A Review on Polychlorinated Biphenyls (PCBs) and Polybrominated Diphenyl Ethers (PBDEs) in South Asia with a Focus on Malaysia

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Contents

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1 Introduction

The monarchy of Malaysia consists of peninsular Malaysia, located between Singapore, Thailand and Indonesia, and states of Sabah and Sarawak on the island of Kalimantan (Borneo). Malaysia has a total landmass of 329,758 km^2 and is almost as diverse as its culture (Fig. 1).

Since 1970s the leading sector of development has been a range of export orientated manufacturing industries such as textiles, electrical and electronic goods, rubber products, while Malaysia became the world's largest producer of oil palm in the 1970s (Drabble 2001). Due to the current policy of achieving high income status by 2020 and transform Malaysia into a multi-sector economy, Malaysia is attempting to move farther up in the value-added production chain by shifting its focus on high tech industries (Central Intelligence Agency 2015). Thus, 34.7 % of the total Gross Domestic Product (GDP) generated in Malaysia in 2014 was from industrial sector, followed by agriculture and other service industries which accounted for 9.3 % and 56 % respectively. In which, the electrical and electronic contributing 35 % of country's total exports between January to May 2015 (Department of Statistics Malaysia 2015).

Polychlorinated biphenyls (PCBs) are aromatic, synthetic chemicals with a chemical formula $C_{12}H_{10-n}Cl_n$, where n ranges from 1 to 10 (Fig. 2). PCBs consist of 209 congeners which exhibit wide differences in their chemical characteristics and biological effects (Kannan et al. 1989). PCBs were used widely in electrical equipments like capacitors and transformers and in hydraulic fluids, heat transfer fluids, lubricants, and plasticizers. PCBs have been used commercially since 1929 (De Voogt and Brinkman 1989) but its presence in the environment was not recognized until 1966, when Jensen identified PCBs in human and wildlife samples (Jensen 1966).

PCBs are well known environmental contaminants with persistence, bioaccumulation and human health problems (Safe 1994). Approximately two million tonnes of PCBs have been produced commercially and about 10 % of which still remains in the environment today (WHO 2003). Besides, potentially toxic coplanar PCBs have been determined in humans, rats, dogs, cats, rhesus monkeys (terrestrial), finless porpoise, Dall's porpoises, Baird's beaked whales, striped dolphins and killer whales (marine) (Kimbrough et al. 1975; Kannan et al. 1989, 1993; Golub et al. 1991; Kannan 2000). Mono- and non-*ortho* coplanar PCBs that persist in the environment and in animals cause reproductive dysfunction (Barsotti et al. 1976; Golub et al. 1991; Kannan et al. 1988). The Stockholm Convention entered into force in 2004 and recommended that all equipment containing PCBs are eliminated by the year 2025 and then manage the rest with environmentally sound policies until 2028. In fact based on the Stockholm Convention website, Malaysia has only signed the Stockholm Convention but that the country has not ratified the Convention to date, therefore Malaysia has yet to develop a National Implementation Plan on POPs. Recently, the International Agency for Research on Cancer (IARC) has classified PCBs as carcinogen Group 1 (carcinogenic to humans), which further underline the significance of PCBs monitoring (IARC 2015).

Fig. 1 Location of Malaysia in Southeast Asia

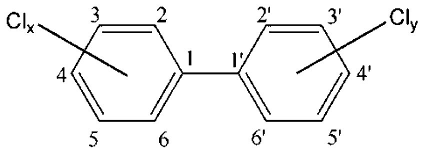

Fig. 2 The general chemical structure of chlorinated biphenyls

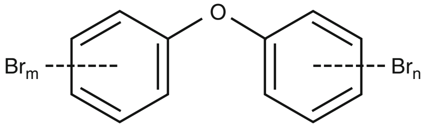

Fig. 3 Structure of polybrominated diphenyl ether (PBDEs)

Polybrominated diphenyl ethers (PBDEs) (Fig. 3) have been widely used as flame retardants (BFRs). PBDEs like PCBs are hydrophobic, lipophilic and thermally stable and are capable of bioaccumulating in food chain (Rahman et al. 2001; de Wit 2002; Kannan et al. 2005). Furthermore, the similarity between the structures of PCBs and PBDEs suggests similar toxicity to animals and humans (Ogata et al. 2009; Hong et al. 2010). The higher proportion of lower brominated PBDE congeners in the brain tissues of little brown bats compared to fat tissues indicated that lower brominated PBDE congeners could cross the blood-brain barrier more efficiently than the higher brominated PBDE congeners (Kannan et al. 2010). Studies carried out by McDonald (2002), Fowles et al. (1994), Zhou et al. (2002) and Branchi et al. (2002) show that PBDEs in humans disrupt thyroid hormones, cause neurobehavioral deficiency and possibly cause cancer. Hence in 2009, Stockholm Convention has listed commercial Penta-BDE and Octa-BDE as POPs.

Although PCBs-containing electrical equipment and other applications are not manufactured in Malaysia, they have been imported for a while until they were banned in June 1998 (Hashim 2003; Ibrahim 2007). PCBs have been used in heat exchangers and hydraulic systems while PBDEs were commonly used as flame retardants in a series of applications including textiles, television sets, plastics and wire insulation. Waste motor and transformer oils are considered as a main source of PCBs emission into the environment in Malaysia (Jahromi et al. 2014). There is still approximately 15 % of known PCBs residing in developing countries including Malaysia, mostly as a result of shipments of wastes from industrialized countries (Abel and McConnell 2009).

2 PCBs and PBDEs in E-Waste in Malaysia

Solid waste is a major environmental problem in Malaysia. In 2008, 23,000 tons of waste were produced each day in Malaysia with less than 5 % being recycled and approximately 19 % of waste being ended up in the drains, polluting the environment including PCBs and PBDEs (Wu et al. 2008; Tue et al. 2010; Desa et al. 2012).

Department of Environment (DOE) Malaysia has defined e-wastes as wastes from the used electronic and electrical (EEE) equipment such as accumulators, mercury switches, transformers, cathode-ray tubes (CRT) or PCBs-containing capacitors (DOE 2008), which are regulated in Malaysia since 2005 and listed as scheduled wastes. According to the E-waste Inventory of Malaysia, total volume of e-waste generated in 2008 was 688,000 metric tonnes and it will reach 11.2 million metric tonnes by 2020. Currently, there are 18 full recovery facilities and 128 partial recovery facilities permitted by the DOE of Malaysia for the segregation, dismantling and treatment of e-waste. Despite the law that e-waste could only be treated and recovered by the licensed facilities in Malaysia, Environmentally Sound Management (ESM) is lacking in the collection, treatment and recovery of e-waste (Suja et al. 2014).

