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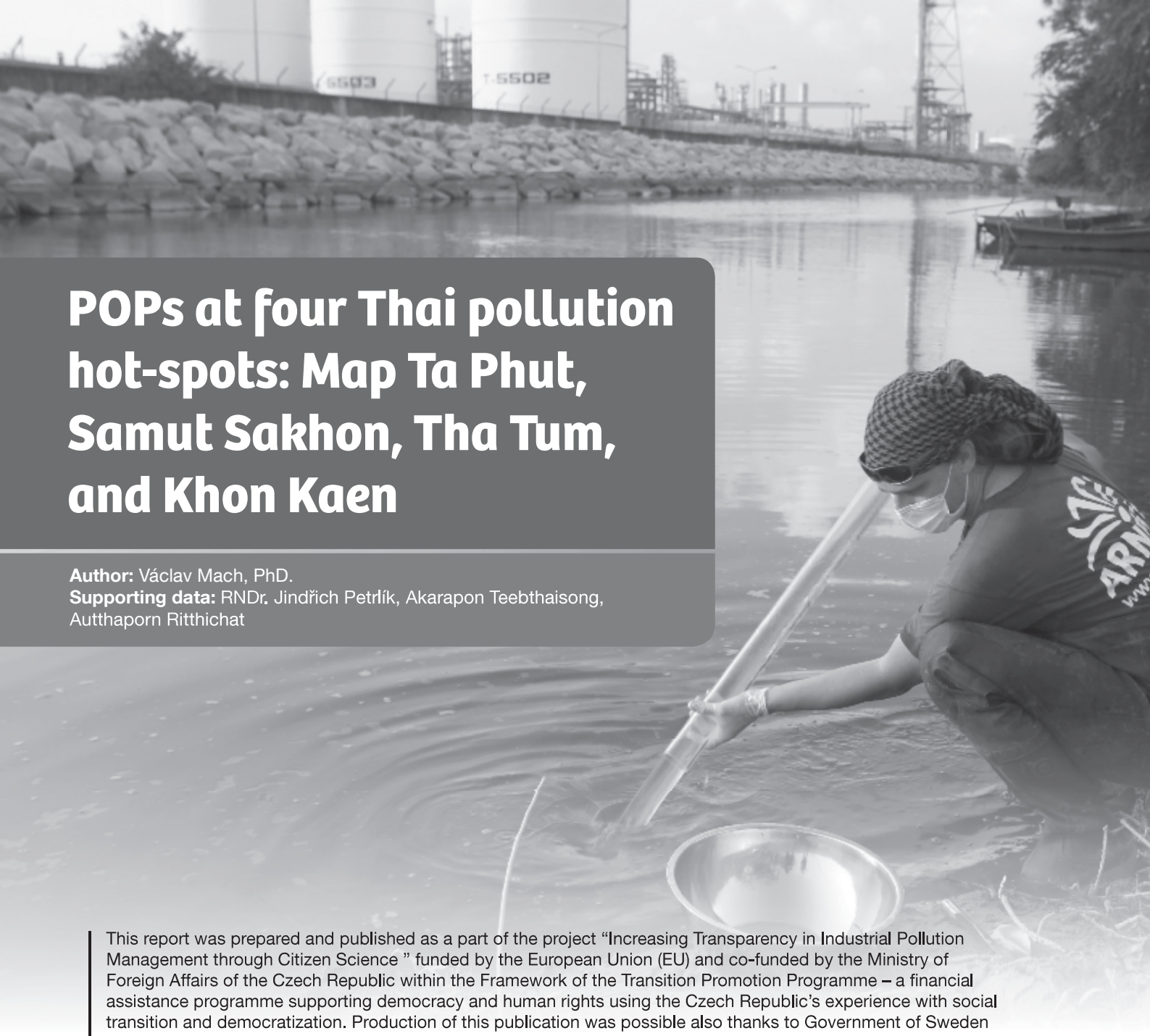

