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# Geographical distribution of persistent organic pollutants in the environment: A review

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**Abstract**

The sources, distribution, transformation, toxicity and accumulation of persistent organic pollutants (POPs) in aquatic and terrestrial ecosystems have attracted global concern and attention over the last several decades. Although, POPs are toxic, degrade slowly and have a tendency to accumulate in the food chain, they are still widely used worldwide in many fields, such as industrial and agricultural activities. In addition, discharge of POPs into waterways may lead to serious health-related and environmental problems. This review provides an overview of the continental distributions of many types of POPs and the health risks associated with the exposure to POPs in daily life. This review also discusses the distribution of POPs in Malaysia, and the future work that will be conducted in the Klang River, one of the basins subjected to pollution due to development and urbanization.

**Key words**

Classification, Dispersal, Geographic distribution, Impacts, POPs, Remediation



Water is the most delicate part of the environment and is vital for human and industrial development. Water pollution is one of the biggest environmental issues worldwide. Consuming polluted water affects all the vital organs of human beings including heart and kidneys. Other health problems associated with polluted water are poor blood circulation, skin lesions, vomiting, cholera, gastroenteritis and damage to the nervous system. An increase in population leads to an increase in the demand for safe water supplies.

Over the last several decades, many countries have become increasingly concerned about the ecological risks associated with different environmental pollutants. Persistent organic pollutants (POPs) are one of these pollutants. Persistent organic pollutants are type of chemical pollutants those can be highly persistent in the environment for a long time, migrating through air, water, soil and sediments. These compounds also bio-accumulate in fatty tissue, which can harm wildlife and human health (Arslan-Alaton and Olmez-Hanci, 2013). In view of this, in May 2001, the Stockholm Convention (SC) on POPs was established (UNEP 2012). In 2012, the SC targeted 22 POPs; out of which twelve POPs known as the 'dirty dozen' were targeted when the Convention was first adopted, and ten more were added in 2009 and 2012 (Tang 2013).

According to El-Shahawi *et al.* (2010), there are two types of persistent organic pollutants, intentional POPs and unintentional POPs. Intentional POPs are the compounds produced as desired products *via* various chemical reactions that include chlorine. In contrast, unintentional POPs are produced as unwanted products of combustion or chemical process that take place in the presence of chlorine compounds. Figure 1 shows the classification of POPs.

Ritter *et al.* (1995) demonstrated that POPs include two subgroups, polycyclic aromatic hydrocarbons (PAH) and certain halogenated hydrocarbons. Halogenated hydrocarbons are divided into chlorinated and brominated POPs (Xu *et al.,* 2013). The 'dirty dozen' are chlorinated POPs, and examples of brominated POPs include tetrabromodiphenyl ethers, pentabromodiphenyl ethers, hexabromodiphenyl ethers, heptabromodiphenyl and hexabromobiphenyl. Although many different forms of POPs may exist, the main POPs of concern are the 'dirty dozen': aldrin, endrin, chlordane, dichlorodiphenyltrichloroethane (DDT), dieldrin, heptachlor, mirex, toxaphene, hexachlorobenzene (HCB), polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) (Arslan-Alaton and Olmez-Hanci 2013).

POPs have the following four characteristics: They are highly persistent; Travel long distances through air and water; bio-accumulate in fatty tissue and Highly toxic, even at low levels (Tang, 2013). POPs are very stable with respect to hydrolysis due to the carbon–chlorine bond and are typically hydrophobic ('water-hating') and lipophilic ('fat-loving') (Jones and Voogt, 1999). These compounds are also highly resistant to degradation by biological, photolytic and chemical means, and their degree of resistance to biological and photolytic degradation depends on the number of chlorine substitutions and/or functional groups (Jones and Voogt, 1999). Thus, POPs remain in the environment for a long time.

Current concern is the growing trend of POPs due to their toxicity and tendency to accumulate in food chains. POPs in the environment are transported at low concentrations due to the movement of fresh and marine water. Furthermore, they can also be transported over long distances in the atmosphere because of their semi-volatility. POPs tend to travel to colder areas and then sink due to low temperatures. The settled contaminants remain in the area for a long time because the temperature prevents them from readily breaking down. Several studies have stated that POPs have a half-life of years or decades in soil/sediment and several days in the atmosphere (Jones and Voogt, 1999).

POPs can be produced from many sources. For example, volcanic activity and forest fires produce dioxins and dibenzofurans. In addition, POPs are able to enter the atmosphere from industrial sources such as power stations, heating stations and incinerating plants, as well as from household furnaces, agricultural spray usage, evaporation from water surfaces, soil or from landfills (El-Shahawi *et al.,* 2010).

Other activities that generate POPs are the use of obsolete oil, repairing and maintenance of equipment, demolition of buildings, evaporation, cement manufacture, animal carcass incineration, coal combustion, lixiviation of dumps and recycling operations, municipal incineration, hazardous medical waste, sewage sludge, industrial chlor-alkali plants, aluminum secondary plants, organic chlorine pesticide plants, cock plant, sewage sludge, landfills-hazardous waste/plastic waste, organochlorine pesticide storage and fly ash storage (El-Shahawi *et al.,* 2010).

