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ORIGINAL PAPER

The status and distribution of PCBs along the coast of Vietnam

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Abstract Polychlorinated biphenyls (PCBs), well-known as an important scientific achievement, are now considered as one of the most persistent organic pollutants (POPs) that need to be strictly controlled and forbidden worldwide (the Stockholm convention on POPs). Vietnam is one of the countries that encounters with serious issues from PCB contamination. This study presented a comprehensive review on the status and contamination of PCBs along the coast of Vietnam. The contaminated PCBs data in the water, sediment and biological samples from 18 provinces along Vietnam coastline were collected from various sources. A comparison in PCBs contamination between Vietnam and other Asian countries was included. The status on PCBs contamination in Vietnam since participated as a party of the Stockholm convention on POPs in 2002 was also assessed. The results showed that Vietnam is facing serious PCBs contamination problems as it evidences the spread and accumulation of PCBs in the marine environment. The implementation of the Stockholm convention on POPs (PCBs in particular) has not yet demonstrated significant effect on the reduction in PCBs contamination in the environment. This information on PCBs contamination in Vietnam urges government to strengthen the mechanism, policy and legislation, the management capacity for PCBs as well as applying advanced and modern technologies in reducing, disposing and eliminating PCBs from the environment.

Keywords POPs · PCBs · Coastal area · Environment · Vietnam

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Introduction

A polychlorinated biphenyl (PCB) is an organic chlorine compound with the formula $C_{12}H_{10-x}Cl_x$. PCB was synthesized for the first time in Germany in 1881, and it was commercialized in 1929 by the Swann Chemical Company (USA). There are 209 different PCB congeners, 130 of which are found in commercial PCB products which common names as Arochlor (made in the USA and the UK), Chlorphene (Germany), Fenchlor (Italy), Phenochlor (France) or Kanechlor (Japan), etc. Six PCB congeners (including PCB28, PCB52, PCB101, PCB138, PCB153 and PCB180) are considered "indicator PCBs" and usually selected as markers of PCBs pollution (EFSA 2005). PCBs were originally considered a scientific achievement. They were widely used as dielectric and coolant fluids in electrical apparatus, carbonless copy paper and in heat transfer fluids to list just those applications. However, since 1970s, many countries stopped producing PCBs because of their toxicity and environmental persistence. Among them, 12 PCB congeners (IUPAC no.: PCB77, PCB81, PCB 126, PCB169, PCB105, PCB114, PCB118, PCB123, PCB156, PCB157, PCB167 and PCB189) show toxicological effects similar to dioxins (Van den Berg et al. 2006). PCB production was banned by the United States Congress in 1979 and by the Stockholm convention on persistent organic pollutants in 2001.

PCBs are not produced in Vietnam. However, the likely PCBs contaminated oil from other countries was imported from the late 1940s until 1980s in the form of industrial fluids such as hydraulic fluids, lubrication oils and as plasticizers (VEA 2012). It has been estimated that about 27,000–30,000 tons of oil contaminated by PCBs were imported from the former USSR, China and Rumania (Sinh et al. 1999; MONRE 2006). Electrical equipment containing PCBs, such as transformers, was imported from Australia until the mid-1980s (Kannan et al. 1995). Weapon being used extensively during the Indochina War is an additional PCBs source in Vietnam (Thao et al. 1993a, b).

On 22 July 2002, Vietnam ratified the Stockholm convention and became the 14th party of the convention which aimed to eliminate or restrict the production and use of persistent organic pollutants (POPs) in general and PCBs in particular. Vietnam committed to stop PCBs use before 2020 and entirely destroy PCBs by 2028.

As a first effort to implement the Stockholm convention, Vietnam co-operated with international environmental organizations on POP-related projects on public warning about POP's toxicity and step-by-step stop using POPs product. The most significant project on the management aspect is "PCBs management in Vietnam." The project was implemented from 2010 to 2014, with the overall goal of building Vietnam's national capacity to manage PCBs and safely storing large amounts of PCBs in demonstration provinces for future destruction. In addition, a PCBs inventory and a data base have been developed by the Vietnam Environmental Agency (VEA).