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CONTENT

Summary

Persistent organic pollutants (POPs) are toxic chemicals that persist over long periods of time in the environment. These chemicals are industrially synthesized organic chemicals (DDT, aldrin, chlordane, dieldrin, endosulfan, PCBs, and many others) or unintentional products of chemical and combustion processes (dioxins, hexachlorobutadiene, hexachlorobenzene, PCBs and other). The demand for agricultural productivity caused a rapid increase in the use of organochlorine pesticides in Thailand during the period from 1950 to early 1970. Moreover some other POPs as PCBs were imported to Thailand in various products. Environmental implications from historical use of organochlorine pesticides, PCBs, and other POPs remain. Furthermore, unintentional POPs are still synthesized and emitted into the environment from many industrial processes. This study is focused on the presentation of data related to contamination by POPs in four hotspot areas in Thailand. These hotspots areas are: The Map Ta Phut industrial complex, the Samut Sakhon hotspot area, the Tha Tum industrial complex, and the Pulp and Paper industrial area near Khon Kaen. The data were obtained from these hotspot areas during three sampling campaigns conducted in Thailand, from February 2015 to March 2017. The field campaigns served for inspection of the hotspot areas and collecting organic (fish, mollusc, shellfish, and chicken eggs) and inorganic samples (soil, sediment, and ash). The background fish samples were taken in the Thap Lan National Park – representing an unpolluted area of Thailand. The background egg sample was bought in a supermarket in Bangkok. Collected samples were analysed for content of multiple POPs – dioxins (PCDD/Fs), PCBs, chlorobenzenes, organochlorine pesticides, polycyclic aromatic hydrocarbons, polybrominated diphenyl ethers, hexabromocyclododecane, and brominated flame retardants. Our results show that there are residues of organochlorine pesticides still present in the environment of Thailand. The most common organochlorine pesticide is DDT and its residues, which agrees with literature information and amounts of used pesticides. The most problematic POPs found in the hotspot areas are unintentionally produced chemicals such as dioxins, hexachlorobenzene, pentachlorobenzene, PCBs, hexachlorobutadiene, hexachlorocyclohexane. These contaminants can be created during industrial processes, such as paper bleaching, small metallurgical facilities used as waste recycling operations, open burning of waste (e-waste in particular), chlor-alkali production, production of plastics or waste incineration. The most contaminated matrix in the hotspot areas are eggs, because most of the egg samples exceed the maximum residue limits of hexachlorobenzene and hexachlorocyclohexane for Thailand or maximum levels of PCBs and PCDD/Fs for European Union.

1. Introduction

Persistent organic pollutants are industrially synthesized organic chemicals or unintentional products of chemical and combustion processes that persist over long periods of time in the environment and are toxic for people and wildlife. [1] These contaminants accumulate in tissues of living organisms and are often found in higher concentrations at the upper levels of food chains. [2] Persistent organic pollutants (POPs) can also be transported over long distances by natural processes that involve soil, water, and wind. [3] POPs may be divided into two broad groups: agricultural organochlorine pesticides and industrial chemicals; though some POPs, for example hexachlorobenzene (HCB), were used as both pesticides and industrial chemicals. Some POPs, such as polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), are generated unintentionally as by-products of various industrial processes. [4] Problems associated with POPs are not only found in rural areas with historic or recent agricultural applications of organochlorine pesticides, but are also found in urban and industrial areas, where industrial manufacturing processes, solid waste landfills, pesticide stockpiles, waste incineration, and disease vector control programs induce the emission of large amounts of POPs. Many POPs were originally developed and synthesized for use during the 1930s–40s, and their applications became widespread around the world during the 1950s and 1960s. By the early 1970s, concerns over environmental persistence and the adverse effects on humans culminated in restricting POPs use in many countries. Subsequent restrictions and bans became worldwide by the late 1990s and early 2000s. [5]