**Persistent Organic Pollutants (POPs)**

**Dirty dozen :** Ten intentionally produced chemicals – aldrin, endrin, chlordane, dichlorodiphenyltrichloroethane (DDT), dieldrin, heptachlor, mirex, toxaphene, hexachlorobenzene (HCB) and polychlorinated biphenyls (PCBs) – and two unintentionally produced substances – polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are the POPs of the main concern. Since the Stockholm Convention, these twelve POPs are known as the 'dirty dozen' (El-Shahawi *et al.,* 2010). Below, we describe all of these POPs briefly:

**Polychlorinated biphenyls (PCBs) :** Polychlorinated biphenyls are a group of organic compounds comprising a chlorine-substituted biphenyl complex, and their toxicity varies depending on the changes in the degree of chlorination. Although PCBs were banned in the late 1970s/early 1980s, they are still ubiquitous in the environment (Gioia *et al.,* 2011). PCBs are a semi-volatile POP and are formed from anthropogenic activities. PCBs are theoretically classified into 209 congeners, which feature variation in the position and number of chlorine atoms along two phenyl rings. Thus, these congeners have different toxicities and physico-chemical properties. Due to their extraordinary chemical stability and heat resistance, PCBs have been extensively used as the main components in dielectric fluids, organic diluents, flame retardants, plasticizer adhesives, and electrical and hydraulic equipment, including hydraulic systems, capacitors and transformers (Arslan-Alaton and Olmez-Hanci, 2013).

**Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) :** Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans are tricyclic aromatic compounds with chlorine-substituted dibenzodioxin and dibenzofuran complexes. They are molecules with planar geometry and have similar chemical and physical structures. There are 135 isomers of furans and 75 isomers of dioxins, which are differentiated by the number and location of chlorine atom additions. Biological and chemical (including toxicological) properties depend on the position of chlorine atoms. PCDDs and PCDFs are produced as unwanted by-products in the flue gas from municipal solid waste and industrial waste incinerators by the synthesis of chlorinated compounds and from the manufacture of certain pesticides, fungicides and herbicides (Arslan-Alaton and Olmez-Hanci, 2013).

**Organochlorine pesticides (OCPs) :** Organochlorine pesticides (OCPs) are widely used as fungicides, herbicides and insecticides in agricultural fields. They can be transferred to the ecosystem by infiltration and runoff. The five major groups of OCPs are DDT and its analogs, hexachloro-cyclohexane (HCH), cyclodienes and similar compounds, toxaphene and related chemicals, and the caged structures mirex and chlordecone. OCPs are categorized based on their chemical structure. HCH comprises eight steric isomers, including the well-known γ-isomer-lindane. Like DDT and its analogs, these isomers have unusually different properties. Cyclodienes and related compounds include aldrin, isodrin, endrin, dieldrin, heptachlor, telodrin, chlordane, isobenzam and endosulfan. The pesticide toxaphene is formed from a complex mixture of chemicals. Chlordecone and mirex are slowly metabolized and are readily stored in the body. OCPs are banned in Europe, South America and North America for agricultural or domestic uses as stated by the Stockholm Convention in 1980s. However, certain OCPs are still in use; for example, DDT is used as an antifouling agent and to control mosquito growth (Arslan-Alaton and Olmez-Hanci, 2013).

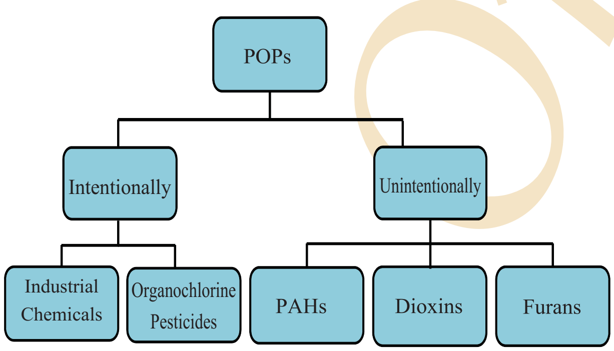



**Fig. :** Classification of POPs (El-Shahawi *et al.* 2010).

## Continental distribution of POPs

### South America

**Negro River Basin, Argentinean Patagonia:** Ondarza *et al.,* (2014) studied the OCP (DDTs, endosulfans, HCHs, chlordanes) and PCB contaminant levels in different tissues of the Patagonian silverside (*Odontesthes hatcheri*). PCBs were analyzed by Shimadzu.