Since 1990s, Vietnamese research on POP and PCBs pollution in particular in the environment focused on areas that have high population density and of industrial importance: Hanoi, Ho Chi Minh City and main agricultural areas in the Red River and the Mekong River deltas (MONRE 2015). As few studies were conducted on the coastal environment in Vietnam, PCB data are still lacking and is only considered locally. Herein, we provide a comprehensive review on PCBs pollution along the coast of Vietnam. The available data of PCBs contamination from 18 coastal provinces are collected and evaluated. The effectiveness of the Stockholm convention participation on contaminated PCBs management and treatment is also mentioned.

Material and method

Since 1995, studies and assessments of PCBs pollution along the Vietnamese coast have been published. The study areas are shown in Fig. 1. However, the Vietnamese coastal PCBs database is limited and does not cover the country in a systematic. By geographic location, the most important studies on PCBs pollution along the coast of Vietnam are:

For the coasts in the North, most studies are on the Quang Ninh, Hai Phong and Nam Dinh Provinces (Nhan et al. 1998, 1999; Minh et al. 2002, Hong et al. 2008; IMER 2009, 2010, 2016). This region has the earliest data on PCBs pollution. However, these early studies target PCBs pollution in sediments but not in water, none in marine organisms.

Along the coast of central Vietnam, reports on PCBs in the Thanh Hoa, Nghe An, Thua Thien Hue and Da Nang Provinces have been published (Frignani

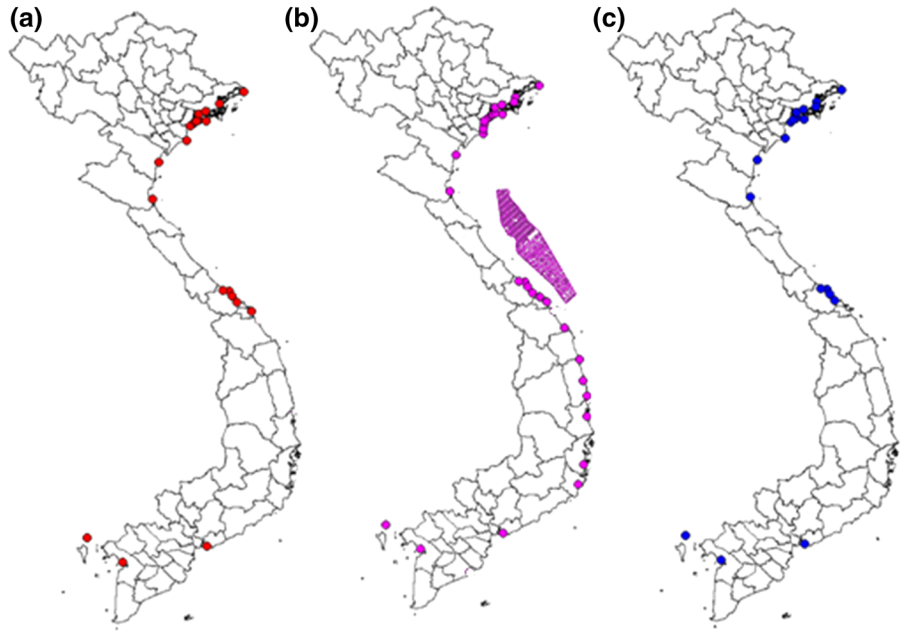

Fig. 1 PCBs sampling areas of **a** water (2008–2016), **b** sediment (1998–2016) and **c** biological samples (2008–2016). All samples were collected along with 18 coastal provinces in Vietnam

et al. 2007; Romano et al. 2013; Tham et al. 2016; IMER 2009, 2016). In this area, data on PCBs in sediments prevail. One important study provides sediment data on 402 offshore sampling sites along the coasts from Ha Tinh to Quang Nam Provinces (Huy et al. 2016). Until now, this data set is the only systematic one set on PCBs distribution in the offshore marine zones of Vietnam. Some limited studies on PCBs in sediments of typical coastal lagoons in the provinces of Thua Thien Hue, Binh Dinh, Phu Yen, Khanh Hoa and Ninh Thuan have been published (Giuliani et al. 2011). These lagoons are special ecosystems with an important role in economic development, aquaculture, tourism and community health.

The Southern coastal area is the region with the least PCBs pollution data. Only for Ba Ria–Vung Tau and Kien Giang Provinces, data are available (IMER 2009).