3 PCBs in Malaysia

3.1 PCBs in Sewage Sludge

A research conducted by Ahmad et al. (2005) on palm oil and sewage sludge revealed PCB congeners such as PCB-28, 52, 101, 118, 138, 153 and 180 in oil and PCBs congeners 28, 52 and 101 in sludge, while PCBs 118, 138, 153 and 180 were not detected (3.37–70.6 ng/g). On the other hand, Halim (2007) investigated the concentrations of PCBs in sewage sludge using two types of extraction methods. The samples were extracted using supercritical fluid carbon dioxide ($SFCO_2$) and subcritical water extraction (SWE) and PCB-28, 52, 101, 118,138, 153 and 180 were determined using GC-ECD. The concentration of PCBs in the sludge samples extracted using $SFCO_2$ were comparatively higher (31.2–82.0 ng/g) than samples extracted using SWE (20.2–60.1 ng/g).

3.2 PCBs in Pellet

Plastic resin pellets (0.1–0.5 cm) are found on beaches around the world. A Japanese study (Ogata et al. 2009) analyzed samples of polyethylene pellets from 30 beaches in 17 countries including Malaysia to determine the concentration of organochlorine compounds. Sampling locations in Malaysia were Langkawi, Penang and Borneo and the median concentration of the sum of 13 PCB congeners (CB-66, 101, 110, 149, 118, 105, 153, 138, 128, 187, 180, 170, 206) recorded at these places were 8 ng/g-pellet, 12 ng/g-pellet and 10 ng/g-pellet, respectively (Fig. 4).

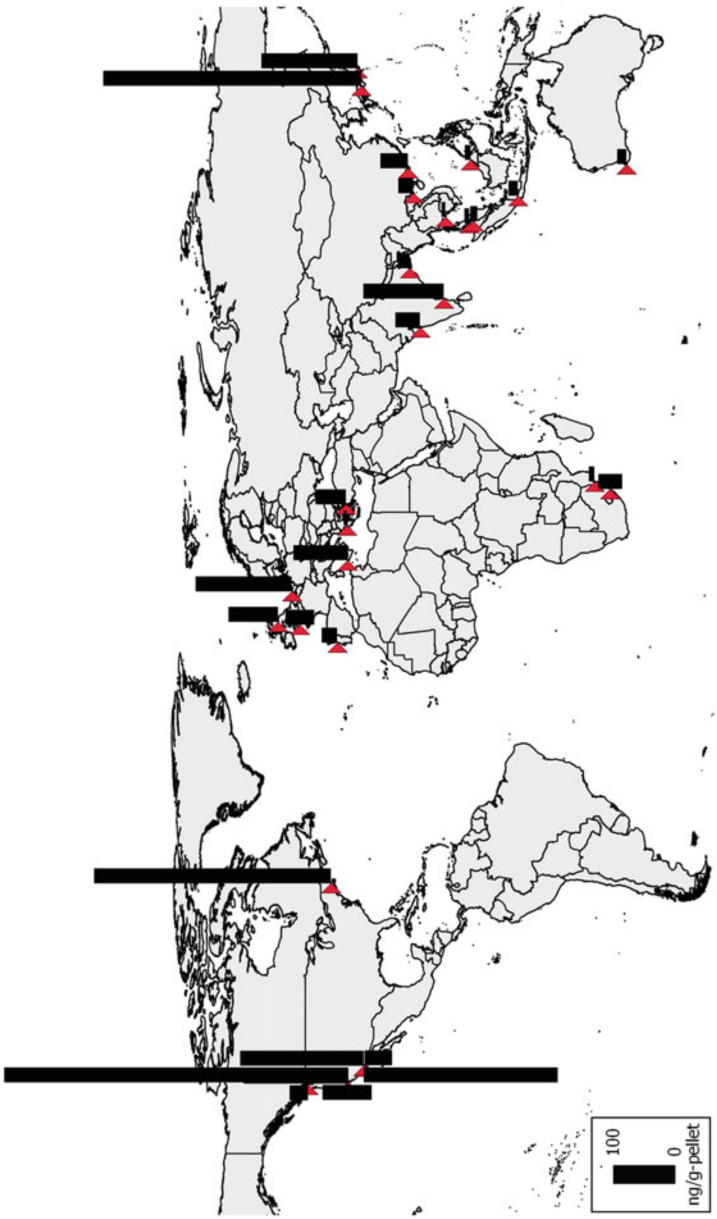

Fig. 4 Median concentration of ∑13 PCBs (ng/g-pellet) in beached plastic pellets. ∑13 PCBs is the sum of concentrations of CB# 66, 101, 110, 149, 118, 105, 153, 138, 128, 187, 180, 170, 206. (Source: Ogata et al. 2009)

3.3 PCBs in Air

PCBs were measured in air using Polyurethane foam (PUF) passive air samplers (PAS) in Malaysia, Japan, Vietnam and the Philippines by Kwan (2014). The air samplers were deployed at six locations in these Asian countries including Malaysia (Port Dickson) during dry and wet seasons for a month. CB-66, 101, 110, 149, 118, 105, 153, 138, 128, 187, 180, 170 and 206 were measured. Result showed that the atmospheric concentration of PCBs in Malaysia (less than 5 pg/m^3) was not as high as in other countries. For example, Philippines recorded a high 80 pg/m^3.

3.4 PCBs in Mussels

Bivalves such as mussels are suitable bio-indicator for monitoring trace toxic contaminants in coastal waters due to their wide distribution, sessile lifestyle, easy sampling, tolerance to a considerable range of salinity, resistance to stress and high accumulation of a wide range of chemicals (Goldberg et al. 1978). A study using green mussels (*Perna viridis*) was conducted in Penang, Malaysia. Mussel samples were collected from six stations on the island of Penang (Weld Quay Pier, Marine Depot, Pulau Jerejak, Permatang Damar Laut, Batu Maung and Gertak Sanggul) and three more stations in Singapore waters (Selatar, Serangoon and Ponggol). The concentration of PCBs analysed in Malaysia was in the range of 99.9–599.9 ng/g on a dry weight basis (Sivalingam et al. 1982).

Besides, Monirith et al. (2003) also examined the contamination of persistent organochlorines (OCs) including PCBs in mussels collected from coastal waters of Asian countries like Cambodia, China, Hong Kong, India, Indonesia, Japan, Korea, Malaysia, Philippines, Far East Russia, Singapore, and Vietnam. The sampling locations were at different parts of Malaysia (Kuala Penyu and Trayong of Sabah, Sangkar Ikan and Tanjung Rhu of Langkawi, Butterworth and Penang Bridge of Penang, Bagan Bridge of Selangor, Lukut and Pasir Panjang of Negeri Sembilan, Tanjung Batu of Malacca and Pasir Puteh of Johor Bahru). Generally the concentration of PCBs in Malaysia was in low range from <4.2 to 60 ng/g lipid weight. However, high concentration of PCBs was found at Pasir Puteh, Johor Bahru which recorded 230 and 250 ng/g lipid weight respectively. The mean and range of PCBs concentrations from Asian countries in two studies are shown in Table 1.

Similarly, there was another study that used mussel samples, including green mussels (*Perna viridis*) and blue mussels (*Mytilus edulis*) to measure the levels of PCBs in the coastal waters of Asian countries (Ramu et al. 2007). Mussels were collected at Port Dickson, Pantai Lido, Pasir Puteh, Sebatu and Penang in Malaysia and the concentrations of PCBs analyzed in this study were in between 25 to 160 ng/g lipid weight. PCBs concentrations in mussels collected from coastal waters of Asian countries are shown in Fig. 5.

