC), is an organochlorine insecticide used throughout the world. HCH is available in two formulations: technical HCH and lindane. A total of eight HCH isomers have been identified in technical HCH. However, only the γ-HCH, α-HCH, β-HCH, and δ-HCH and ε-HCH isomers are stable, and these are the ones commonly identified in technical formulations [26]. Generally, technical HCH consists of approximately 60–70% α-HCH, 5–12% β-HCH, 10–15% γ-HCH, 6–10% δ-HCH, and 3–4% ε-HCH. Lindane contains more than 90% of γ-HCH, but lindane used in many countries is almost pure γ-HCH [27]. Total concentration HCH can be evaluated by the sum of ϒ-HCH, α-HCH, β-HCH, and δ-HCH.

4.2. Contamination status of DDT and HCH

Data about DDT and HCH residues in sediment in Vietnam are relatively adequate, including sediment in freshwater, brackish water, and seawater. There are research results about DDT and HCH in sediment from 1994 up to now (**Table 3**). According to data in **Table 3**,

Location	Year of sampling	Number of samples	Depth of sampling (cm)	Component of analyzed DDTs; HCHs	Concentration DDTs; HCHs (ng/g)	Reference	Remark
A. Northern Vietnam							
Diem Dien Estuary, Thai Binh coast lines	1995/1996	1	0–5	*p,p′*-DDT; *p,p′*-DDE; *p,p′*-DDD; ϒ-HCH, α-HCH, β-HCH, δ-HCH	6.2; 0.36	[3]	Sediment, intertidal mudflat areas
Ha Long Bay	1997	1	0–5	*p,p′*-DDT; *p,p′*-DDE; *p,p′*-DDD; ϒ-HCH, α-HCH, β-HCH, δ-HCH	7.2; 1.8	[3]	Marine sediment
	1998	1	–[a]	*p,p′*-DDT; *p,p′*-DDE; *p,p′*-DDD; ϒ-HCH, α-HCH, β-HCH, δ-HCH	28; 6.1	[4]	Estuary sediment
	2003–2004	16	–	*p,p′*-DDT; *o,p′*-DDT; *p,p′*-DDE; *o,p′*-DDE; *p,p′*-DDD; *o,p′*-DDD; ϒ-HCH, α-HCH, β-HCH, δ-HCH	1.60–274; N.D[b] – 0.85	[3]	Surface sediment
Set River, Hanoi city	2006	2	–	*p,p′*-DDT; *o,p′*-DDT; *p,p′*-DDE; *o,p′*-DDE; *p,p′*-DDD; *o,p′*-DDD; ϒ-HCH, α-HCH, β-HCH, δ-HCH	215–680; <0.2	[2]	Sediment, river
Kim Nguu River, Hanoi city	2006	2	–	*p,p′*-DDT; *o,p′*-DDT; *p,p′*-DDE; *o,p′*-DDE; *p,p′*-DDD; *o,p′*-DDD; ϒ-HCH, α-HCH, β-HCH, δ-HCH	82–1100; <0.2–17	[2]	Sediment, river
Yen So Lake, Hanoi city	2006	6	–	*p,p′*-DDT; *o,p′*-DDT; *p,p′*-DDE; *o,p′*-DDE; *p,p′*-DDD; *o,p′*-DDD; ϒ-HCH, α-HCH, β-HCH, δ-HCH	17–109; <0.2–36	[2]	Sediment, lake
CauBay River, Hanoi city	2012	10	–	*p,p′*-DDT; *p,p′*-DDE; *p,p′*-DDD; ϒ-HCH, α-HCH, β-HCH, δ-HCH	51.84–92.76; 4.65–11.39	[27]	Sediment, river
B. Central Vietnam							
Phu Da, Hue city	1990	1	No data	*p,p′*-DDT; *p,p′*-DDE; *p,p′*-DDD; ϒ-HCH, α-HCH, β-HCH	0.52; 0.43	[11]	Sediment, paddy field