Results and discussion

PCBs in coastal water

The geographical distribution of PCBs in coastal water is shown in Fig. 2 with data obtained from 2008 to 2016 (Table S1). Total PCB concentration ranges between 2.7 and 5543.4 ng/L. The lowest value is observed in the open water (Sam Son beach in Thanh Hoa Province), and the highest value was reported in the Bach Dang river mouth (Hai Phong Province). The monitoring data show that the total PCB concentrations in the river mouths, with an average concentration of 762.3 ng/L (min–max levels: 22.4–5017.7 ng/L), are above there in the other areas such as lagoon (21.4–112.0 ng/L), bay (27.4–208.0 ng/L) and open water (2.7–731.7 ng/L). It should be noted that, in the river mouths, all the monitoring sites were identified or specific for estuaries of the large river basins in North and Central Vietnam, where the economic activities are intense. Therefore, the relatively high concentrations of PCBs in the river mouths are likely the result of land-based contaminants loading. In general, PCBs concentrations were the lowest in the open water areas. The water along the coasts of Quang Ninh and Hai Phong shows the highest concentration of total PCBs, followed by Da Nang Province. All these values were above the US EPA (2010) guidelines for aquatic life protection (30 ng/L). These high PCBs concentrations are ascribed to high priority economic development of these cities, which reflect the busy industrial activities in these regions. The PCBs concentrations in the oceans reported by WHO (1993) were in range of 0.05–0.60 ng/L. PCBs concentrations found in areas along the coast of Vietnam

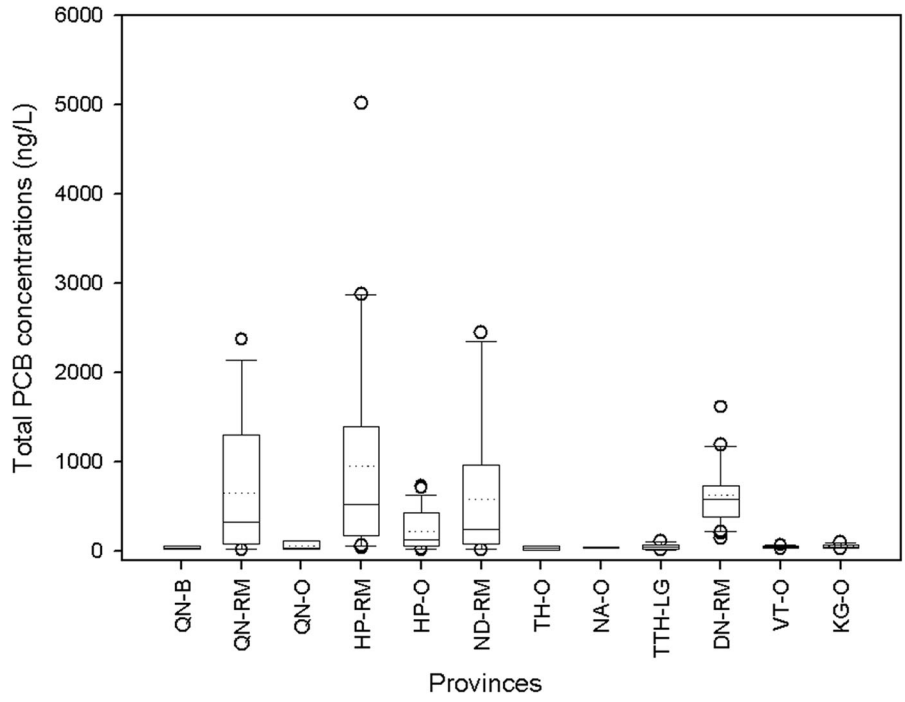

Fig. 2 Distribution of PCBs in coastal water from various locations in Vietnam. The boundaries of the box indicate the 25th and 75th percentiles, whiskers indicate the 10th and 90th percentiles, the median and mean values are shown by the straight and the dotted line, respectively. *QN* Quang Ninh, *HP* Hai Phong, *ND* Nam Dinh, *TH* Thanh Hoa, *NA* Nghe An, *TTH* Thua Thien Hue, *DN* Da Nang, *VT* Ba Ria–Vung Tau, *KG* Kien Giang, *B* bay, *O* open water, *LG* lagoon, *RM* river mouth

are much higher than these PCBs levels in other countries, which was reported previously. For example, total PCB concentrations detected along the coast in Singapore ranging from 0.04 to 61.7 ng/L, in Gulf of Mexico and Atlantic Ocean (North) < 0.003 ng/L, in the Northern Pacific Ocean was 0.59 ng/L and the Dutch Wadden sea was 0.62 ng/L (Wolanski 2006). In another study, Bao et al. (2012) revealed that PCBs levels in eight islands along China's coastal line were in range of 35.5–476.9 ng/L.