Table 1 Mean and range (in parenthesis) of PCBs concentration (ng/g lipid weight) in mussels from Asian countries

Country	PCBs (ng/g lipid weight)	
	Reference: Monirith et al. (2003)	Reference: Ramu et al. (2007)
Cambodia	35 (<3.8–220)	250 (200–300)
China	120 (15–540)	61 (3.8–160)
Hong Kong	310 (40–710)	401 (30–1200)
India	340 (9.8–600)	319 (56–640)
Indonesia	87 (5.6–210)	793 (510–1400)
Japan	3000 (510–12,000)	561 (83–2000)
South Korea	170 (30–340)	262 (17–1000)
Malaysia	**56 (<4.2–250)**	**89 (25–160)**
Philippines	290 (22–640)	1500 (1100–1900)
Russia	3200 (2700–3700)	NA
Singapore	90	NA
Vietnam	160 (21–450)	99 (26–290)

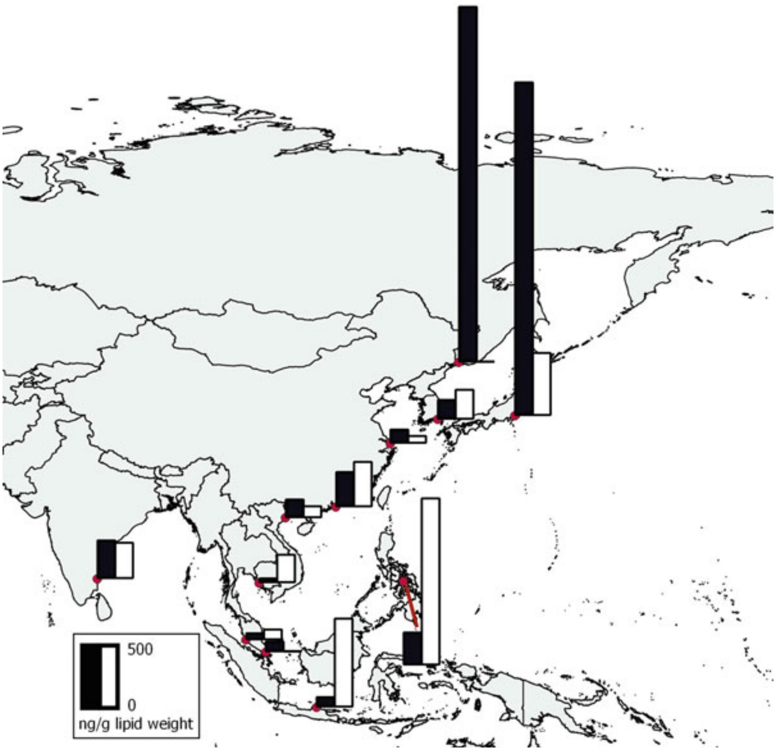

Fig. 5 Distribution of mean PCBs concentrations in mussels collected from coastal waters of Asian countries based on data from Monirith et al. (2003) (*black bar*) and Ramu et al. (2007) (*white bar*)

3.5 PCBs Concentration in Sediment, River Waters and Surface Seawaters

There was only one study each on the concentration of POPs including PCBs in river waters and surface seawaters by a Japanese group. It was found out that the total PCBs concentration was 0.45 ng/L in Selangor River water, and <5.0 ng/g of PCBs in the sediment samples from the same location (Iwata et al. 1994). Whereas the surface waters at the Straits of Malacca contained 0.02 ng/L of PCBs (Iwata et al. 1993), which was similar to the POP contamination levels at South China Sea.

3.6 PCBs Contamination in Fresh Water Fishes and Marine Organisms

Muhammad (2006) analyzed six species of fresh water fishes and seven species of marine organisms. All samples were collected from the northern region of peninsular Malaysia. The PCB concentrations in these fresh water samples ranged from 7.8 to 22.5 ng/g wet weight and the more toxic PCB-126 congener was detected only in the snakehead fish at very low concentration (0.03 ng/g wet weight). PCBs concentrations in marine organisms were generally lower than in the fresh water fishes. All the fish species in both categories and PCBs concentration are listed in Table 2.

3.7 PCBs in Human Breast Milk

PCBs were analyzed in human breast milk from non-smoking, healthy primipara mothers in the age group of 23–38 who were living in Penang and Kedah, Malaysia (Sudaryanto et al. 2005). Basically PCBs were detected in all the breast milk samples and the mono-*ortho* coplanar PCBs, were detected with an average concentration of 11 ng/g lipid weight, followed by non-*ortho* PCBs with concentration of 0.062 ng/g lipid weight. The same study also showed the result of average total TEQ levels to be 0.013 ng TEQs/g lipid weight. PCB levels in breast milk from Malaysia (Total PCBs with mean concentration of 80 ng/g lipid weight) were comparatively lower than developed countries, but slightly higher than other developing countries such as India, Vietnam, Cambodia and the Philippines (Fig. 6).

Table 2 Concentration of PCBs in fresh water fishes and marine species in Malaysia

Fresh water species	% Lipid (mean)	Concentration range of PCBs (ng/g wet weight)	Marine species	% Lipid (mean)	Concentration range of PCBs (ng/g wet weight)
Catfish (*Clarias batrachus*)	1.08	0.08–33.9	Small mackerel (*Rastrelliger sp.*)	1.20	0.03–2.5
Snakehead (*Channa striatus*)	1.03	1.69–20.4	Bigeye croaker (*Pennahia macrophthalmus*)	1.16	0.13–1.7
Gourami (*Trichogaster sp.*)	1.08	0.11–52.3	Mullet (*Mugil cephalus*)	1.35	0.09–1.9
Javanese carp (*Puntius gonionotus*)	1.04	0.04–22.2	Queenfish (*Scomberoides commersonnianus*)	1.04	0.07–5.2
Sultan fish (*Leptobarbus hoevenii*)	1.09	5.2–43.7	Catfish (*Arius sp.*)	1.20	0.18–3.3
Climbing perch (*Anabas testudineus*)	1.01	0.38–14.2	Shrimps (*Metapenaeus sp.*)	1.04	0.12–2.1
			Blood cockles (*Anadara granosa*)	1.06	0.05–3.7

Source: Muhammad (2006)

4 PBDEs in Malaysia

4.1 PBDEs in Mussels

The green mussels (*Perna viridis*) and blue mussels (*Mytilus edulis*) collected from various locations in Asia by Ramu et al. (2007) were studied for PBDEs. Based on their analysis, PBDEs were detected in all mussel samples indicating widespread contamination of these compounds in the coastal waters of Asian region. The level of contamination varied among sampling locations. Lower residue levels of PBDEs were found in samples from Cambodia, Vietnam, India and Malaysia in comparison to samples from Korea, Japan, Hong Kong, China and the Philippines. The total concentration of PBDEs in mussels collected from Malaysia ranged from 0.84 (at Sebatu) to 16 ng/g lipid weight (at Pasir Puteh) with relatively higher concentration of mono- to hepta-BDEs. On the other hand, the concentration of octa- to deca-BDEs in all mussel samples were below detection limit except at Pasir Puteh, where 0.19 ng/g lipid weight was detected. All these data are summarized in Table 3 (Fig. 7).