Location	Year of sampling	Number of samples	Depth of sampling (cm)	Component of analyzed DDTs; HCHs	Concentration DDTs; HCHs (ng/g)	Reference	Remark
A Luoi, Hue city	1990	1	No data	*p,p′*-DDT; *p,p′*-DDE; *p,p′*-DDD; ϒ-HCH, *α*-HCH, β-HCH	68; 2.4	[11]	Sediment, municipal sewage
C. Southern Vietnam							
Can Tho city, Mekong River delta	2003–2004	4	No data	*p,p′*-DDT; *p,p′*-DDE; *p,p′*-DDD; ϒ-HCH, *α*-HCH, β-HCH	1.8–4.3; <0.02–0.11	[11]	Sediment, canals in Can Tho city
Duyen Hai, Mekong River delta	1998	1	–	*p,p′*-DDT; *o,p′*-DDT; *p,p′*-DDE; *o,p′*-DDE; *p,p′*-DDD; *o,p′*-DDD; ϒ-HCH, *α*-HCH, β-HCH	0.48; 0.113	[14]	Near the mouth of Mekong, shrimp farming area
Tra Vinh, Mekong River delta	1998	1	–	*p,p′*-DDT; *o,p′*-DDT; *p,p′*-DDE; *o,p′*-DDE; *p,p′*-DDD; *o,p′*-DDD; ϒ-HCH, *α*-HCH, β-HCH	67.49; 0.65	[14]	Sediment, canals
Saigon River, Hochiminh city	2004	5	No data	*p,p′*-DDT; *o,p′*-DDT; *p,p′*-DDE; *o,p′*-DDE; *p,p′*-DDD; *o,p′*-DDD;	37[c]	[15]	Sediment, canals, densely populated areas
	1996	11	–	*p,p′*-DDT; *p,p′*-DDE; *p,p′*-DDD	1.76–253.6	[8]	Sediment, canals, densely populated areas

[a]Not reported.
[b]Not detected.
[c]Mean value.

Table 3. Concentration of DDTs and HCHs (ng/g) in sediment from Vietnam.

DDT and HCH have deposited in the sediment in Vietnam in a wide range and for a long time with considerable extent. DDT and HCH residue in sediment in Vietnam is on the decreasing trend.

Monitoring surveys of DDTs and HCHs residue in sediment have been conducted during the early 1994s. In northern Vietnam, DDTs and HCHs were found in environmental sediment of Thaibinh province (Diem Dien Estuary, coast lines of Thai Binh province), Quangninh province (Halong Bay) and Hanoi city (Set, Kim Nguu, CauBay River; Yen So Lake). DDTs and HCHs have penetrated into the estuaries, urban rivers, lakes, and coastal areas. HCHs had low residues in most of the sediment samples. Besides, high DDTs concentrations were found in the sediment of Kim Nguu River (1100 ng/g) and Set River of Hanoi city (680 ng/g) in 2006 [2]. This can be explained by the usage of DDTs in the big cities of Vietnam in the past. Both DDTs and HCHs have been used in Vietnam in considerable amounts as pesticides for crop protection and as vector control for public health purposes. DDT had been imported and used in Vietnam from 1957 up to 1994.

In Central Vietnam, DDTs and HCHs were found in the environmental sediment of Hue city (Phu Da, A Luoi). DDTs and HCHs penetrated into the canals near paddy fields or municipal sewage at medium levels. In southern Vietnam, DDTs and HCHs also found in Mekong River Delta (Duyen Hai and Tra Vinh), Can Tho city, and Hochiminh city. DDTs and HCHs are distributed in wide spaces such as drainage from rice fields, river near ferry harbor, river near the mouth of Mekong, shrimp-farming areas, and canals in the densely populated areas. Highest DDTs concentrations were found in the sediment of Saigon River, Hochiminh city (253.6 ng/g) [8].

