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# Residue of Selected Persistent Organic Pollutants (POPs) in Soil of Some Areas in Vietnam

*Toan Vu Duc, Chi Do Thi Lan and Mai Ngo Tra*

## Abstract

This chapter evaluates the contamination of selected persistent organic pollutants (S-POPs) in soil of some typical areas in Vietnam (mangrove forest, industrial, and urban areas in northern part). S-POPs are composed of polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs). The collected data and analyzed results indicated the wide occurrence of significant S-POPs residues in study areas. The main sources of S-POPs are discussed by using composition analyses and diagnostic ratios of S-POPs indicator. Risk assessment of S-POPs in soil is assessed by using the guidance of the US Environmental Protection Agency. The obtained results have contributed to assess the S-POPs fate in the soil environment in Vietnam.

**Keywords:** soil, PCBs, PAHs, residues

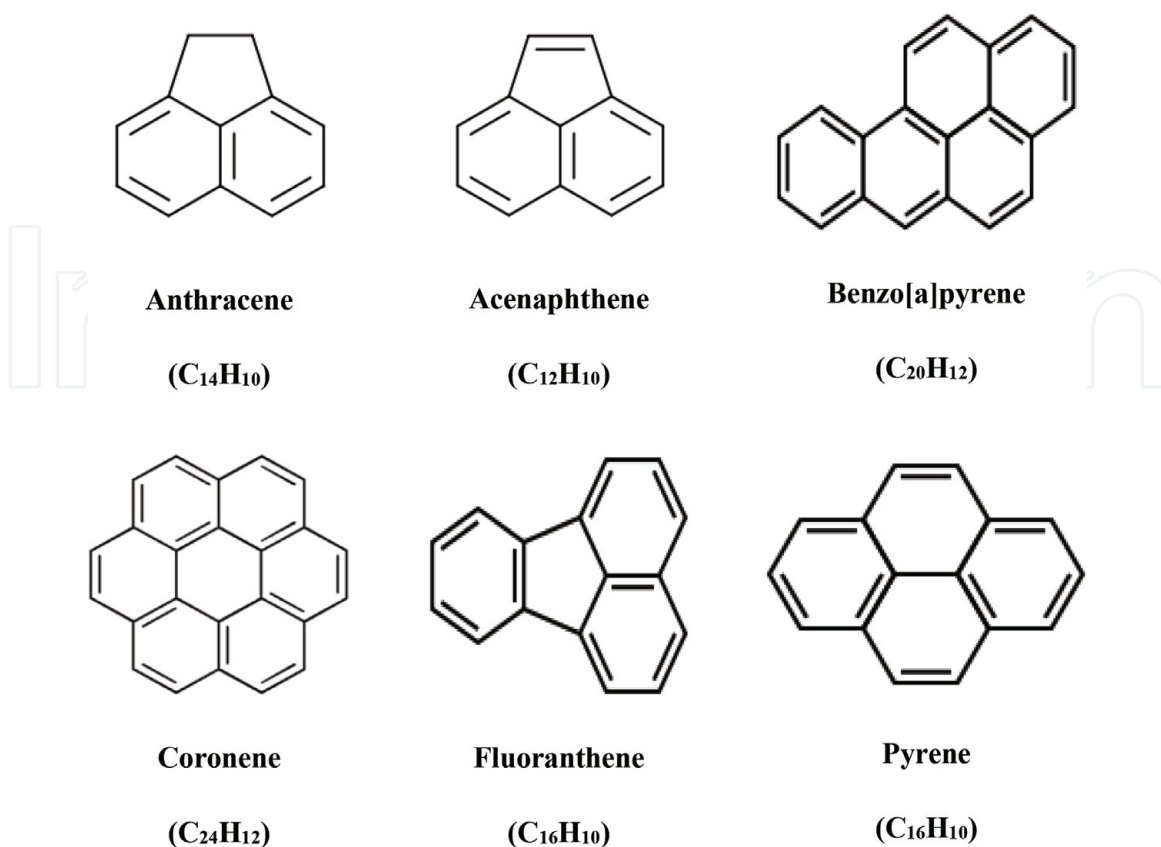
## 1. Introduction

Of all the persistent organic pollutants (POPs) with a potential environmental and human health impacts, polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs) have received a lot of attention. Concern over the toxicology of these compounds (S-POPs) has led to international efforts to research on their contamination and fate in the environment. S-POPs are distributed into every compositions of environment and seriously affected public health.