In Thailand the demand for agricultural productivity caused a rapid increase in the use of pesticides. During the period from 1950 to early 1970, most of the imported pesticides were organochlorine pesticides. The first record of the POPs use in Thailand was in 1949, when DDT was first introduced as a means of malaria control. [6] The Malaria epidemic in 1951 was very serious and killed over 40,000 Thai people; therefore, DDT has been widely applied. Moreover, DDT has also been used in agriculture for pest control. Dieldrin, aldrin, and endrin were introduced to Thailand in 1955 and lindane (γ-hexachlorcyklohexane) and toxaphene followed in 1959. These organochlorine pesticides have been widely applied for the pest control of almost all crops including cassava, fruit, and vegetable crops. In 1971 toxaphene, DDT, and lindane formed the volume of 62; 1,968; and 17 metric tons respectively. In the same year the volume of dieldrin, aldrin, endrin, chlordane, and heptachlor were less, as 8, 6, 0.8, 3, and 1 metric tons respectively. In general, the importation of these organochlorine pesticides had increased until they were banned in specified years due to impacts posed on human health and the environment. Import of most of organochlorine pesticides has been banned since 1980s: endrin in 1981, toxaphene in 1983, DDT for agricultural use in 1983 and for malaria control in 1994, aldrin, dieldrin, and heptachlor in 1988, chlordane for public health use in 1995 and for agricultural use in 2000. (table1) [7] According to the National Implementation Plan of Thailand [8] mirex and HCB have never been imported or used in Thailand. There is evidence that stockpiles of obsolete organochlorine pesticides might be found in the old pesticide storage at agricultural facilities.

According to the National Implementation Plan of Stockholm Convention [8] polychlorinated biphenyls (PCBs) have never been imported to Thailand for industrial use in form of liquid. The main purpose for which they were used in a relatively large quantity was as a dielectric fluid for electric capacitors and transformers. Capacitors and transformers were imported into Thailand until 1975. Moreover, PCBs have been used in small amounts as industrial fluids for hydraulic systems and gas turbines, as lubricating oil, and as a plasticizer. [6] Imported volumes and the date for all these purposes have never been recorded. PCBs importation has been controlled by the Toxic Act Committee in Thailand since 1975, and no importation permit was granted. In October 2004, PCBs were reclassified from a Type III chemical, that of which the production, import, export, or having in possession must obtain a permit, to a Type IV chemical, that of which the production, import, export or having in possession is prohibited. The PCBs inventory carried out in 2005 indicated that

there were 973 PCBs containing capacitors and transformers at a total weight of almost 1,912 tons being kept in safe storage. [8] Nevertheless, the actual amounts may be higher due to lack of import data, identification technique and equipment, and information. [9] According to the Department of Industrial Works, data collected under the Basel Convention showed that approximately 761 tons of PCBs wastes were exported during 1992-2002. Some of used capacitors and transformers were sent to France, United Kingdom, and Belgium for a final disposal. [7] Besides the intentional production of PCBs, there is also unintentional formation of PCBs from cement, chlorine or steel industries.

Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/Fs) and some other POPs (PCBs, HCB, and HCHs) are unintentionally formed and released from thermal processes involving organic matter and chlorine as a result of incomplete combustion or chemical reactions. [10] Industrial source categories listed in the Annex C, Part II and Part III of the Stockholm Convention on POPs have the potential for comparatively high formation and release of these chemicals into the environment. These industrial source categories also proceed to some extent in Thailand. In 2005 PCDD/Fs inventory has been carried out and potential releases of PCDD/Fs emission to air, water, land, product, and residue were estimated from mass production multiplying with default emission factor proposed by the UNEP's Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases. The maximum emission to residue was found at the amount of 773.30 g I-TEQ/a, followed by emission to air at the amount of 286.30 g I-TEQ/a. The amount of emission to product, land and water were 8.31, 6.64, and 1.33 g I-TEQ/a, respectively. Emission to residue was found to be the highest for production of chemicals and consumer goods at an amount of 384.16 g I-TEQ/a (49.68%), followed by uncontrolled combustion process of 236.10 g I-TEQ/a (30.53%)), ferrous and non-ferrous metal production of 99.64 g I-TEQ/a (12.89%), waste incineration of 32.45 g I-TEQ/a (4.20%), and power generation and heating of 14.28 g I-TEQ/a (1.85%). Emission to air was found to be the highest for uncontrolled combustion process at an amount of 144.24 g I-TEQ/a, followed by waste incineration of 42.37 g I-TEQ/a, power generation and heating of 33.33 g I-TEQ/a, miscellaneous of 21.81 g I-TEQ/a and ferrous and non-ferrous metal production of 20.20 g I-TEQ/a. [8] According to the National Implementation Plan of Stockholm Convention from 2005, Best Available Techniques (BAT) and Best Environmental Practices (BEP) were not applied to any of source categories of PCDD/Fs due to a limitation on financial and technical supports to these source categories.