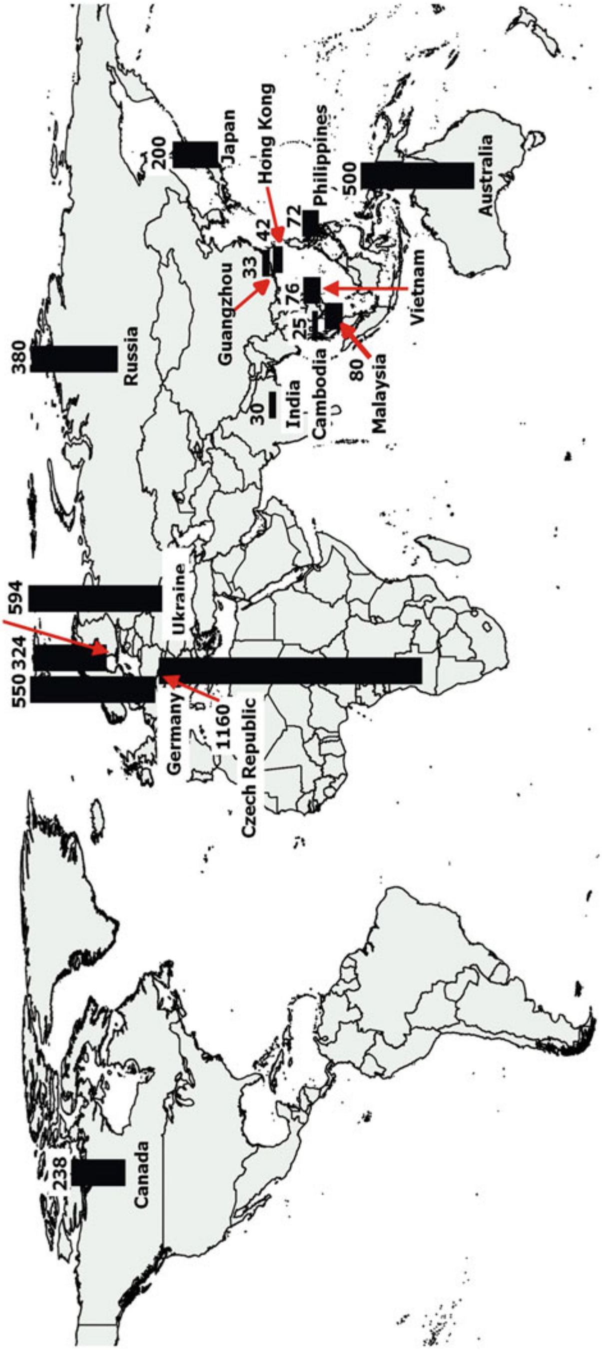

Fig. 6 Comparison of PCBs in human breast milk from developing and developed countries (ng/g lipid weight). (Source: Sudaryanto et al. 2005)

Table 3 Concentration of PBDEs (ng/g lipid wt.) in mussels from coastal waters of Malaysia

Location	Lipid (%)	PBDEs		
		Mono-hepta[a]	Octa-deca[b]	Total
Port Dickson	0.28	2.1	bdl	2.1
Pantai Lido	0.71	14	bdl	14
Pasir Puteh	1.5	16	0.19	16
Sebatu	1.8	0.84	bdl	0.84
Penang	0.95	1.2	bdl	1.2

Source: Ramu et al. (2007)
bdl below detection limit
[a]Sum of BDE-3, BDE-15, BDE-28, BDE-47, BDE-99, BDE-100, BDE-153, BDE-154, and BDE-183
[b]Sum of BDE-196, BDE-197, BDE-206, BDE-207, and BDE-209

4.2 PBDEs in Soils at Municipal Waste Dumping Sites

Huge amount of municipal waste is being disposed in open dumping sites with lack of effective management or treatment in Asian developing countries. The total municipal solid waste (MSW) generation in Malaysia has increased from 5.91 million tonnes in 2001 to 6.97 million tonnes in 2005 and is expected to increase about 2.5–3 % annually due to population and economic growth (Tarmudi et al. 2009). In Malaysia particularly, landfilling is the main option of waste disposal (90–95 %) with a recycling rate of 5–10 % despite the fact that approximately 70–80 % of the waste is recyclable (Johari et al. 2014). Eguchi et al. (2013) investigated the BFR contamination of soils from municipal waste dumping sites in five Asian developing countries (India, Vietnam, Malaysia, Indonesia and Cambodia). Soil samples in Malaysia were collected from the open dumping sites at Kuala Lumpur and Penang. A total of 14 PBDE congeners from mono- to deca-BDE were detected in all soil samples and the concentration of BDE-209 is significantly higher than other PBDE congeners in most of the samples. The levels were highest in Vietnam (mean: 95 ng/g dry weight, range: 1.2–430 ng/g dry weight), followed by Indonesia, Cambodia, India, and the lowest levels were detected in Malaysia (mean: 6.2 ng/g dry weight; range: 4.6–7.8 ng/g dry weight) (Eguchi et al. 2013). Concentration of PBDEs in soil samples from waste dumping sites of Malaysia can be found in Table 4. The higher PBDE levels in municipal waste dumping sites than those reference site also suggested that municipal waste dumping sites are a potential source of PBDEs in Asian developing countries.

4.3 PBDEs in Landfill Leachates

PBDE-containing products at landfills or municipal solid waste dumping sites (MSWDS) have been identified (Rahman et al. 2001). The concentration levels of