PAHs are a group of organic compounds containing only carbon and hydrogen, constituted by two or more fused-benzene rings. They are a ubiquitous group of several hundred chemically related compounds, environmentally persistent with various structures and varied toxicity. PAHs have low polarization, solubility, and volatility change and accumulate in organisms from low molecular weights to high molecular weights [1]. With low-molecular-weighted PAHs, the solubility is high while accumulating in low organisms with high volatility. In contrast, with high-molecular-weighted PAHs (four or more rings), the solubility is low, and accumulation in the organism is high with low volatility. The amount of benzene rings in the chemical structure of the PAHs determines the solubility in water. As the number of benzene rings increases, the hydrophobicity of the PAHs increases. PAHs are relatively inert chemical compounds. Since they are composed of benzene rings, PAHs have the properties of aromatic hydrocarbons, which can participate in substitution and addition reactions. The low solubility of PAHs in water will lead

to PAHs that tend to adsorb in soil and sediment, thus greatly affecting their ability to be biodegradable by microorganisms. PAHs interact strongly with sediment organic carbon, which have relatively low volatility, resulting in bioaccumulation and toxicities in some aquatic organisms [2, 3]. International researches often concentrated on 16 representative PAHs including naphthalene (Nap), acenaphthylene (Acey), acenaphthene (Ace), fluorene (Flu), phenanthrene (Phe), anthracene (Ant), fluoranthene (Flt), pyrene (Pyr), chrysene (Chr), benzo[a]anthracene (BaA), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[a]pyrene (BaP), indeno[1,2,3-cd]pyrene (IcdP), dibenzo[a,h]anthracene (DahA), and benzo [g,h,i]pyrene (BghiP) (**Figure 1**).

PAHs are formed from two sources: natural and man-made sources. Some PAHs in the environment originate from natural sources such as combustion (natural forest fires, volcanic eruptions), rock formation processes, sedimentation processes, oil leaks, or coal mines (this is human activities) [4, 5]. However, natural sources are not the main source. In terms of human activities, PAHs are formed by incomplete combustion of raw materials, such as coal, oil, gas, wood, grass, and waste, or the process of smoking, grilling, or frying food. Almost all sectors (industrial production, agriculture, livelihoods, transport, and other activities) can generate PAHs [3, 6]. PAHs generated from different sources have different characteristics. In the environment, PAHs can be found everywhere: air, water, sediment, soil, and organisms [7]. The existence of PAHs in many environmental components is due to the PAHs spread and deposition process. Initially, PAHs are discharged into the air, which exists in either gaseous form or are adsorbed onto the dust. Under normal conditions, the amount of PAHs contained in the dust can account for up to 90% [8, 9]. By the spreading process, PAHs can be transported in long distance in the air, which then condense and accumulate in soil, water, sediment, and organisms. Studies on PAHs in soils are prevalent because of PAHs' high accumulation



**Figure 1.**  
Structure of some typical PAHs.

potential, and traceability in soil is easier to detect than in other component environments.

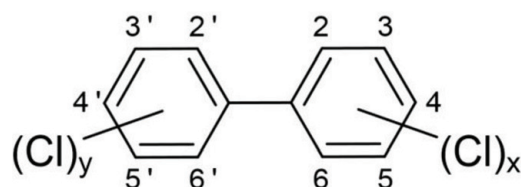
There are many types of PAHs that cause cancer and gene mutations [1, 10, 11]. Human are exposed to PAHs through food, water, breathing air, or direct contact with materials containing PAHs. Scientists have now discovered hundred types of PAHs. Most studies focus on a number of characteristic of PAHs, which most significantly are health damage (cancer and genetic mutations) and volatility in the environment.

PCBs are chemical industrial products which have a global environmental health hazard. PCBs groups have 209 isomers and congeners with 1 to 10 chlorine atoms attached to the biphenyl molecule (**Figure 2**). The physical and chemical properties of PCBs are important in studying their fate and their transformation in the environment. PCBs vary from colorless for the lower chlorinated compounds to yellow for the most highly chlorinated types. They exhibit low water solubility (from  $1.2 \cdot 10^{-10}$  to  $6.5 \cdot 10^{-5}$  g/m<sup>3</sup>), low Henry constant (from  $0.3 \cdot 10^{-4}$  to  $8.97 \cdot 10^{-4}$  atm<sup>3</sup>/mole), and low electrical conductivity. In contrast, PCBs have high boiling point (from 285 to 456°C) and high value of lgKow (from 4.3 to 8.3). PCBs with fewer chlorine atoms are, in general, less persistent, more water soluble, and more flammable than PCBs with more chlorine atoms. PCBs are very resistant to decomposition and are also non-corrosive as well as relatively non-flammable. Due to these properties, PCBs can be distributed in many places in the environment, into the food chain and accumulated in the human body and other organisms.