PCBs in coastal sediment

Studies on PCBs contamination of the sediments were carried out earlier and are more comprehensive than these in water. In 17/28 coastal provinces (Fig. 3), sediment samples were collected from different areas such as river mouths, bays, lagoons and in the open water. Intensive offshore monitoring (60–100 m water depth) was organized in the central part of Vietnam from Ha Tinh to Quang Nam Provinces (Huy et al. 2016). Concentration of total PCBs in the river mouths varied between 0.04 ng/g dry wt. (at Balat river mouth, 2004) to 178.29 ng/g dry wt. (at Han river mouth, 2015) (Table S2). All the PCBs concentrations in the sediments were below the Vietnamese criteria for marine sediments (189 ng/g dry wt), (National Technical regulation on sediment quality, QCVN 43: 2012/BTNMT). It is obvious that the PCBs concentrations in the sediment from river mouths are higher than those in lagoons, bays and in the open water, which is consistent with the results of PCBs found in water. High concentrations of PCBs in sediment were found in the mouth of the Han river in 2013–2014 (mean value of 97.69 ng/g dry wt, ranging from 49.29 to 178.29 ng/g dry wt.) (Tham et al. 2016). The Han river flows through Da Nang city to the sea. The Han port, an important river port for Da Nang and Quang Nam Provinces, is located close to the river mouth. The Han river also obtains the water of many industrial and urban sources in vibrant Da Nang city. PCBs found in these regions are mainly anthropogenic compounds. Therefore, the presence of PCBs in the sediments offshore from Ha Tinh to Quang Nam (a distance of about 30–150 km offshore), with an average concentration of 2.78 ng/g (min–max: 0.36–5.18 ng/g dry wt.), is an indicator of the spread and accumulation of PCBs in the marine environment.

Lagoons in the central Vietnam are important ecosystems among other because they supply aquatic products for the region. PCBs pollution in sediments indicates a potential hazard for benthic organisms. The

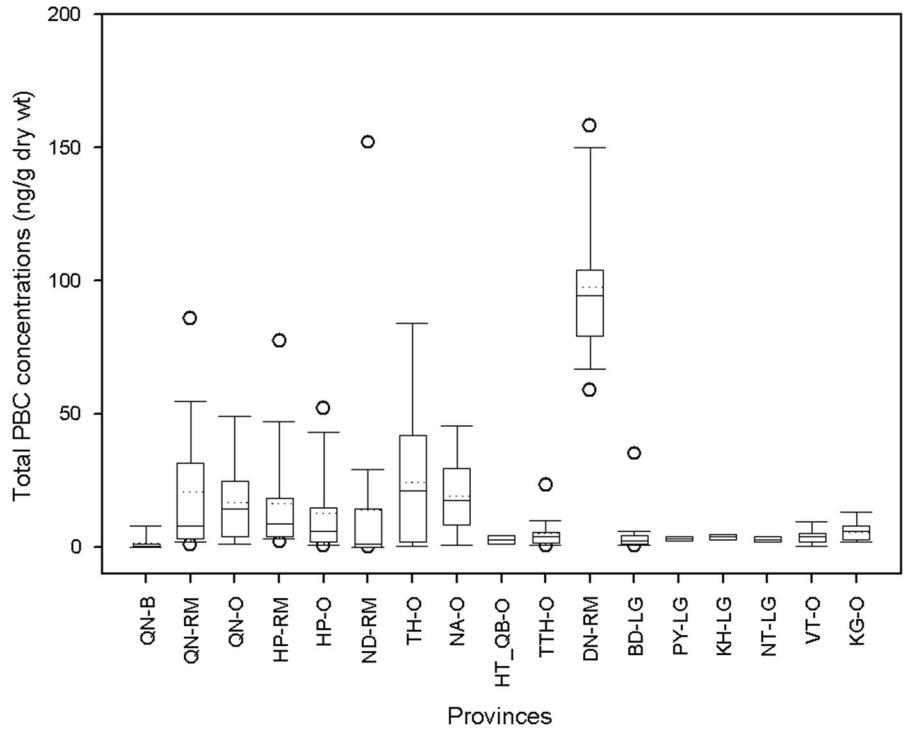

Fig. 3 Distribution of PCBs in coastal sediment from various locations in Vietnam. *HT_QB* Ha Tinh to Quang Binh, *BD* Binh Dinh, *PY* Phu Yen, *KH* Khanh Hoa, *NT* Ninh Thuan