Ondarza *et al.* (2014) discovered that the concentration of contaminants in all tissues decreased from the headwaters (UV) to downstream areas (LV). The contaminant with the highest concentration was OCPs (306–3449 ng $g^{-1}$ lipid) followed by PCBs (65–3102 ng $g^{-1}$ lipid) in all the tissues from all the valleys. This revealed that agriculture as the main source of contamination along the river. The most prevalent OCPs were DDT (75 ± 9.6%) followed by endosulfans (21 ± 8.3%), HCHs (2 ± 1.4%) and chlordanes (2 ± 1.3%). Furthermore, fish from the UV area showed highest PCB concentrations due to presence of industries in the upper stream.

Gills of fish possessed the highest total contaminant level followed by liver, gonads and muscles in both genders, with an exception of muscle of females from UV and the gonads of males from MV. The gills acquire high concentrations of pollutants because they are in direct contact with the aquatic environment (Ondarza *et al.,* 2014).

**Lenga estuary, Chile :** Pozo *et al.* (2014) revealed that PCB concentrations (ng $g^{-1}$) were higher than those of HCB in the surface sediments from the Lenga estuary in the VIII region of Central Chile.

Table 2 shows the concentration of PCBs and HCB (ng $g^{-1}$ d.wt.) in the surface sediments from nine stations in the Lenga estuary. The total PCB concentration varied from ~20 to 10,000 ng $g^{-1}$ d.wt. (i.e., 0.02–10 µg $g^{-1}$ d.wt.) (3100 ± 3400). High levels were detected in the central part of the estuary at stations L2, L3, L4, L6 and L7, as shown in Fig. 3. The PCB congener composition for nine sites in the Lenga estuary is shown in Fig. 5. The PCB profile was dominated by moderately to highly chlorinated congeners, with hexa-Cl accounting for 40% and hepta-Cl for 30% of total PCB concentration. In their study, the PCB concentrations in sediments from the Lenga estuary were higher than the previous study of other coastal sediments around the world (Pozo *et al.,* 2014).

The HCB concentration in the surface sediments of the Lenga estuary varied between 1 (at L1) and 870 ng g$^{-1}$ d.wt. (at L4) (117 ± 239) (Fig. 4). The central part of the estuary (station L4) had the highest HCB concentration. These levels were higher than previous studies carried out in in central Chile. Focardi *et al.,* (1996) reported that HCB level in the organisms of Bio Bio River was 29–214 ng g$^{-1}$, while Cifuentes *et al.* (2003) reported that HCB levels in seabird eggs ranged from 102–236 ng g$^{-1}$ in Concepcion Bay (Bio Bio region) and Valdivia (Los Lagos region) (Pozo *et al.,* 2014).

## North America

**Gulf of Batabano, Cuba :** Alonso-Hernandez *et al.* (2014) investigated various OCPs and PCBs in the sediments from the Gulf of Batabano, Cuba. These authors found that DDT isomers were the predominant contaminant, with concentrations ranging from 0.019 to 1.27 ng g$^{-1}$ d.wt.

The estimated concentration of all the PCBs in surface sediments from the Gulf of Batabano were in the range of 0.11–0.28 ng g$^{-1}$ d.wt., with a mean value of 0.19 ng g$^{-1}$ d.wt. All the analyzed congeners were found to be below the detection limit of 0.019 ng g$^{-1}$ d.wt. However, the values obtained much lower than those reported from Cienfuegos Bay i.e., 1.9–16 ng g$^{-1}$ d.wt. (Tolosa *et al.,* 2010; Alonso-Hernandez *et al.,* 2014).

Estimation of the concentration of organochlorine pesticides (HCB, the DDT group, p,p'-DDT, p,p'-DDE, p,p'-DDT, c-HCH, aldrin, heptachlor and mirex) in the surface sediments of the Gulf of Batabano indicates higher OCP concentrations in the near shore area and station SS-16 showed the highest concentration of both isomers.

According to established Sediment Quality Guidelines (SQG), the concentrations of PCBs and OCPs encountered in the surface generally do not cause an adverse effect on sediment-dwelling organisms. Compared to concentrations reported in coastal environments from other parts of the world, PCB and OCP concentrations in the