Brominated flame retardants (BFRs) are a group of bromine-containing organic compounds which are used to prevent or retard the spread of fires. They are present in a broad range of consumer and industrial products, such as electronic and electrical devices, printed circuit boards, furniture, construction materials, and automotive parts and plastics. Polybrominated diphenylethers (PBDEs) and hexabromocyclododecane (HBCD) are among the most widely used BFRs and have attracted significant interest during the last decade. Many BFRs are hydrophobic and persistent in the environment, leading to contamination of humans, wildlife, and ecosystems. BFRs have been highlighted as a problem meriting serious and urgent attention. [11] BFRs pose a potential threat to human health and the environment. Due to a growing number of both human health and environmental concerns associated with BFRs, the tetrabromodiphenyl ether, pentabromodiphenyl ether, hexabromodiphenyl ether, heptabromodiphenyl ether, HBCD, and hexabrombifenyl have been regulated under the Stockholm Convention on POPs in 2009 and/or 2013. Despite this, BFRs may be present in a diverse array of goods and wastes, especially electronic waste. In 2003, the total electronic waste produced in Thailand was estimated at approximately 58,000 tons. Contamination by some BFRs (e.g. PBDEs) in electronic waste storage facilities was reported in Thailand recently. [12] The evidence of cited study suggests that improper storage of e-waste may constitute a source of BFRs to the Thai environment.

Efforts have been made to regulate and phase out POPs through international environmental treaties, such as the Stockholm Convention on POPs. The Stockholm Convention, which came into

effect in 2004, initially identified twelve chemicals or chemical groups for regulation and elimination of production and use. The number of chemicals added to the list of POPs under the Stockholm Convention has been increasing, with 28 chemicals or chemical groups presently listed for elimination. Thailand has signed and ratified the Stockholm Convention on POPs since 22 May 2002 and 31 January 2005 respectively. In accordance with the main provisions of the Stockholm Convention, each country that is a party to the Convention prohibits and/or takes legal and administrative actions required for the elimination and/or restriction of production and use of chemicals listed in Annexes A and B to the Convention, as well as on reduction or elimination of POPs releases resulting from intended or unintended production, as well as releases related to stocks and wastes containing POPs. The Stockholm Convention regulates the following pesticides: chlordecone, hexachlorocyclohexane (HCH), pentachlorobenzene (PeCB), DDT, aldrin, chlordane, dieldrin, endosulfan, endrin, heptachlor, hexachlorobenzene (HCB), mirex and toxaphene. Further, it regulates these industrial chemicals: PCBs, HCB, hexabromobiphenyl, hexabromodiphenyl ether, heptabromodiphenyl ether, PeCB, perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride, short chain chlorinated paraffin (SCCP), tetrabromodiphenyl ether, pentabromodiphenyl ether, and decabromodiphenyl ether. It also regulates unintentional by-products: polychlorinated dibenzofurans (PCDFs), polychlorinated dibenzo-p-dioxins (PCDDs), hexachlorobutadien (HCBD), HCH, PeCB, HCB, and PCBs. [13]