Canadian Council of Ministers of the Environment (CCME) recently issued interim marine sediment quality guidelines (ISQG) including the threshold effect levels (TEL) of 21.5 ng/g dry wt. of total PCBs for sediment-dwelling organisms (CCME 2002). The collected data show that there has been PCBs accumulation in the central coastal lagoon sediment. However, most concentrations of PCBs in sediment were below the CCME ISQG/TEL (21.5 ng/g dry wt.). Only in the Thi Nai lagoon (Binh Dinh Province) in 2005 (Giuliani et al. 2011) and in Tam Giang–Cau Hai (Thua Thien Hue Province) in 2002 (Frignani et al. 2007), the measured values of 24.7 and 44.7 ng/g dry wt. exceeded the ISQG/TEL guidelines.

PCBs levels in sediments from Vietnamese bays were compared with those found in the Osaka (Japan), Masan (Republic of Korea) and Daya (China) bays. In general, PCBs levels of Vietnam were relatively low as compared to the sediments in these countries. However, the PCBs concentrations in the river mouths were relatively high (Table 1). Nevertheless, the data from the other countries date from the 1990s, while the data obtained along the Vietnamese coasts are more recent. These might indicate that the accumulation of PCBs in the sediments of the bays and the open water in Vietnam is not as critical as in some other surrounding Asian countries. This does, however, not exclude problems with accumulation of PCBs in the sediments over time in Vietnamese estuaries.

In 2009, the project "Investigation of PCBs volume, assessment of pollution level and zoning of pollution areas caused by PCBs disposal and PCBs residue in the whole country" (VEA 2009) estimates the total volume of PCB-containing waste oil was 6.2 million kg nationwide, of which 1.7 million kg in the coastal provinces, mainly in the North (Quang Ninh, Hai Phong, Nam Dinh and Ninh Binh) (Fig. 4). The high PCBs residual volume corresponds with the high concentrations of PCBs in coastal water and in the sediments in these provinces. This is important for the development of the marine tourism and the marine ecosystem conservation in these provinces. Therefore, protecting human and ecosystem health from risks of PCB emissions should be a main focus of the PCB management in this area.

Bioaccumulation of PCBs in the coastal area

Only limited data on the biological accumulation of PCBs in the marine ecosystems of Vietnam have been

Table 1 Comparison of total PCBs in coastal sediments of some Asian countries

Location	Year	Total PCB in marine sediment ng/g dry weight			References
		Estuary/river mouth	Bay	Open water	
Halong bay (Quang Ninh)	2003, 2004		0.11–10.1		Hong et al. (2008)
Osaka bay (Japan)	1990		63–240		Iwata et al. (1994)
Masan bay (Korea)	1997		1.2–41.4		Hong et al. (2003)
Daya bay (China)	1999		0.9–11.2		Zhou et al. (2001)
Cua Luc river mouth (Quang Ninh)	2008–2009, 2012–2016	0.64–120.0			Sinh (2012), IMER (2009, 2016), Viet et al. (2000)
Van Uc, Lach Tray, Bach Dang, Thai Binh river mouth (Hai Phong)	2009	1.77–82.55			IMER (2010)
Balat estuary (Nam Dinh)	2004, 2012-2016	0.04–158.38			IMER (2016), Hong et at. (2008)
Han river mouth (Da Nang)	2013, 2014	49.29–178.29			Tham et al. (2016)
Minjiang river estuary (Southeast China)	1999	15.8–57.9			Zhang et al. (2003)
Yangtze estuary (China)	2001	nd-19.0			Liu et al. (2003)
Tra Co (Quang Ninh)	2012–2016			1.19–51.25	IMER (2016)
Do Son (Hai Phong)	2003, 2009, 2012–2016			0.45–53.65	IMER (2010, 2016)
Sam Son (Thanh Hoa), Cua Lo (Nghe An)	2012–2016			0.23–84.05	IMER (2016)
Ha Tinh to Quang Nam Provinces 60–100 m water depth	2012			0.59–5.18	Huy et al. (2016)
Ba Ria–Vung Tau	2008, 2009			0.46–9.71	IMER (2009)
Phu Quoc (Kien Giang)	2008, 2009			1.95–14.67	IMER (2009)
Hongkong	1997–1998			nd-97.9	Richardson and Zeng (1999)
Singapore	2003			1.4–329.6	Wurl and Obbard (2005)