**Table 1 :** POPs listed in the Stockholm Convention amendment (Xu *et al.,* 2013)

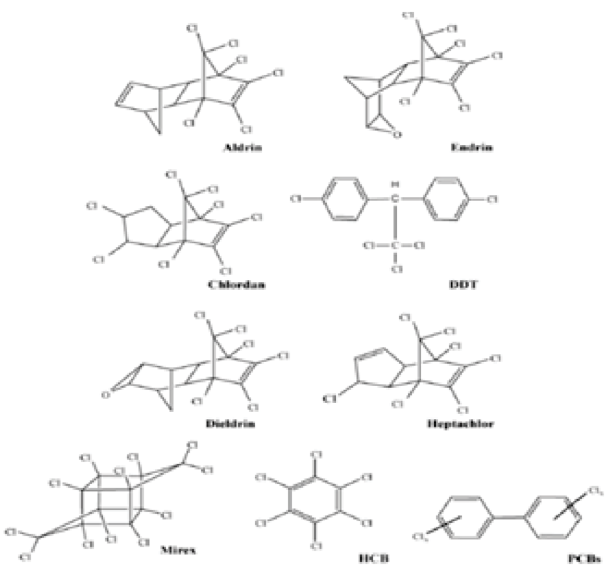
| Item | Chemicals | CAS no. | Type | Isomers and homologues |
|---|---|---|---|---|
| **2001 amendment** | | | | |
| 1 | Aldrin | 309-00-2 | Pesticide | Aldrin and isodrin |
| 2 | Dieldrin | 60-57-1 | Pesticide | - |
| 3 | Endrin | 72-20-8 | Pesticide | - |
| 4 | Chlordane | 57-74-9 | Pesticide | α- and β-isomers |
| 5 | Heptachlor | 76-44-8 | Pesticide | - |
| 6 | HCB | 118-74-1 | Pesticide and industrial | - |
| 7 | Mirex | 2385-85-5 | Pesticide | - |
| 8 | Toxaphene | 8001-35-2 | Pesticide | Hundreds of isomers |
| 9 | DDT | 50-29-3 | Pesticide | Hundreds of isomers |
| 10 | PCBs | - | Industrial and by-product | pp-DDT, op-DDT, pp-DDE, pp-DDD |
| 11 and 12 | PCDDs and PCDFs | - | By-product | 209 Congerners |
| **2009 amendment** | | | | |
| 13 | Chlordane (Kepone) | 143-50-0 | Pesticide | - |
| 14 | Lindane (γ-HCH) | 58-89-9 | Pesticide | - |
| 15 | α-HCH | 319-84-6 | Pesticide and by-product | - |
| 16 | β-HCH | 319-85-7 | Pesticide and by-product | - |
| 17 | Hexabromobiphenyl | 36355-01-8 | Industrial | 42-Congeners |
| 18 | Tetra-BDE and penta BDE | - | Industrial | Co-exist in commercial Penta-BDE |
| 19 | Hexa-BDE and hepta-BDE | - | Industrial | Co-exist in commercial Octa-BDE |
| 20 | PFOS and its salts PFOSF | 1763-23-1 | Industrial | Side-chain isomers |
| 21 | Pentachlorobenzene | 307-35-7 | Pesticide, Industrial and by-products | - |
| **2011 amendment** | | | | |
| 22 | Endosulfan | 115-29-7 | Pesticide | α- and β-isomers |

surface sediments of Batabano Gulf were low and similar to those reported for pristine and remote environments (Alonso-Hernandez *et al.,* 2014).

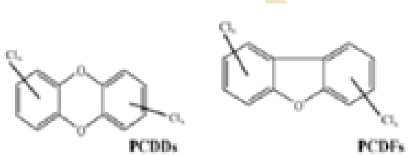
**Europe**

**Huveaune River, France :** In Europe, Kanzari *et al.* (2014) reported PCBs, organochlorine and organophosphorous pesticides (OCs and OPs) in the surface sediments of Huveaune River.

The concentration of total PCBs ranged from 2.8 to 435 $\mu g \cdot kg^{-1}$ d.wt. (Table 3), with a mean concentration of 148 ± 164 $\mu g \cdot kg^{-1}$ d.wt. and the concentrations of total pesticides ranged from 0.07 to 1.25 $\mu g\ kg^{-1}$ d.wt., with a mean concentration of 1.23 ± 1.29 $\mu g\ kg^{-1}$ d.wt. (Table 4). The distribution of POPs showed that the pollutant concentration was relatively higher at the mouth of the river. Stations H5 (195.3 $\mu g \cdot kg^{-1}$ d.wt.), H6 (435.0 $\mu g \cdot kg^{-1}$ d.wt.), H7 (200.3 $\mu g \cdot kg^{-1}$ d.wt.), H8 (416.3 $\mu g \cdot kg^{-1}$ d.wt.) and H9 (134.9 $\mu g \cdot kg^{-1}$ d.wt.) were considered as highly polluted sediments. The other stations, i.e., H3, H4, H10 and H11 were considered as moderately polluted (14.2–38.6 $\mu g \cdot kg^{-1}$ d.w.),




Intentionally produced POPs




Unintentionally produced POPs

**Fig. 2 :** Chemical structure of common POPs (Jone and Voogt, 1999).

and station H2 was reported as slightly polluted (2.8 $\mu g \cdot kg^{-1}$ d.w.) (Kanzari et al., 2014).

All the contaminant levels were compared with Sediment Quality Guidelines, and the contamination levels at all the stations were mostly lower than their respective SQG. However, for PCBs, five stations (H5, H6, H7, H8 and H9) were higher than their effect range median (ERM) values, indicating that the sediments possessed high potential toxicity, which may cause adverse effects to living biota (Kanzari *et al.,* 2014).