Environmental implications for human health from historical use of organochlorine pesticides, PCBs, and other POPs remain. Unintentional POPs are still synthesized and emitted to the environment from many industrial processes. [5] Toxic burdens and emissions of POPs need to be assessed, as well as mitigated. This study is focused on the presentation of the data related to contamination of organic and inorganic matrices by POPs in four hotspot areas. These hotspots areas are: The Map Ta Phut industrial complex, the Samut Sakhon hotspot area, the Tha Tum industrial complex, and the Pulp and Paper industrial area near Khon Kaen. The data presented in this report were obtained during a sampling campaign conducted in Thailand in February 2016. The sampling campaign represents an important part of the project “Increasing Transparency in Industrial Pollution Management through Citizen Science.” This is a joint project of the Czech non-governmental organization Arnika Association and the Thai partner, Ecological Alert and Recovery – Thailand (EARTH). The main goals of the project are to increase the negotiating power of communities affected by industrial pollution in their demands for corporate and government accountability and to increase transparency in industrial pollution management policies and processes in Thailand. These goals include: 1) enabling communities affected by industrial pollution to generate scientific evidence, 2) broadening awareness about environmental and health damages from industrial pollution, and 3) promoting citizens’ right-to-know in Thailand and raise awareness on good practices of right-to-know legislation from the European Union, as a participatory mechanism for pollution reduction and prevention.

Tab. 1: Banned POPs in Thailand according to Department of Agriculture. "PH" means public health use, "AG" means agricultural use.

Chemicals	Date of ban	Reasons
Aldrin	1988	Persistent, accumulate in living organisms
Chlordane	1995 (PH), 2000 (AG)	Possible carcinogen, persistent, high impact to environment, many alternatives
DDT	1983 (AG), 1994 (PH)	Persistent and accumulation in food chains, possible carcinogen in tested animals
Dieldrin	1988	Persistent, accumulate in living organisms, high acute poisoning, high risk for users
Endrin	1981	Persistent in agricultural products and in food chain, harm to non-target organisms
Heptachlor	1988	Persistent, accumulate in living organisms
Hexachlorobenzene	1980	Never imported
Mirex	1995	Never imported
PCBs	2004	Risk to human health and the environment
Toxaphene	1983	Possible carcinogen in tested animals, persistent

2. Sampling

The majority of sampling was conducted in February 11-22, 2016. The sampling plan was designed in cooperation with Marek Šír, Martin Bystrianský, and Jindřich Petrlík. The field campaign served for inspection of the hotspot areas and collecting most of the organic (fish, mollusc, shellfish, and chicken eggs) and inorganic samples (soil, sediment, and ash). Additional samples were taken in February 2015 and February 2017. The background fish samples were taken in the Thap Lan National Park – representing an unpolluted area of Thailand – in February 2017. The background egg sample was bought in a supermarket in Bangkok in February 2016.

2.1 Map Ta Phut industrial complex

The Map Ta Phut industrial complex is a pollution hotspot located on the coast of the Gulf of Thailand, approximately 200 kilometres east of Bangkok. The industrial complex is situated in vicinity of the town Map Ta Phut in Mueang Rayong District (Rayong Province, Eastern Thailand). The district has a total land area of 514.5 km^2 and a registered population of 263,524 (as of 2014). An additional unregistered population of at least 90,185 (as of 2009) are mostly workers and their children from northeast Thailand and neighbouring countries. Population density is 687 persons per square kilometre, including the unregistered population.

The Map Ta Phut industrial complex is the country's largest industrial park and the world's 8th largest petrochemical industrial hub. Industrialization of Map Ta Phut has been carried out based on the policy to promote the Eastern Seaboard Development Plan since the early 1980s. It was founded in 1990 and the booming of the petrochemical industry lead to the expansion of the industrial complex. The expansion was done partly by changing parts of assigned buffer zones into industrial zones, and by land reclamation. It is managed by the Industrial Estate Authority of Thailand, a government agency under the Ministry of Industry. The industrial zone was touted as the most modern in the making. Locals were promised that there would be no pollution problems with its high standard of management and control. However, over three decades of industrial development have turned the area into the number-one toxic hotspot in Thailand. The Thai court declared Map Ta Phut and its surrounding areas as a “Pollution Control Zone” in 2009, requiring implementation of pollution reduction, but factories continue to expand.