4.3. Composition analyses of DDTs and HCHs

Composition differences of HCHs isomers or DDTs metabolites in the environment could indicate different contamination sources. DDT can be biodegraded in the environment to DDD under anaerobic conditions and DDE under aerobic conditions. Thus, *p,p′*-DDD was a major breakdown product of DDT in sediment from different places in Vietnam. With regards to DDT metabolites, the ratio of (*p,p′*-DDE + *p,p′*-DDD)/ΣDDT in the sediment samples collected in 2012 from CauBay River ranged between 0.77 and 0.89 (mean 0.80). The obtained ratios indicated that the degradation of DDT occurred significantly, and there is no recent input of DDT in the study areas [28]. This conclusion was suitable with the fact of usage of DDTs and other studies since 2006 in Vietnam. Among the isomers, β-HCH has the lowest water solubility and vapor pressure, which is the most stable and relatively resistant to microbial degradation. Besides, there is the isomerization of α- to β-HCH and of γ- via α- to the more stable β-HCH, which is energetically more favorable in the environment [28]. Therefore, the β-HCH predominance reflects an old source of input of HCH in the environment. Low ratios of α-HCH/γ-HCH may represent the use of lindane, whereas high ratios of these isomers may depict the use of technical HCH [28]. An α-HCH/γ-HCH ratio in areas where lindane has been typically used ranges from 0.2 to 1 compared to a range from 4 to 15 for technical HCH. According to Toan et al., the mean percentages of HCH isomers analyzed in sediment samples from CauBay River followed the order of β-HCH (43.2%) > α-HCH (39.3%) > γ-HCH (10.7%) > δ-HCH (6.9%) [28, 29]. Therefore, the predominance of β-HCH reflects an old source of input of HCH in the environment. Besides, the ratio of α-HCH/γ-HCH in the analyzed sediment samples of CauBay River ranged between 2.68 and 4.09 (mean 3.73). It means that the use of technical HCH is the major source and lindane is the minor source in the study areas.

4.4. Ecological risk assessment of DDTs and HCHs

To evaluate the ecotoxicological significance of DDTs and HCHs contamination in collected sediments, our data in **Table 3** were compared with the interim sediment quality guideline

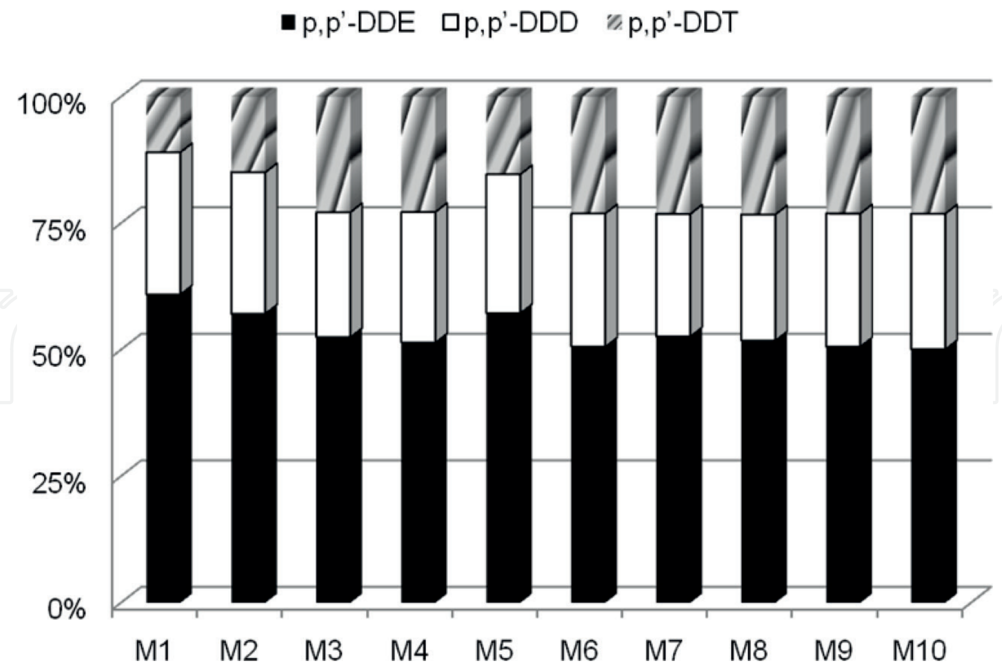

Figure 4. Mean percentages of DDT and its metabolites in sediment samples [28].