nd Not detected

published (Table S3). Studies focus merely on Northern provinces such as Quang Ninh, Hai Phong and Thai Binh; selected estuaries and lagoons in Central part; almost no data are available for the South coastal part. The monitoring time scatters from 1997, 2008, 2009 and 2012–2016. The organisms studied were Green Mussels (*Perna viridis*), Clams (*Meretrix meretrix*), shrimps and birds.

Figure 5 shows the PCBs concentrations in the fat tissue of biological samples from coastal areas of Vietnam. In the Red river estuary (Nam Dinh and Ninh Binh Provinces), resident and migratory birds, shrimps and fish (in 1996–1997) and clams (in 1996–1997, 2012–2016) were analyzed. Resident birds showed the highest concentrations, followed by migration birds, shrimps and clams/mussels while the lowest concentrations were found in fish. This is consistent with the biological magnification and the behavior of marine organisms, in which clam/mussel is the sedentary, bottom-dwelling and water filtering species with higher accumulation than in shrimps and fish. Along the north–south axis, PCB concentrations in the clam/mussel samples were the highest in Quang Ninh 425 (25–900) ng/g lipid wt, followed by Hai Phong 270 (20–744) ng/g lipid wt.

For mussels in Asian countries (Monirith et al. 2003), data on PCB concentrations have been inventoried from 1994 to 2001. In Vietnam, these concentrations range from 21 to 450 ng/g lipid wt., the mean value was 160 ng/g lipid wt., which is much lower than the levels found in the mussels from Japan, Hong Kong and the Philippines, but in line with those measured in Thailand and China. Recent monitoring data are consistent with that those of a previous study,