The Map Ta Phut industrial complex consists of five industrial estates in a total area of approximately 30 square kilometres: Map Ta Phut Industrial Estate (16 km^2), Eastern Hemaraj Industrial Estate (5 km^2), Asia Industrial Estate (5 km^2), RIL Industrial Estate (3 km^2), and Pa Daeng Industrial Estate (1 km^2). According to the Department of Industrial Works, there are a total of 756 registered factories in the Mueang Rayong District and 189 of them are in the town Map Ta Phut. The list of registered factories in the town of Map Ta Phut comprises eight power plants, seventy-five chemical plants, eleven gas production plants or gas refineries, four oil refineries, nine steel production plants, and three plastic pellets production plants. Four of the eight power plants are coal-fired power plants: BLCP Power Co. (2 units with total capacity 1,400 MW), Gheco-One Co. (2 units with total capacity 1,400 MW), Glow Energy Public Co. (natural gas unit with capacity 478 MW and coal unit with capacity 120 MW), and Glow SPP 3 Co. (with capacity 240 MW). Moreover, there are twelve industrial ports – storage and transfer of crude oil, natural gas, LPG, coal, and pesticides. In addition, there are also over 500 unregistered factories outside industrial estates in the Mueang Rayong district.

There are four chlor-alkali production plants in the Map Ta Phut urban municipality, two of them in the Hemaraj Eastern Industrial Estate and two of them in the Map Ta Phut Industrial Estate. The chlor-alkali production plant of Aditya Birla Chemicals Co. is in the Eastern Hemaraj Industrial

Estate, producing liquid chlorine (74,520 tons per year) and epichlorohydrin. The factory area is 66,992 square metres. The chlor-alkali production plant of AGC Chemicals Co. is situated in the Eastern Hemaraj Industrial Estate and uses the electrolysis method at three production units. The factory area is 128,000 square metres. Vinythai Public Co. operates the third chlor-alkali production plant and a vinyl chloride plant, and a PVC plastic powder production plant in the Map Ta Phut Industrial Estate. There are four factories located in one area of 400,000 square metres. The Thai Plastic and Chemicals Co. establishes the last chlor-alkali production plant, a vinyl chloride monomer plant, and a polyvinyl-chloride plant.

There are several water streams flowing through and around the industrial complex. The main water streams are Chak Mak Canal, Bang Berd Canal, Huay Yai Canal, Lord Canal, and Ta Kuan Canal. These water streams receive discharged waste water from many facilities within the estates and are ultimately discharged into the Gulf of Thailand at the estates' southern edge. [14]

2.2 Samut Sakhon hotspot area

Samut Sakhon is located in central Thailand, and with a total area of 872.3 km^2 belongs to the one of the smallest provinces. It is part of the Bangkok Metropolitan Region. Neighbouring provinces are (from the southwest clockwise) Samut Songkhram, Ratchaburi, Nakhon Pathom, and Bangkok. Its total population is nearly 545,400 registered inhabitants, and the province is divided into 3 districts. The districts are further subdivided into 40 communes and 288 villages. It is a coastal province with a network of more than 170 canals flowing into the Tha Chin River and the Gulf of Thailand.

The local economy relies on industry, fishing, seafood processing, agriculture, and it is a leading province for sea salt production. Industrial activities in the studied area are represented mostly with high concentration of small-scale smelting and recycling factories and informal recycling of metal scrap and open burning that are located in Mueang Samut Sakhon district. This is a dense area of industrial growth and lax pollution control, with emerging impact on local workers and children, many of whom are found to have dangerously high lead levels in their blood.

The area is drained by several water streams, including the Ekkachai canal and the Bang Nam Chued canal. They are a tributary of the Tha Chin river. The river is a distributary of the Chao Phraya river. It splits near the province of Chai Nat and then flows west from the Chao Phraya through the central plains, until it empties into the Gulf of Thailand. The Tha Chin drains a total area of 13,681 square kilometres. The Tha Chin Basin is part of the Chao Phraya Watershed. The water quality of rivers flowing into the upper Gulf of Thailand has seriously deteriorated in the past decade. [15] Fish and cockle farming ponds on the coast are connected by a network of canals flowing into Tha Chin River and the Gulf of Thailand.