Physical and chemical properties of PCBs made them useful in industrial. Of the 209 possible PCB congeners, about 100 compounds are recovered in industrial mixtures. PCBs have an excellent insulating property as well as a high heat capacity [1]. Their properties have led to many industrial applications such as insulator in transformers and capacitors, plasticizers, surface coatings, additives in paints, flame retardants, etc.

The industrial application of PCBs started in the early 1939. The following countries have been the main manufacturers of PCBs: Austria, China, Czechoslovakia, France, Germany, Italy, Japan, Russia, Spain, the United Kingdom, and the United States. PCBs mixtures have been marketed under variety of trade names such as Aroclor (the United States, the United Kingdom, Canada, and Australia), Phenochlor and Pyralene (France), Clophen (Germany), Fenoclor (Italy), Chlofen (Poland), Sovol (Soviet Union), Kanechlor (Japan), and Derlor (Czechoslovakia). Between 1929 and 1989, the total world production of PCBs was 1,5 million tons, an average of about 26,000 tons per year. Since 1940, Vietnam has imported between 27,000 and 30,000 tons of PCBs from Russia, China, and Romania, mainly as insulator in transformers.

Since early 1960, scientists discovered that PCBs are toxic, affecting human health. PCB poisoning has occurred, including Yusho in Japan in 1968 and Yucheng in Taiwan in 1979, causing hundreds of deaths and thousands of people suffering from various effects.



**Figure 2.**  
Structure of PCBs ( $x + y \leq 10$ ).

PCBs have been demonstrated to cause cancer and a number of serious non-cancer health effects in animals, including effects on the immune system, reproductive system, nervous system, and endocrine system and other health effects. Studies in humans provide supportive evidence for potential carcinogenic and non-carcinogenic effects of PCBs. The degree of impact depends on the substance in the PCB group.

PCBs enter the environment in three main ways: by disposing of PCB-containing waste in landfills, and from which PCBs enter the groundwater, into the river, into the sea; incorrect combustion of PCB waste causes PCBs to disperse into the atmosphere; and due to PCB leakage from electrical appliances such as transformers and capacitors. The transport of PCBs in the environment is due to the effects of air, water, animals, and some other pathways. PCBs can accumulate in the fat, milk, brain, serum, liver, and muscles of the human body and can be excreted from the body through urine and breast milk. After detecting the toxicity of PCBs, many countries around the world have in turn prohibited the production and use of PCB. In Vietnam, PCB has been restricted since 1992.

## 2. Residue of PAHs in mangrove forest soil in Northern Vietnam

### 2.1 Contamination status of PAHs

Mangrove forests are important habitats and are of high economic value. Mangroves in Vietnam are severely damaged by a variety of causes, including pollutants. Mangroves of Dong Rui, Tien Yen, Quang Ninh, situated in Northern Vietnam, are a unique ecosystem, close to Vietnam's largest coal mining area and thermal power plants. The research has found that PAHs in soil of Dong Rui mangrove are present with significant concentrations.

Studies of PAHs in soil are quite diverse and show that concentration of PAHs accumulated from region to region, ranging from mild to very severe. The concentration of PAHs in mangrove forests around the world fluctuates in a large range from a few hundred  $\mu\text{g}/\text{kg}$  to thousands of  $\mu\text{g}/\text{kg}$ , some places even higher concentration than the accumulation in industrial land.

Our studies of PAHs in mangrove forest soil are implemented in Dong Rui area from August 2014 to January 2017. Comparison of PAH concentrations in Dong Rui mangroves with other places showed that PAHs in Dong Rui mangrove at the lowest value are still higher than those in mangroves in the Sundarbans, India. However, since the highest value in Dong Rui is smaller than in India, Hong Kong, so it can be said that the level concentration of PAHs of mangrove in Dong Rui is average (Table 1).

Among 16 PAHs (classified by the US Environmental Protection Agency) studied at Dong Rui mangroves, Vietnam from August 2014 to January 2017, there were

Place	Min values	Max values	Mean values
Mangroves: Dong Rui, Vietnam (this study)	312.5	1407.0	692.6
Mangroves: the Sundarbans, India	132	2938	634
Four wetlands mangroves: Hong Kong	356	11098	1142
Mangroves: Ho Chung, Hong Kong	1162	3322	2202

Source: [5, 14, 15].