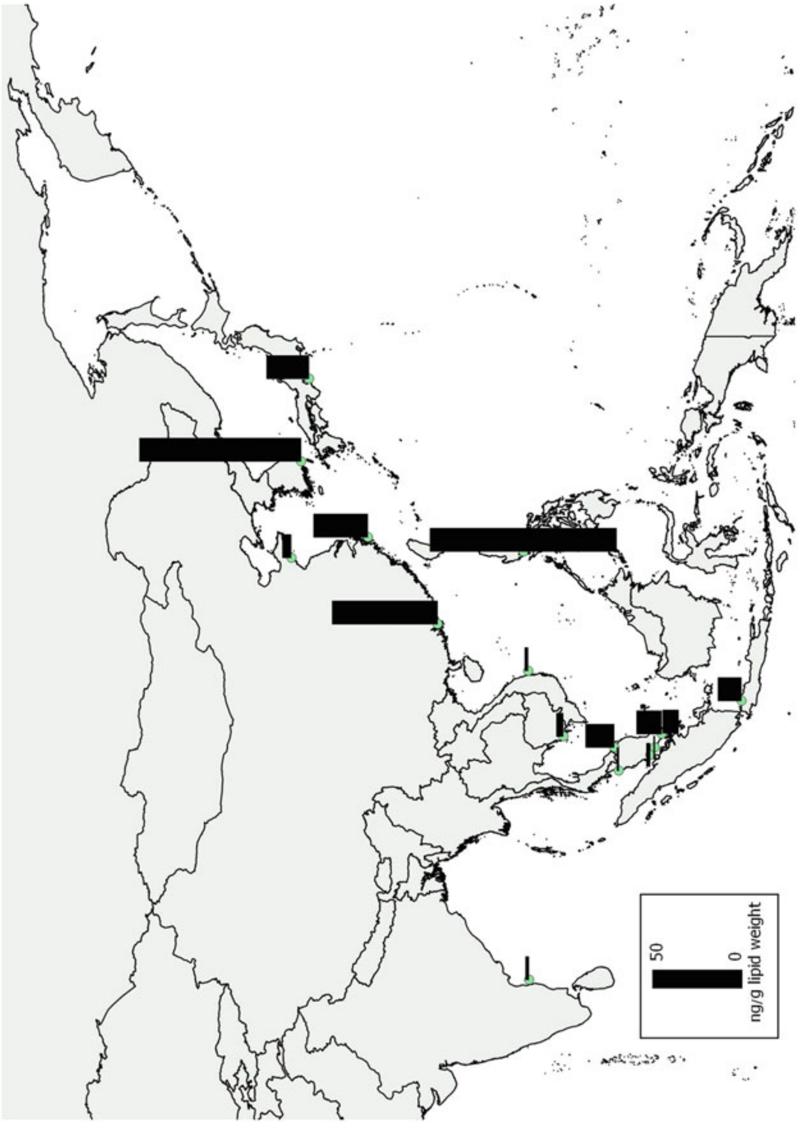

Fig. 7 Geographical distribution of PBDEs concentrations in mussels from coastal waters of Asia. (Source: Ramu et al. 2007)

Table 4 Concentration of PBDEs (ng/g dry weight) in soils of waste dumping sites in Malaysia

	Mean (min–max)	
	Reference sites	Dumping sites
TOC (%)	1.9 (0.36–3.4)	4.5 (3.3–5.7)
PBDEs		
BDE3	<0.003	<0.003
BDE15	0.003 (<0.003–0.006)	0.12 (0.007–0.24)
BDE28	<0.003	0.32 (0.02–0.62)
BDE47	0.02 (0.02)	0.41 (0.29–0.54)
BDE99	0.01 (0.01–0.02)	0.36 (0.25–0.48)
BDE100	0.008 (0.007–0.01)	0.03 (<0.003–0.05)
BDE153	0.005 (<0.003–0.01)	0.02 (<0.003–0.05)
BDE154	0.01 (0.008–0.02)	0.44 (0.02–0.85)
BDE183	0.02 (0.02–0.03)	0.53 (0.09–0.97)
BDE196	0.01 (0.006–0.02)	0.18 (0.04–0.32)
BDE197	0.02 (0.01–0.03)	0.33 (0.01–0.65)
BDE206	0.07 (0.05–0.09)	0.21 (0.14–0.28)
BDE207	0.08 (0.05–0.1)	0.29 (0.14–0.43)
BDE209	2.1 (1.1–3.0)	3.0 (2.4–3.5)
$\sum_9$PBDEs[a]	0.09 (0.07–0.11)	2.2 (0.7–3.7)
∑PBDEs[b]	2.4 (1.3–3.4)	6.2 (4.6–7.8)

[a]Sum of mono- to hepta-BDE congeners (BDE3, 15, 28, 47, 99, 100, 153, 154, and 183)
[b]Sum of mono- to deca-BDE congeners (BDE3, 15, 28, 47, 99, 100, 153, 154, 183, 196, 197, 206, 207 and 209)
Source: Eguchi et al. (2013)

PBDEs in the landfills were generally higher than those found in rivers and coastal waters (Kwan 2014). Among eight MSWDS from tropical Asian countries, leachate samples were collected at Tamang Beringin, Kuala Lumpur once during the wet season in 2003 and twice during the dry season in 2004. Based on her findings, the concentration of PBDEs in the MSWDS leachates from tropical Asian countries in this study were higher than those reported in other countries such as Japan, South Africa, Canada, United States of America and Sweden. Particularly Thailand, Cambodia, India, Malaysia and the Philippines were the hotspots of PBDE contamination, probably because of the rapid urbanization and industrialization (Table 5).

4.4 PBDEs in Sediments

PBDEs being lipophilic with low solubility in water tend to accumulate in sediments or particulate matter, aiding their distribution further to marine biota. Many previous studies have shown the predominance of BDE-209 in sediments probably due to high production and usage of technical deca-BDE products (Eljarrat et al. 2005; Moon et al. 2007a; Tokarz et al. 2008; Toms et al. 2008;

Table 5 Concentration of PBDEs in the leachate samples from MSWDS Tamang Beringin, Malaysia

PBDEs	Concentration (ng/L) (min–max)	PBDEs	Concentration (ng/L) (min–max)
BDE-33/28	0.459–2.83	BDE-153	15.6–31.9
BDE-75	[a]ND	BDE-154	5.73–9.28
BDE-47	23.5–48.5	[d]Hexa-BDEs	22.3–47.5
BDE-66	0.898–3.82	BDE-183	7.27–21.8
BDE-77	ND-0.072	[e]Hepta-BDEs	11.5–31.7
[b]Tetra-BDEs	26.4–60.0	[f]Octa-BDEs	26.5–36.5
BDE-85	0.219–2.97	BDE-206	6.73–11.6
BDE-99	33.9–72.8	BDE-207	6.34–9.08
BDE-100	4.55–11.0	[g]Nona-BDEs	22.3–34.8
BDE-119	ND-0.27	BDE-209	22.3–31.2
[c]Penta-BDEs	40.3–81.8		

Source: Kwan (2014)
[a]ND = Not detected by the instrumental analysis
[b]Tetra-BDEs = ∑BDEs 47, 49, 66, 71, 75, 77
[c]Penta-BDEs = ∑BDEs 85, 99, 100, 116, 118, 119, 126
[d]Hexa-BDEs = ∑BDEs 138, 153, 154, 155, 166
[e]Hepta-BDEs = ∑BDEs 179, 181, 183, 188, 190
[f]Octa-BDEs = ∑BDEs 196, 197, 202, 203
[g]Nona-BDEs = ∑BDEs 206, 207, 208

Chen et al. 2009). This statement was further substantiated by Kwan (2014), who investigated the occurrence of PBDEs in surface sediment samples from urban areas of tropical Asian countries, including Lao PDR, Cambodia, Vietnam, India, Indonesia, Thailand, the Philippines and Malaysia. According to her analysis, nearly all the sediment samples from Lao PDR, Cambodia, Vietnam, India (Mumbai), Thailand, the Philippines and Malaysia have exhibited the predominance of BDE-209. Relative to the sediment samples from Japan (with a total PBDE geometric mean concentration (GMC) of 100 ng/g dw (dry weight)), studies from Kwan (2014) indicated the lowest total PBDE GMC in Lao PDR (9.38 ng/g dw). Compared to the GMCs of total PBDEs found in Vietnam (34.2 ng/g dw), Indonesia (42.2 ng/g dw), Cambodia (58.4 ng/g dw), India (67.3 ng/g dw), Thailand (160 ng/g dw), and the Philippines (178 ng/g dw), Malaysia (Klang river) recorded a marginally higher readings than these countries with 275 ng/g dw. In addition, Kwan (2014) has also correlated concentrations of PBDEs in the aquatic environment such as sediments to the GDP per capita and the number of MSWDS; higher population and more MSWDS will result in higher concentration of PBDEs in sediments.