**Africa**

**Bizerte Lagoon, Tunisia :** PCBs and OCPs were analyzed by Barhoumi *et al.* (2013) in eighteen surface sediment samples collected from the Bizerte Lagoon, Tunisia. The PCB and OCP analyses involved high-resolution gas chromatography in conjunction with a Ni electron capture detector. The total concentrations of ten PCBs and four OCPs in the sediments of this area ranged from 0.8 to 14.6 ng $g^{-1}$ d.wt. (mean: 3.9 ng $g^{-1}$ d.wt.) and 1.1 to 14.0 ng $g^{-1}$ d.wt. (mean: 3.3 ng $g^{-1}$ d.wt.) respectively. Distribution of total PCBs in the surface sediments of the Bizerte Lagoon depended on the activities near the stations, including sewage discharge, garbage incineration, operation of repair facilities and maintenance operations (Barhoumi *et al.,* 2013).

Among the OCPs, the concentration of dichlorodiphenyltrichloroethane and its metabolites (DDTs) and hexachlorobenzene (HCB) were 0.3–11.5 ng $g^{-1}$ d.w. (1.9 ng $g^{-1}$ d.wt.) and 0.6–2.5 ng $g^{-1}$ d.wt. (1.4 ng $g^{-1}$ d.wt.) respectively. The predominant congeners were PCB 153, 138 and 180, which accounted for 60% of the total PCBs. Moreover, the dominant DDTs were p, p-DDT. Barhoumi *et al.* (2013) concluded that as compared to other regions of the world, the Bizerte Lagoon exhibited low level of PCBs and moderate levels of HCB and DDTs.

**Asia**

**Yongxing Island :** Sun *et al.* (2014) analyzed POPs in marine organisms from the South China Sea. Five marine fish species were obtained from Yongxing Island, South China Sea to investigate the presence of PCBs and dichlorodiphenyltrichloroethane and its metabolites (DDTs). The concentration of POPs in marine fish muscle from this island revealed that the PCB and DDT concentration ranged between 6.3–199 and 9.7–5831 ng $g^{-1}$ lipid weight respectively. However, the concentration of contaminants was lower than the global range. Among the fish species studied, yellow striped goatfish had highest concentration of PCBs and DDTs, which might be due to the different feeding and living habits of fish. Based on the contaminant distribution pattern, agrochemical sources are more significant than industrial sources on Yongxing Island.

**Natuna Island, South China Sea :** Hao *et al.* (2014) reported that the concentration of PCBs and DDTs in marine fish from Natuna Island, South China Sea, ranged from 14.3 to 48.1 and 7.99 to 40.3 ng $g^{1}$ lipid weight respectively. Snakefish (*Trachinocephalus myops*) showed highest concentration of PCBs and DDTs, which might be attributable to their different feeding and living habits. PCBs were the predominant POPs in all marine fish, followed by DDTs. PCB 153 was the predominant PCB congener.

**Health risk assessment :** The risk assessment values include two types of toxicity data: ERL (effects range low, the biological effect probability was less than 10%) and ERM (effects range median, the biological effect probability was greater than 50%). In general, when the organic pollutant residue extent is lower than the ERL, the toxicity risk is lower than 25% and when a pollutant content is higher than the ERM, the toxicity risk is higher than 75% (Hui and Zang, 2014).

According to the US Environmental Protection Agency (US EPA, 2005), the chemical substances are classified into carcinogens and non-carcinogens according to risk-based corrective action (RBCA) model. For carcinogens, the model calculates the risk value and sets the upper limit of acceptable cancer risk level from $10^{-6}$ to $10^{-4}$. For non-carcinogens, the model calculates hazard providers, and the maximum acceptable risk value is 1.0. The health risk assessments follow these steps: hazard identification, dose–response assessment, exposure assessment and risk characterization. Concentrations with 95% confidence level limits have been used to reflect the overall soil pollution at four lakes in China. The relationship of dose–response expresses the adverse effects of pollutants on the human body and assesses the toxicity of non-carcinogens and carcinogens. The toxicity parameters of pollutants of four lakes were from the IRIS database of US EPA (Hui and Zang, 2014).

The carcinogenic risk value is calculated by the following equation:

Hi = EDI x CSF

where, Hi is the carcinogenic risk value, DI is the average daily intake (mg $kg^{-1}$ $day^{-1}$) and CSF is the cancer slope factor (mg $kg^{-1}$ $day^{-1}$).

The non-carcinogenic risk value is calculated by the following equation:

Hi = EDI/RFD

where, Hi is the carcinogenic risk value; EDI is the average

**Table 2:** Concentrations (ng $g^{-1}$ d.w.) of PCBs and HCB in surface sediments from nine stations in the Lenga estuary

| Compound | MDL | L1 | L2 | L3 | L4 | L5 | L6 | L7 | L8 | L9 | Mean ± SD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total PCBs | 2 | 136 | 10,220 | 9513 | 13,791 | 1619 | 10,900 | 4888 | 26 | 28 | 6000 ± 5000 |
| HCB | 0.3 | 1 | 6 | 466 | 870 | 163 | 363 | 111 | 1 | 8 | 117 ± 233 |