**Table 1.**

Concentrations of  $\Sigma_{16}$  PAHs ( $\mu\text{g}/\text{kg}$ ) in soil in some mangrove areas in the world.

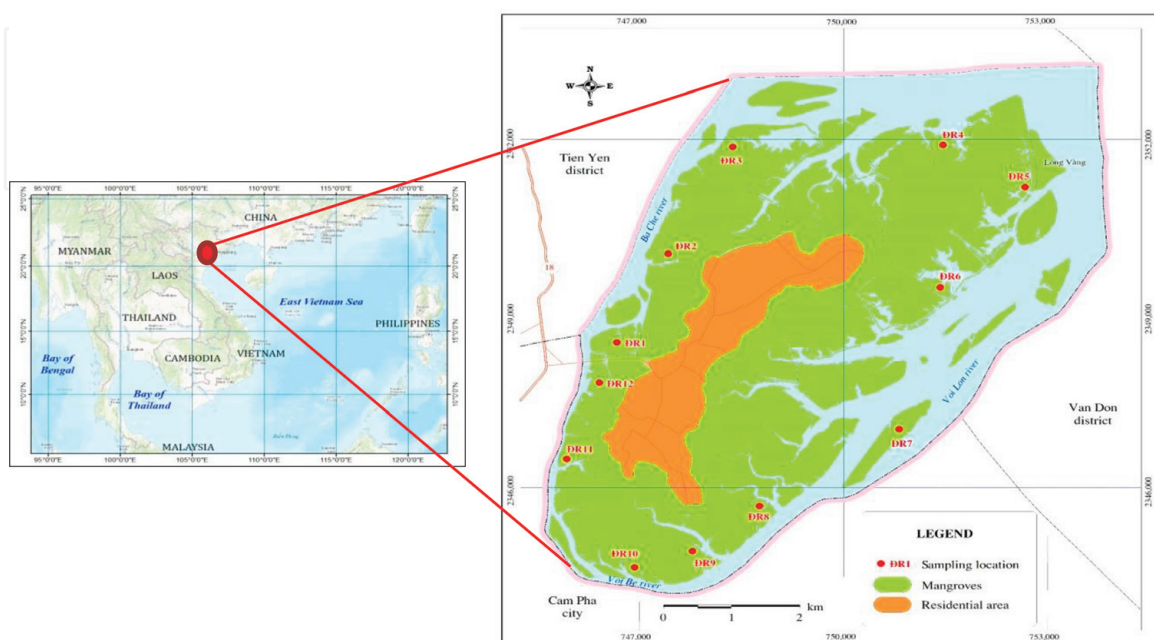


8 PAHs (BaA, Chr, BbF, BkF, BaP, Ind, BghiP, DahA) identified as potentially carcinogenic. Those PAHs are composed of four or more benzene rings, which are highly durable in the environment, less degradable, and have high accumulation in soil [12, 13]. Considering the ratio of  $\Sigma_8$ PAHs to  $\Sigma_{16}$ PAHs at the sampling sites, most  $\Sigma_8$ PAHs were found to be high compared to  $\Sigma_{16}$ PAHs. The percentage of  $\Sigma_8$ PAHs/ $\Sigma_{16}$ PAHs ranged from 50.2% to 71.4% with an average of 59.6%. This is also consistent with studies by Hussein et al. (2016) on PAHs in soils with an average of  $\Sigma_8$ PAHs/ $\Sigma_{16}$ PAHs of 67.1% [4] (**Figure 3**).

Of the 16 typical PAHs, PAHs can be represented from two benzene rings to six benzene rings. Two-ring PAHs are Nap; three-ring PAHs include Acy, Ace, Flu, Phe, and Ant; four-ring PAHs include Py, Flt, BaA, and Chr; five-ring PAHs include BbF, BkF, BaP, and DahA; and six-ring PAHs include Ind and BghiP. Considering the accumulation of PAHs in terms of the number of benzene rings, four-ring PAHs were dominant (32%), while two-ring PAHs were the lowest (3%). Five-ring PAHs are 25% larger than the rate of three-ring PAHs (22%) and six-ring (18%). This result is also consistent with the study by Ishwar Chandra Yadav et al. (2017) in soils in Kathmandu (Nepal) [16] with four-ring PAHs > five-ring PAHs > 3-ring PAHs > 6-ring PAHs > 2-ring PAHs.