2.3 Tha Tum industrial complex

Tha Tum industrial complex is a pollution hotspot situated in the vicinity of the town of Tha Tum, 140 kilometres east of Bangkok. The industrial complex and the town Tha Tum is located in the sub district of Tha Tum, which is part of the Si Maha Phot District (Prachinburi Province, Eastern Thailand). The Tha Tum sub district consists of 10 villages within a radius of 5 km of the industrial area, with a registered population of 16,647 (as of December 2014).

Tha Tum industrial complex is the largest industrial park in Prachinburi Province. The industrial complex consists of 304 industrial parks and factories in its surroundings. There are several power plants, pulp and paper industries, and many other factories. According to the Department of

Industrial Works, there are a total of 163 registered factories in the Tha Tum sub district (as of September 2015). There are five power plants belonging to the National Power Supply Plc., with a total capacity of 658 MW. The first of them with a capacity of 328 MW uses a mix of bituminous coal and biomass (coal 85-90 % and biomass 10-15 %). The second one uses black liquor from a craft process in the pulp industry with a capacity of 32.9 MW. The other tree power plants use biomass as pieces of wood, bark and rice husk with a capacity of 297 MW in total. The pulp and paper industrial area of Double a Plc. covers over 1.6 square kilometres. The pulp industry area consists of five paper mills with total capacity 1,419,000 tons per year, a chlorine dioxide producing plant, a white liquor producing plant, lime kilns, two waste water plants (total capacity of 46,000 cubic meters per day). The 304 industrial parks and surroundings includes other industries as production of ethanol from cassava, production of corrugated cardboard, metal coating and machinery manufacturing, production of car engine parts, production of carbon copy paper, hard disk drive manufacturers, motorcycle parts manufacturing, and many others.

The area of the Tha Tum sub district is drained by a few water streams (Bang Pakong Canal, Hat Nang Kaeo Canal) to the Prachinburi River, laying 5.5 kilometres north from the industrial complex.

2.4 Pulp and Paper Industrial Area in Khon Kaen Province

One of biggest pulp and paper industrial areas in Thailand is located 30 kilometres north of the city of Khon Kaen. The city is the administrative centre of Khon Kaen Province (northeast Thailand) and is situated 450 kilometres northeast of Bangkok. The pulp and paper industrial area is surrounded by eleven villages in a radius of five kilometres. These villages belong to two sub districts: Kut Nam Sai (part of the Nam Phong District) and Khok Sung (Ubolratana District) and consist of 1,397 households. The pulp and paper industrial area alone is positioned in Kut Nam Sai sub district.

The pulp and paper industrial area established by Phoenix Pulp and Paper Plc. covers 1.9 square kilometres. Aside from factory space, there is also a waste landfill and eucalyptus forest on 6.6 square kilometres. The industrial area has two pulp and paper production lines with a total production capacity of 240,000 tons per a year. Within the area there are chemical plants, including a chlor-alkali production plant (20 tons of sodium hydroxide per day), a chlorine dioxide production plant (12 tons of chlorine dioxide per day), a sulphur dioxide production plant (0.6 tons of sulphur dioxide per day), and an oxygen production plant (13 tons of oxygen per day). There are also two power plants, a lime kiln, a waste incinerator (15,6 tons of ash per day), and a waste water treatment plant (8 tons of sludge per day) in the industrial area.

The area is drained by the water stream Chot flowing through the eucalyptus forest. The water stream is a tributary of the Phong River (Nam Phong) passing north of the area. The river is an important water resource in the northeast of Thailand, with an average width of about 70-80 meters and an average depth of 6-7 meters. The river water is used not only for community and municipal water supply, industry, agriculture and aquaculture, but also the river itself is a recipient of waste waters from communities and industries and run-off from agriculture. [16] The Phong River suffers from low dissolved oxygen levels due to waste water influx.