5 PCBs and PBDEs in Sea Turtle

Several studies have reported that persistent organic pollutants (POPs) such as PCBs and PBDEs are found in sea turtle populations. Due to the lipophilic properties of these compounds and the mobilization of lipids by sea turtle for egg production, it is likely that POPs are transferred from nesting females to eggs and hatchlings during reproduction (Kwan 1994). van de Merwe et al. (2010) have analyzed POP contamination in a nesting population of *Chelonia mydas* in Malaysia, and investigated the maternal transfer of these chemicals to eggs and embryos as well as their impacts on hatchling development. Eggs and blood were collected from 11 adult female *Chelonia mydas* nesting at the Ma'Daerah Turtle Sanctuary, Terengganu, Malaysia in 2004 and analyzed for POP concentrations. The result showed significant correlation between maternal blood and eggs, and between eggs and hatchling, in other words, these chemicals are being transferred from nesting female *Chelonia mydas* to eggs and hatchlings. Additionally, this study also proved that the less lipophilic congeners tend to preferentially transfer from eggs to hatchlings, while the highly lipophilic congeners stay back with the mother. In general, hatchlings are at high risk from exposure to PCBs and PBDEs (Table 6).

6 Pan Asian Comparisons

6.1 Comparison of PCBs and PBDEs Concentrations in Human Breast Milk

By comparing the concentration of total PCBs (obtained by summing up the concentration of individually resolved peaks of PCB isomers and congeners) in human breast milk samples collected from mothers residing in Malaysia (Sudaryanto et al. 2005) to other Asian countries (Kunisue et al. 2002, 2004a, b, 2006; Sudaryanto et al. 2006; Wong et al. 2013). Malaysia recorded one of the highest level of PCBs contamination with 80 ng/g lipid weight. the highest concentration of PCBs around the same sampling year was detected at Payatas, Philippines with concentration of 92.5 ng/g lipid weight in 2004. The highest PCBs contaminated human breast milk sample since the year of 1989 until 2009 was collected at Hong Kong in 1989, followed by Dong Nai in 1991 and Chennai in 1988, with concentration of 640, 353 and 110 ng/g lipid weight respectively (Table 7).

Generally, PCBs contamination gradually decreased over the years as shown by readings at Chennai and Phnom Penh, which dropped from 110 to 34 ng/g lipid weight and from 39 to 20 ng/g lipid weight. The only exception is PCBs concentration in Bangkok which increased from 15 ng/g lipid weight in 1989 to 52 ng/g lipid weight in 1991.

Table 6 The concentration of PCBs and PBDEs in eggs and blood from nesting females and hatchlings of *Chelonia mydas*

	Concentration (pg/g wet mass)					
	In egg		In maternal blood		In hatchling blood	
POP compound	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range
PCB 99	17.4 ± 1.4	13.0–27.7	39.4 ± 4.8	22.0–64.3	81.4 ± 8.2	50.0–124.0
PCB 118	16.4 ± 1.3	11.6–23.6	33.9 ± 5.8	18.4–83.6	58.0 ± 7.1	36.0–105.8
PCB 128	14.1 ± 1.2	9.9–20.1	28.7 ± 3.8	16.3–54.4	35.4 ± 2.5	23.1–47.1
PCB 138 (+158)[a]	45.6 ± 8.9	17.0–94.1	62.9 ± 13.9	25.8–174.6	101.3 ± 20.9	46.7–226.7
PCB 153 (+132)[a]	65.8 ± 13.1	25.8–136.4	93.9 ± 24.4	30.6–288.6	171.9 ± 43.1	64.7–462.0
PCB 180 + 193	53.5 ± 7.5	33.9–100.4	114.0 ± 13.5	72.0–202.0	91.1 ± 11.9	55.0–165.2
PCB 183	14.8 ± 1.8	9.7–25.9	52.0 ± 12.1	19.8–134.2	63.8 ± 12.0	28.0–142.4
∑PCB	553.6 ± 54.6	392.8–839.4	578.9 ± 85.6	316.4–1206.5	850.8 ± 105.2	559.4–1456.6
PBDE 47	21.5 ± 1.7	11.1–28.1	13.3 ± 1.2	7.2–20.1	27.7 ± 2.7	14.9–41.4
PBDE 99	32.0 ± 3.6	12.0–54.8	21.3 ± 3.7	5.0–52.8	55.3 ± 12.1	8.9–131.8
PBDE 153	27.4 ± 1.2	20.8–35.2	86.2 ± 10.3	37.5–151.4	<LOD	–
∑PBDE	129.3 ± 8.1	61.7–163.8	120.8 ± 14.1	57.5–224.3	83.0 ± 14.4	23.8–173.2

Source: van de Merwe et al. (2010)

[a]Indicates congeners in parenthesis co-elute. However, due to their rarity in environmental samples, they are unlikely to be significantly contributing to the reported concentrations

Table 7 Comparison of PCBs and PBDEs concentrations (mean) in human breast milk between Malaysia and other Asian Countries (ng/g lipid weight)

Country	Sampling location	PCBs	PBDEs	Survey year	Reference
Vietnam	Ho Chi Minh	28	–		Schecter et al. (1989)
	Dong Nai	353	–		Schecter et al. (1991)
	Hanoi	46	0.57	2007	Tue et al. (2010)
Cambodia	Phnom Penh	39	–		Schecter et al. (1991)
	Phnom Penh	20	–	1999–2000	Kunisue et al. (2004a)
Indonesia	Jakarta	33	2.2	2001	Sudaryanto et al. (2006)
Philippines	Quezon	72	–	2000	Kunisue et al. (2002)
	Payatas	92.5	7.8	2004	Malarvannan et al. (2009)
Hong Kong	Hong Kong	640	–	1985	Ip and Phillips (1989)
		42	–	1999	Wong et al. (2002)
		74	–	1999–2000	Poon et al. (2005)
		6.4	–	2009	Wong et al. (2013)
Thailand	Bangkok	15	–		Schecter et al. (1989)
	Bangkok	52	–		Schecter et al. (1991)
India	Chennai (Madras)	110	–	1988	Tanabe et al. (1990)
	Chennai (Madras)	34	–	2000–2003	Subramanian et al. (2007)
	Kolkata	40	–	2004–2005	Devanathan et al. (2009)
	Mumbai	30	–	2005–2006	Devanathan et al. (2009)
	New Delhi	23	–	2005–2006	Devanathan et al. (2009)
China	Dalian	42	–	2002	Kunisue et al. (2004b)
	Shenyang	28	–	2002	Kunisue et al. (2004b)
	Nanjing	–	7.7	2004	Sudaryanto et al. (2008)
	Shanghai	–	8.6	2007	Ma et al. (2012)
Japan	Kanagawa	1.58	1.79	1999	Akutsu et al. (2003)
	Fukuoka	120	–	2001–2004	Kunisue et al. (2006)
	Japan (4 regions)	73.18	1.74[a]	2005	Inoue et al. (2006)
Malaysia	Penang and Kedah	80	–	2003	Sudaryanto et al. (2005)

[a]Total PBDEs concentration excluding BDE209

However, not many studies have been carried out to examine the PBDEs contamination in breast milk samples collected from Asian countries, and none has been done in Malaysia. Among all studies on PBDEs in breast milk, China recorded the highest concentration of 8.6 ng/g lipid weight and the second highest was Philippines with 7.8 ng/g lipid weight, followed by Indonesia, Japan and Vietnam.