Based on molecular weight, 16 PAHs can be divided into three groups. Low-molecular-weight (LMW) groups of PAHs with 2–3 rings include Nap, Ace, Acy, Phe, Flu, and Ant. Medium-molecular-weight groups (MMW) are groups of with four-ring PAHs, including BaA, Chr, Pyr, and Flt. High-molecular-weight groups (HMW) are groups of five- to six-ring PAHs: BbF, BkF, BaP, DahA, BghiP, and Ind. These subgroups are different in water solubility, lipid modification, and absorption of PAHs. Studies have shown that PAHs in the MMW and HMW groups are less soluble in water, less variable, and more easily absorbed lipids than PAHs in the LMW group. In addition, the toxicity and environmental stability of PAHs in the MMW and HMW groups were also higher than the LMW group.

In this study, the HMW group had the highest percentage of all samples, accounted for 36.63–56.76%. Meanwhile, the MMW group rate ranged from 17.3 to 39.77%, and the LMW group was the lowest, ranging from 17.79 to 31.52%.



**Figure 3.**  
*Mangroves area in Dong Rui, Northern Vietnam.*

## 2.2 PAHs emission characteristics

Determining PAH sources is difficult due to their spread and sustainability in the environment. At present, the studies are based on the characteristics of the PAHs isomer ratios such as Flt/(Flt + Pyr), Ant/(Ant + Phe), BaA/(BaA + Chyr), and Ind/(Ind + BghiP) in the environment to predict the source of PAHs (**Table 2**).

Dong Rui mangrove is surrounded by three rivers: Voi Lon, Voi Be, and Ba Che and estuaries. It is affected of coal mining and coal burning in Cam Pha and Cua Ong areas, Mong Duong I and II thermal power plants, and paper factory. During the coal mining and coal burning process, PAHs have been emitted and spread to Dong Rui mangroves due to wind and tides. Specific PAHs sources may include:

- Activities: smoking, heating, and cooking with sawdust, charcoal, honeycomb, wood, waste incineration, etc.
- Traffic: road traffic activities in island communes and national highway 18 passing through the island commune; water transportation.
- Industrial production: paper mills 2 km away from mangroves, Mong Duong thermal power plant about 7 km from mangroves, and coal mining in Cam Pha, Cua Ong area
- Other activities: burning of wood, charcoal making, burning of forest, burning of straw

The relationship between PAHs composition and source of emissions has been considered from the analysis of the proportions of PAHs in the sample. Each source of waste has the potential to produce some PAHs better than other sources. Therefore, the PAH rates determined from the sample analysis will be indicators that help determine the source of PAHs.

The Flt/(Flt + Pyr) ratio at most sampling locations is greater than 0.5. Therefore, the main source of emissions to the Dong Rui mangroves is the burning of raw materials such as coal, wood, grass, etc. At points close to the traffic

Ratios PAHs	Value	Emission source
Flt/(Flt + Pyr)	<0.4	Gasoline, oil spill
	0.4–0.5	Traffic
	>0.5	Grass, wood, coal
Ant/(Ant + Phe)	<0.1	Gasoline, oil spill
	>0.1	Fire
BaA/(BaA + Chyr)	<0.2	Gasoline, oil spill
	0.2–0.35	Gasoline, oil spill, or fire
	>0.35	Fire
Ind/(Ind + BghiP)	<0.2	Gasoline, oil spill
	0.2–0.5	Traffic
	>0.5	Grass, wood, coal

**Table 2.**

*The relationship between the ratio of some PAHs and their emission source.*

line, Flt/(Flt + Pyr) is in the range of 0.4–0.5. Thus, the main source of emissions in this area is transport.

At all sampling sites, BaA/(BaA + Chyr) ratios were greater than 0.2, and at most sampling sites, BaA/(BaA + Chyr) ratios were greater than 0.35. Therefore, it is possible that the source of the emissions is mainly due to combustion. Similarly, the Ant/(Ant+ Phe) rate at the sampling locations at the time of sampling is greater than 0.1. Thus, the source of emissions is mainly due to burning rather than oil spills. The Ind/(Ind + BghiP) ratio at most sampling points is greater than 0.5. At these locations, the source of the waste is mainly from the burning of raw materials such as coal, wood, and grass. There are some samples near the roads; Ind/(Ind + BghiP) is in the range of 0.2–0.5. As such, these points are mainly affected by the fire of gasoline from vehicles. This is in line with the actual situation in Dong Rui.