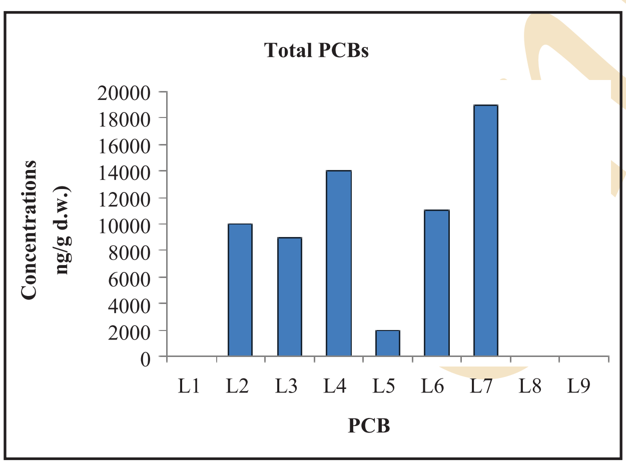



**Fig. 3 :** Concentrations (ng $g^{1}$ d.w.) of PCBs in surface sediments from the Lenga estuary.

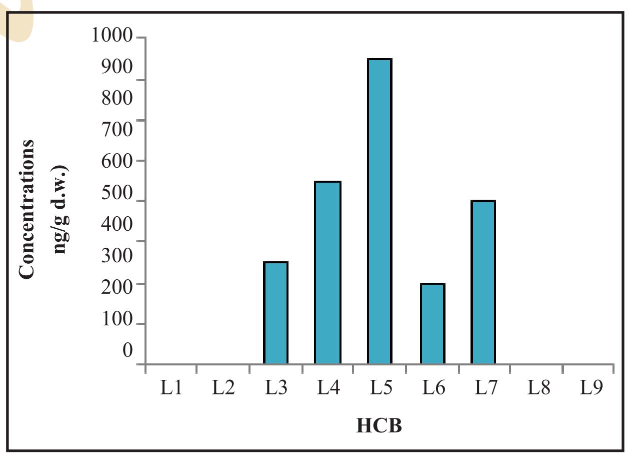



**Fig. 4 :** Concentrations (ng $g^{1}$ d.w.) of HCB in surface sediments from the Lenga estuary.

daily intake (mg $kg^{-1}$ $day^{-1}$), and RFD is the reference dose (mg $kg^{-1}$ $day^{-1}$).

The total risk value is the sum of all pollutant cancer risk values:

$$HI = \sum_{i=1}^{n} Hi$$

No DDT concentrations in sediments were greater than ERM criteria. Thus, the DDT concentrations in the sediments possibly did very little harm to humans and environment. Based on the model of environmental health risk assessment, the non-carcinogenic risk indexes were far lower than one, and the calculated health risks caused by the DDTs and HCHs in the sediments of four lakes were far lower than $1 \times 10^{-6}$. Therefore, the health risks were relatively low in the four lakes.

Compared with the corresponding ecological environmental quality guidelines from Ingersoll and based on the model of RBCA environmental health risk assessment, the sediments of the four lakes posed a low potential hazard to human health and environment, but should still be taken into account.

Ashraf *et al.* (2014) opined that a high risk of cancer is associated with three OCPs: dieldrin, heptachlor epoxide and hexachlorobenzene. Individuals who consumed large amounts of freshwater fish may be subjected to high risk of cancer. The OCP exposure for the group with lower fish intake is acceptable according to the deterministic approach. In contrast, all of the OCPs exceed the acceptable cancer risk level of $10^{-6}$ in the group with higher fish intake, suggesting that heavy consumers may be exposed to levels of OCPs that are greater than the acceptable limits in terms of cancer risk.

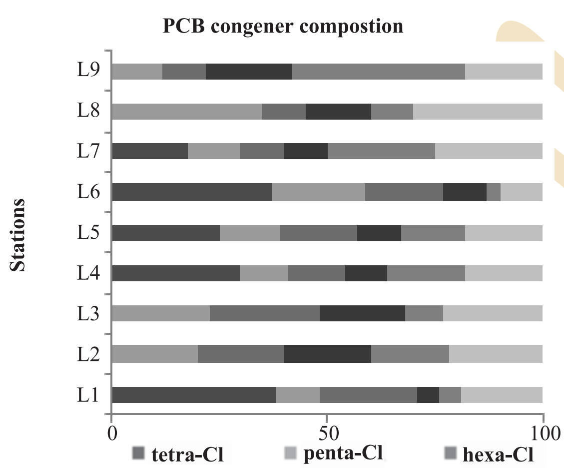



**Fig. 5 :** PCB homologue composition (%) in sediment of Lenga estuary

**POPs in the Malaysian Environment :** According to a study performed by the DOE on 116 rivers in Malaysia, approximately 10 % of these rivers are heavily polluted or dead, 63 % are polluted and only 27 % are healthy. Inadequate sewage and drainage systems are the cause of polluted water in Malaysia. The treatment of raw water from surface water sources for human consumption and for industrial use became more complex and costlier because of water pollution. Obviously, polluted water is dangerous for human health. Consumption of polluted water can seriously affect the human heart and kidneys and cause poor blood circulation, skin lesions, vomiting and damage to the nervous system.