Studies on PCBs and PBDEs concentration in breast milk samples are important because several researches proved that persistent organochlorines (OCs) compounds such as PCBs in human breast milk will be transferred to infants through breast-feeding, especially older primiparae mothers who transfer higher amounts of OCs (Kunisue et al. 2006). Besides, breast-feeding is the primary exposure route for infants, and by examining the concentration of PCBs and PBDEs in daily milk intake, the exposure risks of infants can be estimated (Ma et al. 2012) (Table 8).

Table 8 Comparison of PCBs and PBDEs concentration (mean) in bivalves collected from Asian countries (ng/g lipid weight)

Country	Sampling location	PCBs	PBDEs	Survey year	Reference
Vietnam	Various locations	160	–	1997	Monirith et al. (2003)
	Various locations	99.2	1.98	2003–2005	Ramu et al. (2007)
Cambodia	Various locations	35	–	1998	Monirith et al. (2003)
	Preab Island	250	3.8	2003–2005	Ramu et al. (2007)
Indonesia	Various locations	87	–	1998	Monirith et al. (2003)
	Jakarta Bay	792.5	13.25	2003–2005	Ramu et al. (2007)
Philippines	Philippines	290	–	1998	Monirith et al. (2003)
	Bacoor, Naic	1500	104.5	2003–2005	Ramu et al. (2007)
Singapore	Singapore	90	–	1999	Monirith et al. (2003)
	Singapore	27.52	8.85	2002	Bayen et al. (2003)
Hong Kong	Hong Kong	310	–	1998–1999	Monirith et al. (2003)
	Hong Kong	–	58.16	2004	Liu et al. (2005)
	Hong Kong	401	58.7	2003–2005	Ramu et al. (2007)
India	Various locations	340		1998	Monirith et al. (2003)
	Various locations	318.67	1.87	2003–2005	Ramu et al. (2007)
Korea	Various locations	170	–	1998	Monirith et al. (2003)
	Various locations	262.64	90.59	2005	Ramu et al. (2007)
China	Various locations	120	–	1999–2001	Monirith et al. (2003)
	Pearl River Delta	357.07	–	2001–2002	Fang (2004)
	Qingdao	75	4.9	2002	Pan et al. (2007)
	Various locations	61.08	30.51	2003–2005	Ramu et al. (2007)
Japan	Tokyo Bay	3000	–	1994	Monirith et al. (2003)
	Various locations	560.6	23.68	2003–2005	Ramu et al. (2007)
Malaysia	Malaysia	56	–	1998–1999	Monirith et al. (2003)
	Port Dickson	33	2.1	2003–2005	Ramu et al. (2007)
	Pantai Lido	76	14	2003–2005	Ramu et al. (2007)
	Pasir Puteh	160	16	2003–2005	Ramu et al. (2007)
	Sebatu	25	0.84	2003–2005	Ramu et al. (2007)
	Penang	150	1.2	2003–2005	Ramu et al. (2007)

6.2 *Comparison of PCBs and PBDEs Concentrations in Bivalves*

Basically two major studies that analyzed the concentration of PCBs and PBDEs in mussels as part of International Mussel Watch Programme between 1994 to 2001 and 2003 to 2005 from Asian coastal waters; one was reported by Monirith et al. (2003) and another by Ramu et al. (2007). The concentration of PCBs in mussels collected from Malaysia during 1998–1999 recorded the second lowest at 56 ng/g lipid weight after Cambodia with 35 ng/g lipid weight indicating low PCBs pollution. While the highest PCBs contamination was from Japan which recorded 3000 ng/g lipid weight, followed by India with 340 ng/g lipid weight. Similarly from mussels collected during 2003–2005, the highest PCBs concentration was found in Japanese samples (83–2000 ng/g lipid weight). Again, PCBs concentration in Malaysian coastal waters was low with an average concentration of <100 ng/g lipid weight in comparison to other heavily industrialised Asian countries such as China, Hong Kong, Korea, India, Philippines and Indonesia which showed high PCBs levels in the range of 61–1500 ng/g lipid weight.

The highest concentration of PBDEs was identified in mussel samples collected at Cavite province of Philippines which is an agriculture province. Other countries that showed high level of PBDEs contamination in mussels are Korea, Hong Kong and China. Previous studies pointed out that higher level of PCBs and PBDEs were recorded at urbanised or industrialized locations; areas with shipping activities (Moon et al. 2007a). Particularly untreated effluent that directly discharged into the environment from e-waste manufacturing or treatment plant and municipal waste treatment facility has been proved as the potential source that caused high levels of PCBs and PBDEs at Hong Kong and China (Zheng et al. 2004; Shi et al. 2009). A Korean study (Hong et al. 2009) highlights a growing pollution problem in Asia and in particular a tremendous uptrend in PBDEs pollution in Korea, in comparison to more controlled discharges and releases in Western Europe (Table 9).

6.3 Comparison of PCBs and PBDEs Concentrations in Sediments

Unfortunately there were limited studies on PCBs and PBDEs contamination in Malaysia. In fact, PCBs and PBDEs were widely found in both river and marine sediments due to its persistency. There were 195 ng/g dry weight of PCBs detected at Zhujiang River, China which was also the highest PCBs concentration recorded in Asian countries. This was confirmed in a research conducted by Fang (2004) at the same region (Pearl River Delta) for PCBs. The Pearl River delta region is one of the largest electronic and telecommunication manufacturing bases in China, hence lots of studies have been implemented in the area and previous results did indicate significant level of PCBs and PBDEs pollution within this region. Apart from that, sediment samples collected at canals in lower Mekong River Basin (Laos), Ho Chi Minh city canals (Vietnam) and a sewer system in Hanoi (Vietnam) showed high PCBs contamination with 111, 81 and 104 ng/g dry weight respectively.