(ISQG) and the probable effective level (PEL), issued by the Canadian Council of Ministers of Environment [30]. Hoai et al. [2] reported that the concentrations of DDE, DDD, and DDT in all the Hanoi sediment samples were higher than the ISQG values (1.42, 3.54, and 1.19 ng/g, respectively). The DDE, DDD, and DDT generally exceed the PEL values (6.75 ng/g for DDE, 8.51 ng/g for DDD, and 4.77 ng/g for DDT) but vary among the sediment samples [2]. This conclusion is in agreement with DDTs residues in CauBay River and Hochiminh city [22, 28]. In general, most of the collected sediment samples in **Table 3** had DDTs at low levels as well

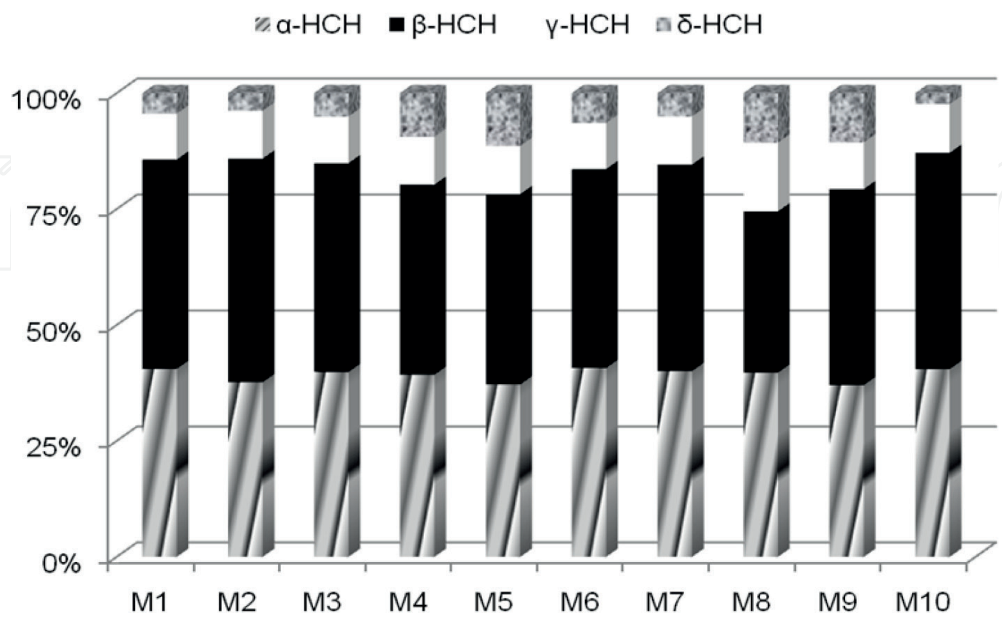

Figure 5. Mean percentages of HCH isomers in sediment samples [28].

as lower than PEL values. With regards to HCHs, no values of ISQG and PEL were reported in the international guidelines. Due to the propensity of DDTs to highly accumulate in various compartments of wildlife and human food webs, further evaluation of ecological risk assessment in Hanoi and Hochiminh city should be undertaken **Figures 4** and **5**.

5. Conclusion

This work investigated the contamination status of S-POPs in sediment of some areas in Vietnam. Wide occurrence and remarkable residue levels of S-POPs have been found in the sediment of study areas. Composition analyses show that S-POPs penetrated in the sediment for a long time. The main sources of S-POPs are from mix sources that have origin form old industrial and agricultural sources. Ecotoxicological of S-POPs is found at low levels. Due to the propensity of S-POPs to accumulate in various compartments of environment, further evaluation of ecotoxicological should be undertaken as a high priority.

Author details

Vu Duc Toan[1]* and Ngo Tra Mai[2]

*Address all correspondence to: vuductoan2001@yahoo.com

1 Thuyloi University, Hanoi, Vietnam

2 Institute of Physics, Viet Nam Academy of Science and Technology, Hanoi, Vietnam

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