### 2.3 Risk assessment of PAHs

The presence of PAHs in the soil of Dong Rui mangroves has shown signs of risk to the ecological environment. To assess the risk of PAHs exposure to humans who live in mangroves area, this study used the cancer risk index (CR). This index looks at the risk of cancer through three pathways: digestive, respiratory, and the skin. Calculation formula CR digestive (cancer risk due to contaminated gastrointestinal tract), CR skin (cancer risk due to exposure to contaminated skin), and CR respiratory (cancer risk due to breathing pollutants) based on formulas 1, 2, and 3. The formulas for calculating the cancer risk index include

$$CR_{\text{digestive}} = \frac{CS \times \left( CSF_{\text{digestive}} \times \sqrt[3]{\left(\frac{BW}{70}\right)} \right) \times IR_{\text{soil}} \times EF \times ED}{BW \times AT \times 10^6} \quad (1)$$

$$CR_{\text{skin}} = \frac{CS \times \left( CSF_{\text{skin}} \times \sqrt[3]{\left(\frac{BW}{70}\right)} \right) \times SA \times FE \times AF \times ABS \times EF \times ED}{BW \times AT \times 10^6} \quad (2)$$

$$CR_{\text{respiratory}} = \frac{CS \times \left( CSF_{\text{respiratory}} \times \sqrt[3]{\left(\frac{BW}{70}\right)} \right) \times IR_{\text{air}} \times EF \times ED}{BW \times AT \times PEF} \quad (3)$$

where

- CS: the concentration of PAH in the soil ( $\mu\text{g}/\text{kg}$ )
- CSF: cancer slope index ( $1/(\text{mg}/\text{kg}\cdot\text{day})$ )
- BW: average weight of the study population (kg)
- EF: frequency of exposure (day/year)
- ED: length of exposure time (year)
- IR air: speed of breath ( $\text{m}^3/\text{day}$ )
- IR soil: absorption rate through the gastrointestinal tract ( $\text{mg}/\text{day}$ )
- SA: coefficient of contact with skin surface ( $\text{cm}^2/\text{day}$ )
- AF: adhesion of the skin when exposed to soil ( $\text{mg}/\text{cm}^2$ )
- ABS: absorption coefficient across the skin
- FE: skin-to-skin contact ratio
- AT: average exposure time (day)
- PEF: dust emission factor ( $\text{m}^3/\text{kg}$ )
- CSF: BaP toxic cancer index, with  $CSF_{\text{BaP digestive}} = 7.3$ ;  $CSF_{\text{BaP skin}} = 25$ ;  
 $CSF_{\text{BaP respiratory}} = 3.85$ , that is determined by the carcinogenic potential of BaP [17]
- CS: ratio between  $TEQ_{16\text{PAHs}}$  and  $TEQ_{\text{BaP}}$  [18].



$$CS = \frac{TEQ_{16PAH}}{TEQ_{BaP}} \quad (4)$$

with  $TEQ = TEF \times$  the concentration of each PAH in the soil sample.

Here, TEF is equivalent toxicity.

Under the guidance of the US Environmental Protection Agency, CR ranges are categorized into five categories: very low risk, low risk, average risk, high risk, and very high risk. The majority of risk assessments used present potentially higher-risk scenarios than the actual ones, according to **Table 3**. The positive side of this approach is that the risks are not underestimated, and population health in the area is more protected.

This research split people who live in Dong Rui mangrove into two groups: group 1 (<10 years old) and group 2 (11–70 years old). This split is based on exposure time, no air intake, average balance, and also the object. All people who live in Dong Rui mangrove are allowed to be referenced. Apply the calculating 1, 2, 3 to calculate CR index (**Table 4**).

In the three components of CR index, the ratio  $CR_{digestive}/CR_{Total}$  was 0.63% for group 1 and 0.55% for group 2. At the same time, the ratio  $CR_{exposure}/CR_{Total}$  for group 1 was 0.37%; group 2 was 0.45%. The ratio  $CR_{respiratory}/CR_{Total}$  was almost negligible in two groups. Thus, the risk of gastrointestinal cancer is highest in the exposure pathways for both groups, followed by the risk of exposure and, ultimately, the risk of breathing.

Comparing the risk of cancer between the two groups showed that the risk of cancer caused by group 2 is 1.6 times higher than that of group 1. In the risk of cancer due to exposure, group 2 is 2.3 times higher than that of group 1. The risk of cancer caused by breathing is the same for both groups. The overall risk for group 1 was 1.9 times higher than that of group 2. Thus, with PAHs in the soil of Dong Rui mangrove, group 2 had a higher risk for cancer than group 1. This could be explained by the longer exposure time of group 2 compared to group 1.