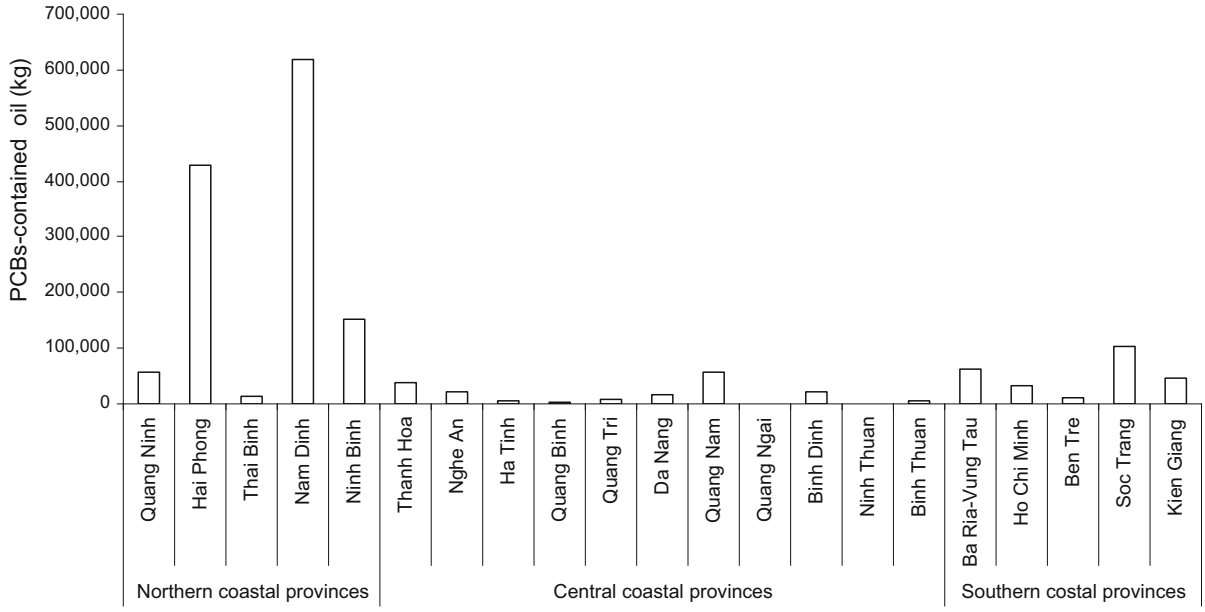

Fig. 4 Amount of PCB-containing waste oil in Vietnam's coastal provinces

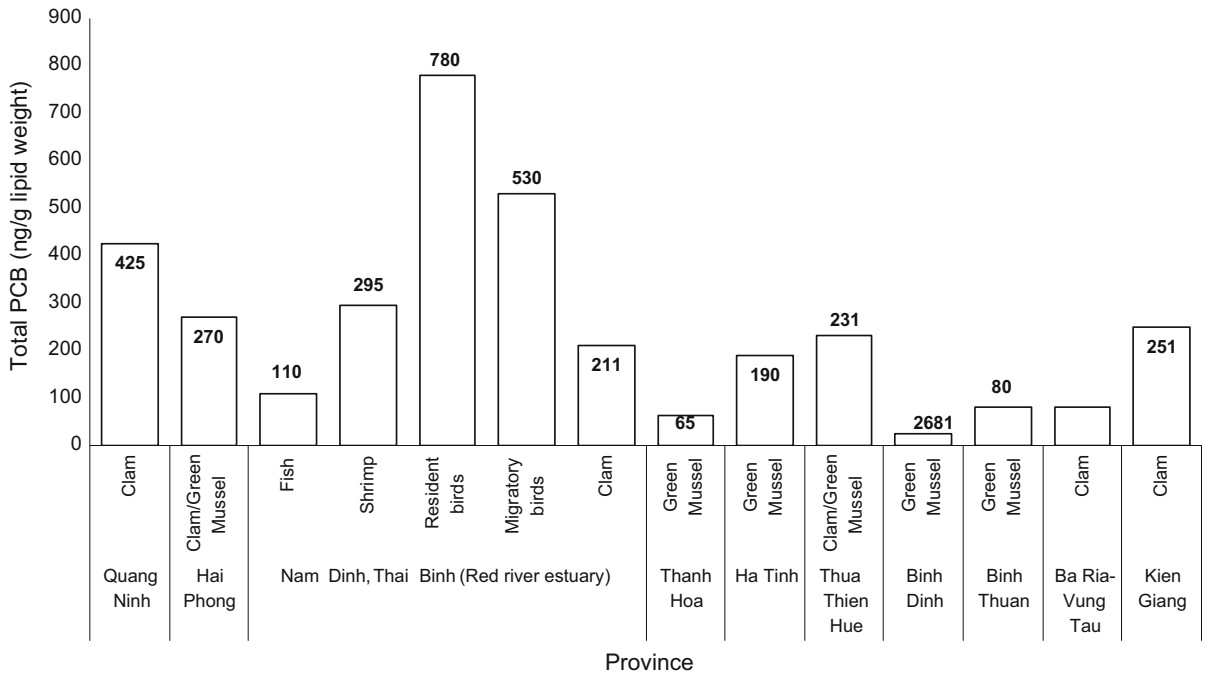

Fig. 5 Mean concentration of total PCB in biosample from Vietnam coastal area

in which no significant difference was demonstrated in the PCB concentration in clams/mussels from Vietnam and those collected along the Pearl river delta in the South of China and the Eastern coast of Thailand. The concentration varied in a range of 13.43–744.48 ng/g lipid wt. (IMER 2009, 2010, 2016), 41.0–729.2 ng/g lipid wt (Ahan-qiang 2004) and 259–579 ng/g lipid wt (Jaikanlaya et al. 2009), respectively.

PCBs in coastal environments after the Stockholm convention on POPs

Vietnam ratified the Stockholm convention on July 22, 2002. To implement the convention, the Decision No. 184/2006/QD-TTg dated August 10, 2006 to approve of the *National Implementation Plan for the Stockholm Convention on POPs* was issued by Prime Minister with the main objects of safe management, minimization and elimination POPs in Vietnam. On PCBs management, the WB/GEF project "PCBs Management in Vietnam" (2010–2014) was developed. This project aims at developing the national capacity in Vietnam to manage PCBs and safely store large amounts of PCBs in pilot demonstration provinces envisaging its destruction in the future (VEA 2012).