On the other hand, exceptionally high concentration of PBDEs (285 ng/g dry weight) was observed at Busan Bay, Korea which is much higher than PBDEs levels in sediments from Hong Kong with 95 ng/g dry weight. In surface sediments, the average ΣPBDEs levels approached that of average ΣPCBs values. However, trends observed in the sediment core suggest that this pattern will alter over time and result in higher surface sediment PBDE concentrations than PCBs in future (Hong et al. 2010). Various diffuse and point sources for PBDEs and PCBs were

Table 9 Mean concentration of PCBs and PBDEs in sediment collected from Asian countries (ng/g dry weight)

Country	Sampling location	PCBs	PBDEs	Survey Year	Reference
Vietnam	Mekong River Delta	0.49	–	1998	Carvalho et al. (2008)
	Red River delta	4.32	–	1995–1996	Nhan et al. (1998)
	Ho Chi Minh	46.4	–	1996	Phuong et al. (1998)
	Ho Chi Minh city canals	81	–	2004	Minh et al. (2007)
	Hanoi (sewer)	104	–	2006	Hoai et al. (2010)
	Thi Nai Lagoon	2.4	1.27	2010	Romano et al. (2013)
Indonesia	Jakarta	–	0.15–130	2007	Sudaryanto et al. (2009)
Philippines	Manila Bay	<0.5–110	<0.1–18	2008	Isobe et al. (2010)
Singapore	Northeast	56.67	6.61	2003	Wurl and Obbard (2005)
	Southwest	101.5	5.54	2003	Wurl and Obbard (2005)
	Singapore	0.88	<1	2004	Bayen et al. (2005)
Hong Kong	Victoria Harbour	18.59	–	1993–1997	Wong and Poon (2003)
	Marshes Nature Reserve	2.9	–	1997	Liang et al. (1999)
	Hong Kong	17.2	–	1997–1998	Richardson and Zheng (1999)
	Hong Kong	19.2	3.03	2004–2005	Kueh and Lam (2008)
	Hong Kong	23.33	95	2006	Kueh and Lam (2008)
Thailand	Lower Mekong River Basin	10	–	2005	Sudaryanto et al. (2011)
Laos	Lower Mekong River Basin (Canal)	111	–	2005	Sudaryanto et al. (2011)
India	Sundarban	–	4.89		Binelli et al. (2007)
Taiwan	Southern Taiwan	1.43	–	2000	Doong et al. (2008)
	Northern Taiwan	11.35	–	2001, 2004	Hung et al. (2006)
	Northern Taiwan	15.52	15.52	2001, 2004	Hung et al. (2006)
Korea	Busan Bay	–	285	2003	Moon et al. (2007a)
	Various locations	–	27.8	2004	Moon et al. (2007b)
China	Pearl River Estuary	11.37	–	1997	Mai et al. (2002)
	Pearl River Delta	–	4.27		Zheng et al. (2004)
	Pearl River Delta	104.28	–	2001–2002	Fang (2004)
	Pearl River Estuary	–	3.13[a]	2004	Mai et al. (2005)
	Qingdao	5.11	1.38	1997, 1999	Pan et al. (2007)
	Zhujiang River	195.47	–	1997	Mai et al. (2002)
	Xijiang River	13.16	–	1997	Fu et al. (2001)
	Zhujiang River	–	12.9[a]	2002	Mai et al. (2005)
	Dongjiang River	–	27.3[a]	2002	Mai et al. (2005)
	Dongjiang River	–	3.94[a]	2006	Shi et al. (2009)

[a]Total PBDEs excluded BDE209

identified in this location. Shipping and other industrial activities were associated with PCB contamination while domestic and industrial waste discharges corresponded with PBDE contamination. Busan Bay is the largest harbor area in Korea which comprises more than four fifth of the country's container cargo and 42 % of the domestically produced marine products, in addition to the fact that 40 % of marine export cargo processed here (Hong et al. 2005).

Despite showing low contamination levels of PBDEs in sediment samples collected from China, concentration of BDE209 in some of these samples were extremely high. The result summarized by Mai et al. (2005) showed 12.9 ng/g dry weight of total PBDEs that consisted of BDE-28, -47, -66, -99, -100, -138, -153, -154 and -183 at Zhujiang River, while the mean concentration of BDE209 was 890 ng/g dry weight (ranged from 26.3 to 3580 ng/g dry weight). Similarly studies conducted by Shi et al. (2009) on the concentration of PBDEs in sediments from Dongjiang River, showed, for the same suite of PBDEs, a PBDEs concentration of 3.94 ng/g dry weight while the concentration of BDE209 was 1190 ng/g dry weight. The main reason for high concentration of BDE209 in Pearl River Delta was due to the manufacturing of electrical and electronic products where BDE209 is the main ingredient of BFR. Such high concentration of BDE209 in the environment poses risks and concern because it may degrade to less-brominated congeners which are more volatile and easily taken up by living organism and transferred to organisms in the higher food chain and bioaccumulate in humans. Recent studies also pointed out that BDE209 can be broken down under sunlight in sediments (Mai et al. 2005).

7 Conclusion and Recommendations

Many tropical Asian countries including Malaysia have experienced a rapid economic development and population growth during the past few decades. Industrialization and urbanization caused high waste generation and release of PCBs and PBDEs into the environment. In general, the concentrations of PCBs and PBDEs in pellets, mussels, air and soil from Malaysian samples were comparatively lower than most of neighboring Asian countries; on the other hand, their levels were high in sediment and leachate samples. Similarly, high levels PCBs were recorded in breast milk samples collected from northern Malaysia. Till now, there is no research on PBDEs in breast milk in Malaysia. Unfortunately, the samples collected in these studies were from selected locations and may not reflect the national status. The previous studies on PCBs and PBDEs contamination in Malaysia were conducted by Japanese researchers. It is surprising to note that local Malaysian universities and research institutes with analytical facilities have not generated substantial national data on these important contaminants. So far there is no nationwide study (geographical distribution) or their temporal trends in Malaysia. Additionally, the spectrum of samples were limited to bivalves, sediments, breast milk and human blood only. Other media need to be studied as well. That will provide a clearer picture of contamination status of Malaysia on a global map. Trend studies will help policymakers to amend regulations accordingly. Despite the fact that concentration of PBDEs in Malaysian air is negligible, it is still needed to be monitored. The reason is that uncontrolled waste dumping occurs in southern hemisphere countries from industrialized countries and global transboundary pollution needs to be monitored (Parolini et al. 2013). In summary, more studies are needed to fully understand POPs contamination status, their transport pathways, sources and their biological impacts on developing nations in Asia, with the emphasis of further researches in Malaysia.

8 Summary

Ever since PCBs and PBDEs were listed as persistent organic pollutant by Stockholm Convention, there are many studies around the world to study these compounds as well as their effects to human health and the environment. Despite the fact that PCBs-containing products being banned in many countries, old equipments that contain PCBs or PBDEs are still being used, especially in South Asian countries. Thus POPs will be released unintentionally into the environment from stockpiles or from waste treatment facilities or from E-waste treatment facility or area with high shipping activities. Owing to the limited research being conducted in Malaysia, the comparison of PCBs and PBDEs pollutions between Malaysia and other Asian countries were mainly focusing on mussels and human breast milk samples. PCBs in breast milk that was collected from Malaysia was the highest among Asian developing countries, while the mean concentration of PCBs in mussels in Malaysia recorded the second lowest. The concentrations of PBDEs in mussels taken from Malaysia was much lower if compared to the high concentration detected at Philippines and Korea. All in all, continual monitoring of these POPs by Malaysian researchers is needed in order to meet the target set by Stockholm Convention and assure the elimination of such compounds from the environment within the time frame.

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