Risk level	Cancer risk index
Very low risk	$CR \leq 10^{-6}$
Low risk	$10^{-6} < CR \leq 10^{-4}$
Medium risk	$10^{-4} < CR \leq 10^{-3}$
High risk	$10^{-3} \leq CR < 10^{-1}$
Very high risk	$CR \geq 10^{-1}$

**Table 3.**  
*Classification of cancer risk.*

Index	Group 1	Group 2
$CR_{digestive}$	3.81343E-06	6.22609E-06
$CR_{skin}$	2.2306E-06	5.18962E-06
$CR_{respiratory}$	7.3941E-11	7.3941E-11
$CR_{Total}$	6.04411E-06	1.14158E-05

**Table 4.**  
*Cancer risk index in groups.*

### **3. Residue of PCBs in soil of some areas in Vietnam**

#### **3.1 General contamination status of PCBs in soil in Vietnam**

Monitoring surveys of PCBs residue in soil have been conducted during the early 1992s. In the Northern Vietnam, PCBs was found in environmental soil of Hung Yen province, Bac Ninh province (Bac Ninh city, Tu Son district, Yen Phong district, Tien Du district) and Hanoi city (Hanoi downtown, Soc Son district, Gia Lam district, Dong Anh district, Thanh Tri district, Tu Liem district) [19, 20]. PCBs penetrated in the urban and rural areas. High PCBs concentrations were found in soil of Hanoi in 1995 (1070.96 ng/g dw) [20].

In the central Vietnam, PCBs was found in environmental soil of Quang Tri province and Hue city. PCBs penetrated in urban soil at significant levels (from 0.9 to 312.5 ng/g, [20]). In the southern Vietnam, PCBs were also found in Mekong River delta (Long An province, Tay Ninh province) Ho Chi Minh city. PCB distributed in wide spaces such as landfill soil (Dong Thanh landfill of Ho Chi Minh city, 17.22 ng/g), paddy field soil, and urban soil [21]. Highest PCBs concentrations were found in urban soil of Ho Chi Minh city (530.5 ng/g) [20].

According to the POP national plan of the Vietnamese government, the use of PCB oils in all equipment will have to be terminated in 2020. PCBs will have to be destroyed in 2028. Therefore, an adequate management and disposal of PCB sources would help to prevent a further PCB release to the environment.

#### **3.2 Case study of PCBs residues in Hanoi**

##### *3.2.1 Study area and soil sampling*

Our studies of PCBs residue in Hanoi, capital of Vietnam, are implemented in 2006. Hanoi city, located in the Red River Delta in the North Vietnam, is the center of culture, politics, economy, and trade of the whole country. Hanoi comprises several urban suburban districts. Due to the important role of Hanoi in safety of public health and environmental quality, an assessment of the content and distribution of PCBs in soil is therefore essential.

Soil sampling followed Vietnamese standards (TCVN). These standards are composed of:

- TCVN 4046–85: Method of soil sampling in agricultural areas
- TCVN 5297–1995: Soil quality—sampling—general requirements
- TCVN 5960–1995: Soil quality—sampling—guidance on the collection, handling and storage of soil for the assessment of aerobic microbial processes in the laboratory
- TCVN 4047–85: Method for the preparation of soil sample for analysis
- TCVN 6857–2001: Soil quality—simplified soil description

The sampling campaign for Hanoi was carried out in February 2006 (60 soil samples), during the dry season. Soil samples were collected from agricultural and industrial areas and towns of all five suburban districts (Soc Son, Dong Anh, Gia Lam, Tu Liem, Thanh Tri), as well as the center of Hanoi, for comparison. The

sampling sites were chosen at random, with an attempt to get them evenly distributed over Hanoi city. The samples were taken with solvent-rinsed stainless steel scoops from the upper 5 cm of the soil and then transferred to pre-cleaned polyethylene bags. The total concentration of PCBs ( $\Sigma$ PCBs) and six selected PCB congeners (PCB28, 52, 101, 138, 153, 180) were analyzed following the method described by Thao et al. (2009) [20].

### 3.2.2 Contamination status of PCBs in soil in Hanoi

The PCB concentrations in the collected soil samples from Hanoi are all shown in **Table 5**. The  $\Sigma$ PCBs concentrations in industrial and urban areas ranged from not detected (N.D) to 190.42 ng g<sup>-1</sup> dw (mean 41.89 ng g<sup>-1</sup> dw).

Due to the historical use of PCBs in Vietnam, its main source of contamination in industrial and urban areas could originate from the dielectric oil used in old hanging transformers and capacitors which were widely used in Hanoi. From these installations, PCBs could have penetrated into the environment by mechanical damage, electrical accidents, and fire. During the retro-filling of dielectric oil containing PCBs, there is a risk of PCBs escaping into the environment [19].