To assess the effect of the Stockholm convention on the PCBs pollution along the Vietnamese coast, Ha Long bay (Quang Ninh Province) (Figs. 6 and 7) and Balat estuary (Nam Dinh Province) (Fig. 8) were selected as the indicator areas. These areas have an important historical record of PCB monitoring data. Temporal variation of PCB contamination in Halong bay during the period from 2008 to 2016 shows an increasing trend in concentrations in water while no clear trend is observed in the sediments. The 1998 data in sediments are similar to these of 2013 and 2016, but much higher than those measured in 2003–2012 and 2014. 2015 witnessed a sudden increase in PCBs concentrations in the water as well as in the sediments. PCB values in clams at Balat estuary in the pre-ratification period (1996–1997) and after the Stockholm convention has been ratified (2012–2016) show large variation and a general increasing trend. These results show no demonstrable effect of the implementation of the Stockholm convention on the short term.

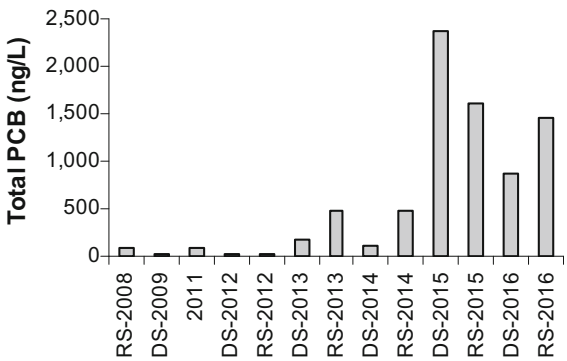

Fig. 6 PCBs concentration in water, Ha Long bay, 2008–2016

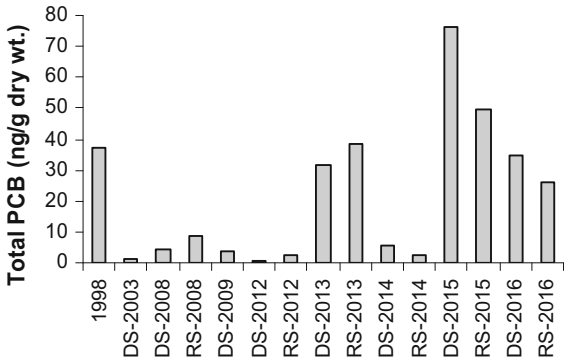

Fig. 7 PCBs concentration in sediments, Ha Long bay, 1998–2016

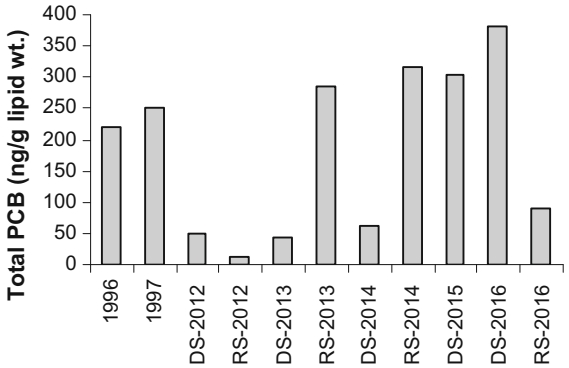

Fig. 8 PCBs concentration in Clams (Meretrix meretrix), Balat estuary, 1996–2016 Note *RS* rainy season, *DS* Dry season

Conclusion

In summary, a comprehensive overview of the status and distribution of PCBs of Vietnamese coastal provinces based on the multimedia monitoring studies from 1996 to 2016 is well described. The presence of PCBs in offshore areas is a strong evidence for the spread and accumulation of PCBs in the marine environment. PCBs contamination in Northern coast is much more serious than other coastal areas of Vietnam. PCBs in water and sediments in river mouths show higher concentrations than that in lagoons, bays or open water. The concentration of PCBs found in mussels from Vietnam is lower than those from the developed countries, but similar to this

in bivalve of the neighboring countries as China and Thailand.

This study also demonstrates that the participation of Vietnam in the Stockholm convention on management and treatment of POPs or PCBs in particular has not been effective enough. This requires Vietnamese government to have stricter policy and legislation, clearer mechanism and stronger management capacity for POPs in general and for PCBs in particular. The support for research and application of advanced and modern technologies in reducing, disposing and eliminating PCBs is essential to control the PCBs contamination in environment. It is also critical for Vietnam to establish a systematic PCBs monitoring network nationwide to protect both human and marine health. This study not only benefits Vietnamese government to tackle the PCBs contamination, but also contributes to the global in the quest of eliminating the POBs in general and PCBs in particular out of environment in the near future.

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