**West coast of Peninsular Malaysia :** In a study conducted by Mohamad *et al.* (2013), the types and concentrations of twelve congeners of PCBs were identified (Table 8). The most toxic congener, PCB 126, was detected in relatively low concentration in the tissues of marine animals. Generally, in all the studied species, the PCB concentrations varied. However, the level of these contaminants were well below the permissible limit. Among the studied species, cockles contained the highest PCB levels (2.61 pg $g^{-1}$) but were still below the permissible limit of 4 pg $g^{-1}$ for the muscle of fish and fishery products. Other species (except for cuttlefish, gray eel catfish, and large-scale tongue sole) contained relatively low level of PCBs. Therefore, in terms of PCB concentrations, these fish and shellfish are safe to consume (Mohamad *et al.,* 2013).

Even though the level is not high, these chemicals can still cause adverse health effects among the residents who consume excessive fish, especially fatty fish. Therefore, setting limits for PCBs in fish and shellfish species is important to limit the risk of exposure to humans through dietary intake.

**Klang Strait :** Sany *et al.* (2014) investigated the concentration of carcinogenic polycyclic aromatic hydrocarbons (c-PAHs) present in the Klang Strait's water, sediment and blood cockles (*Anadara granosa*). The results indicated that the consumption of blood cockles increases cancer risks in consumers with respect to c-PAHs. The calculation of non-carcinogenic risk from polluted water for all the consumers exceeded the US EPA's risk management range at almost all the investigated stations.

**Table 3 :** Concentration of PCBs in sediment samples from the Huveaune River (stations H1 to H11).

| Stations | H1 | H2 | H3 | H4 | H5 | H6 | H7 | H8 | H9 | H10 | H11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CB28 | - | 0.8 | 0.2 | 0.0 | 5.4 | 28.5 | 2.2 | 8.6 | 1.1 | 4.9 | 0.1 |
| CB52 | - | 1.5 | 1.2 | 0.4 | 16.1 | 32.6 | 11.4 | 19.3 | 13.5 | 12.0 | 0.2 |
| CB101 | - | 0.2 | 11.8 | 1.3 | 31.1 | 53.7 | 19.4 | 42.1 | 15.3 | 7.2 | 1.2 |
| CB118 | - | 0.3 | 7.7 | 1.1 | 31.8 | 42.9 | 21.4 | 46.6 | 15.3 | 2.6 | 0.8 |
| CB153 | - | 0.0 | 0.4 | 4.4 | 44.8 | 105.2 | 53.1 | 112.2 | 35.4 | - | 5.4 |
| CB138 | - | 0.0 | 5.2 | 3.9 | 51.0 | 116.6 | 62.6 | 112.2 | 34.0 | - | 4.9 |
| CB180 | - | 0.0 | 12.3 | 3.1 | 15.2 | 55.5 | 30.1 | 75.4 | 20.3 | 1.9 | 4.0 |
| ΣPCB[a] | - | 2.8 | 38.6 | 14.2 | 195.3 | 435.0 | 200.3 | 416.3 | 134.9 | 28.6 | 16.6 |

[a]Sum of the 7PCB recommended by the International Council for the Exploration of the Sea (ICES).

**Table 4 :** Concentration of pesticides in sediment samples from the Huveaune River (stations H1 to H11).

| Stations | H1 | H2 | H3 | H4 | H5 | H6 | H7 | H8 | H9 | H10 | H11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Chlopyrifis | 0.00 | 0.00 | 0.00 | - | - | - | - | - | - | - | 0.00 |
| Endrin | 0.10 | 0.07 | 1.24 | 0.24 | - | - | - | - | - | - | 0.28 |
| *p,p*-DDT | 0.65 | 0.63 | 0.94 | 0.78 | 1.58 | 1.29 | 1.37 | 3.31 | 2.27 | - | 0.74 |
| *o,p*-DDT | - | - | - | - | - | - | 0.06 | 5.48 | - | - | - |

[a]Detected but not quantified

**Table 5 :** Concentration of PBDEs, PCBs and DDTs in marine fish (ng $g^{-1}$ lipid weight) from Natuna Island, South China Sea.