With regard to the soil samples from agriculture areas,  $\Sigma$ PCBs concentrations ranged from N.D to 24.37 ng g<sup>-1</sup> (mean 15.14 ng g<sup>-1</sup> dw). These sites are not far from densely populated towns of five surrounding suburban districts. Therefore,  $\Sigma$ PCBs were probably deposited into the agriculture sites by atmospheric transport from urban areas. In general, the PCBs concentrations were highest in industrial soil samples, followed by those in urban soils and in agricultural soil. This also applies for the usage of PCBs in Vietnam [19].

Locations	$\Sigma$ 6PCBs <sup>a</sup>	$\Sigma$ PCBs <sup>b</sup>
A. Agricultural areas		
Soc Son 1 <sup>c</sup>	N.D–3.27 (2.13)	N.D–21.82 (14.22)
Dong Anh 1	N.D–4.14 (3.09)	N.D–24.37 (18.19)
Gia Lam 1	N.D–3.32 (2.15)	N.D–18.39 (11.94)
Hanoi center 1	N.D–2.27 (0.76)	N.D–11.38 (3.79)
Tu Liem 1	2.63–3.14 (2.84)	16.14–19.65 (17.84)
Thanh Tri 1	3.09–3.89 (3.37)	17.18–21.65 (18.69)
B. Industrial and urban areas		
Soc Son 2 <sup>d</sup>	2.52–4.33 (3.72)	16.24–27.94 (23.98)
Dong Anh 2	3.42–4.95 (4.26)	N.D–37.54 (24.36)
Gia Lam 2	N.D–15.49 (8.97)	N.D–79.44 (45.99)
Hanoi center 2	3.53–39.98 (13.12)	16.82–190.42 (62.45)
Tu Liem 2	4.35–11.84 (8.09)	23.56–63.26 (43.27)
Thanh Tri 2	3.12–5.89 (4.92)	18.92–34.62 (29.76)

<sup>a</sup> $\Sigma$ 6PCBs: sum of six selected PCB congeners.  
<sup>b</sup> $\Sigma$ PCB: sum of all PCB isomers and congeners.  
<sup>c</sup>Soc Son 1: agricultural areas of Soc Son.  
<sup>d</sup>Soc Son 2: industrial and urban areas of Soc Son.

**Table 5.**  
Concentrations of PCBs (ng g<sup>-1</sup> dw) in the surface soil from Hanoi.

### 3.2.3 Temporal trends of $\Sigma$ PCB in soil in Hanoi

With regard to PCBs concentrations in soil samples from Hanoi reported in the period from 1992 to 2006, the increasing temporal trend of PCB levels could be shown. It was reported that the mean  $\Sigma$ PCB concentration in soil samples from Hanoi in 1992 (6 soil samples), in 2000 (8 soil samples), and in 2006 (60 soil samples) range from 9.1 to 29 ng g<sup>-1</sup> (mean 12.6 ± 8.9 ng g<sup>-1</sup>), from 0.6 to 120 ng g<sup>-1</sup> (mean 21.2 ± 25.2 ng g<sup>-1</sup>), and from <0.02 to 190.24 ng g<sup>-1</sup> (mean 28.08 ± 28.57 ng g<sup>-1</sup>), respectively [20, 21]. There are some possible sources of PCBs from 1992 to 2006. PCBs have escaped from dielectric oil containing PCB in transformers and capacitors. It has been reported that the total amount of possible PCB-containing transformers and capacitors across Vietnam might reach 9638 units and 1784 units, respectively [22]. PCBs could have volatilized from a capacitor. The studies of Ehime University concluded that PCBs volatilize and spread easily when capacitors containing PCB that are used over their product life are destroyed. PCBs that escaped into ambient air can pollute food through biological accumulation and also pollute the environmental soil. This should not be disregarded. Besides the possible PCB sources in Vietnam, it should be noted that the inaccurate POPs management can lead to their release to a wide extent in the environment.

## 4. Conclusion

This work investigated the contamination status of selected persistent organic pollutants in soil of mangrove forest and urban areas in Vietnam. Wide occurrence and remarkable residue levels of S-POPs have been found in the soil of study areas. Composition analyses show that S-POPs penetrated in the soil for a long time. The main sources of S-POPs are from mix sources which have origin from anthropogenic sources. Risk assessment of S-POPs found from low- to medium-risk levels. Due to the propensity of S-POPs to accumulate in various compartments of environment, further evaluation of ecotoxicological should be undertaken as a high priority.

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## Conflict of interest

The authors have no conflict of interest.



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