| Species | N | Liquid (%) | Body length (cm) | Body weight (g) | PBDEs[b] | PCBs[c] | DDTs[d] |
|---|---|---|---|---|---|---|---|
| Brushtooth | | | | | | | |
| lizardfish | 6 | 0.90±0.10[a] | 18.4±0.63 | 39.0±2.97 | 5.55±0.67 | 26.4±4.12 | 16.7±2.96 |
| Russel's muckeral-scad | 5 | 0.72±0.02 | 22.5±0.33 | 107.2±3.40 | 7.64±2.27 | 31.9±3.14 | 24.4±6.21 |
| Striped fin goatfish | 7 | 1.65±0.28 | 14.4±0.29 | 30.5±2.01 | 2.85±1.16 | 14.3±3.36 | 10.8±2.81 |
| Snakefish | 5 | 0.46±0.11 | 17.4±1.30 | 44.4±5.54 | 7.82±2.02 | 48.1±6.83 | 40.3±4.48 |
| Truncatetail bigeye | 4 | 0.66±0.06 | 24.8±1.39 | 172.4±31.9 | 3.13±0.20 | 24.9±4.53 | 7.99±2.06 |

[a]mean±SE.
[b]Sum of BDE 47, 66, 85, 99, 100, 153, 154, 209.
[c]Sum of PCB 99, 101, 110, 117, 118, 128, 130, 138, 139, 146, 153, 161, 175, 178, 180, 187, 190, 193.
[d]Sum of p,p-DDE, o,p-DDD, p,p-DDD, o,p-DDT, p,p-DDD

**Table 6 :** Risk assessment of sediment samples collected in July 2007 from Huoshaohei Lake (HSH,H), Xihulu Lake (XHL,X), Wanghua Lake (WH,W), and Keqin Lake (KQ,K), Heilongjiang, China. The concentrations are in ng $g^{-1}$.

| Pesticide | ERL | ERM | Range of concentrations | | <ERL (%) | | | | | ERL-ERM (%) | | | | | >ERM (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | H | X | W | K | H | X | W | K | H | X | W | K | H | X | W | K |
| p,p-DDT | 1.00 | 7.00 | 0-1.13 | 0-1.54 | 0-0.57 | 0-1.12 | 87 | 92 | 100 | 93.8 | 13 | 8 | 0 | 6.25 | 0 | 0 | 0 | 0 |
| p,pDDD | 2.00 | 20.0 | 0-0.02 | 0-0.02 | 0-0.01 | 0-0.03 | 100 | 100 | 100 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| p,p-DDE | 2.20 | 27.0 | 0-0.05 | 0-0.01 | 0-0.04 | 0-0.02 | 100 | 100 | 100 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

However, the HI hazard index values for polluted sediments and blood cockle consumption were lower than the US EPA's recommended values at most of the stations. The combined results of individual locations and consumers showed that the risks (either carcinogenic or non-carcinogenic) of c-PAHs in different matrices of the Klang Strait, Malaysia, were mostly acceptable, and serious attention should be given to this region. Additionally, the concentration of c-PAHs in blood cockles' soft tissue were significantly correlated with PAH concentrations in both water and sediments. More attention should be focused on controlling the discharge of PAHs into the Klang Strait and the Klang River before the risk increases (Sany *et al.,* 2014).

This review provides an overview of the continental distribution of several types of POPs and health risks associated with exposure to POPs in daily life. Various OCP and PCB chemicals are used in most continents for agricultural and industrial activities. Discharge of these pollutants in the environment may affect aquatic and terrestrial life. However, the risk estimation of POP exposure

**Table 7 :** Health risk values of different lakes.

| | HSH | | XHL | | WH | | KQ | |
|---|---|---|---|---|---|---|---|---|
| | CR | NCR | CR | NCR | CR | NCR | CR | NCR |
| Mean | 5.98E-07 | 1.10E-02 | 7.22E-07 | 5.09E-02 | 2.48E-07 | 1.21E-02 | 3.71E-07 | 2.3E-02 |
| Minimum | 0 | 0 | 0 | 1.02E-05 | 0 | 0 | 1.23E-08 | 0 |
| Maximum | 3.21E-06 | 1.02E-04 | 4.22E-06 | 3.18E-01 | 4.59E-06 | 3.26E-02 | 6.24E-06 | 3.19E-02 |

**Table 8 :** Polychlorinated biphenyls (four non-ortho-PCBs and eight mono-ortho-PCBs congeners) and toxic equivalents (WHO-iTEQ) as pg $g^{-1}$ in fish and shellfish species.

| Fish and Shellfish Analytes | Malabar red Sanapper | Sixbar grouper | Large-scale tongue sole | Cuttlefish | Cookies | Prawn | Long-tailed butterfly ray | Grey-eel catfish | Japanese threadfin bream |
|---|---|---|---|---|---|---|---|---|---|
| Non-ortho PCB | 0.66 | 0.75 | 1.62 | 1.94 | 2.57 | 0.61 | 0.66 | 1.65 | 0.6 |
| Mono-ortho PCB | 0.01 | 0.13 | 0.12 | 0.14 | 0.04 | 0.04 | 0.01 | 0.11 | 0.05 |
| WHO-iTEQ(pg/g) | 0.67 | 0.88 | 1.74 | 2.08 | 0.65 | 0.65 | 0.67 | 1.76 | 0.65 |

can be determined based on the risk assessment discussed above.

**Conflicts of Interest :** The authors declare that there is no conflict of interest regarding the publication of this paper.

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