The Thai state, under the auspices of its development planning agencies, identified Khon Kaen as the centre of development growth of the northeast of Thailand in the 1970s. [17] Thus, the sitting of the Phoenix plant along the Phong River was clearly part of the state's broader program of regional development. The plant was established in 1982 and received privileges, such as reductions in business and corporate income taxes for a set period and expenditures on electricity, water supplies, and other infrastructure as a form of state support. [18] Throughout the 1990s, the pulp and paper

plant was repeatedly charged with polluting the Phong River and was ordered to halt production by the provincial governor, the Department of Industrial Works, the Pollution Control Department, or a combination of state agencies. [19]

2.5 Lists of samples

An inventory of inorganic and organic samples collected in the hotspot areas is listed in Tables 2 and 3, respectively.

Tab. 2: List of inorganic samples

Name	Matrix	Coordinates	Sampling Spot Description
Map Ta Phut hotspot			
MTP 1-1	Sediment	12°40'34.37"N 101°10'29.66"E	Huai Yai Canal; Waters from petrochemical industry
MTP 1-6	Sediment	12°40'10.98"N 101°10'46.70"E	Ta Kuan Canal
MTP 1-7	Sediment	12°41'30.89"N 101° 9'4.17"E	Chak Mak Canal; Chlor-alkali plant; Chemical plant; Coke plant
MTP 1-8	Sediment	12°40'10.95"N 101° 9'29.18"E	Chak Mak Canal; Chlor-alkali plant; Chemical plant; Coke plant
MTP 1-12	Sediment	12°40'40.75"N 101° 6'49.86"E	Sea; Sai Thong Beach
MTP 1-13	Sediment	12°40'44.52"N 101° 6'33.32"E	Bang Kraphrun Canal
MTP 1-14	Sediment	12°40'12.42"N 101° 9'37.71"E	Sea; 120-150m away from eastern canal; Chlor-alkali plant; Chemical plant; Coke plant; Government survey 300,000 t of this black mud in the bay
MTP 1-15	Sediment	12°41'26.22"N 101° 7'10.62"E	Bang Boet Canal; Chlor-alkali plant; Chemical plant
MTP 1-16	Sediment	12°41'23.50"N 101° 7'12.05"E	Bang Boet Canal; Chlor-alkali plant; Chemical plant
MTP 1-17	Sediment	12°40'43.67"N 101° 7'12.01"E	Bang Boet Canal; Chlor-alkali plant; Chemical plant

Name	Matrix	Coordinates	Sampling Spot Description
MTP 2-2	Sediment	12°45'32.06"N 101° 9'46.65"E	Canal Huai Phrao; upstream from RIL industrial estate
MTP 2-3	Sediment	12°44'3.23"N 101°10'7.09"E	Canal Huai Phrao; downstream from RIL industrial estate
MTP 2-5	Sediment	12°40'59.83"N 101° 9'46.08"E	East from Chak Mak Canal; Chlor-alkali plant; Chemical plant
MTP 2-6	Sediment	12°40'32.51"N 101° 9'27.05"E	Chak Mak Canal; Chlor-alkali plant; Chemical plant; Petrochemical and Refinery plant
MTP 2-6 (1)	Sediment	12°40'32.51"N 101° 9'27.05"E	Chak Mak Canal; Chlor-alkali plant; Chemical plant; Petrochemical and Refinery plant
MTP 2-14	Sediment	12°43'56.62"N 101° 6'1.24"E	Upstream Bang Kraphrun Canal
MTP 2-15	Sediment	12°43'17.11"N 101° 6'37.07"E	Upstream Chak Mak Canal
Samut Sakhon Hotspot Area			
SMS 1-1	Sediment	13°30'46.21"N 100°16'48.07"E	Tha Chin River mouth
SMS 1-3	Sediment	13°30'45.08"N 100°16'43.54"E	Tha Chin River mouth
SMS 1-5	Sediment	13°29'18.25"N 100°19'48.06"E	Luang Sahakon Canal
SMS 1-6	Sediment	13°29'14.99"N 100°20'2.39"E	Sea; 400 metres east from Luang Sahakon Canal
SMS 1-8	Sediment	13°29'24.40"N 100°21'21.01"E	Fish farm
SMS 1-8	Sediment	13°29'24.40"N 100°21'21.01"E	Fish farm

Name	Matrix	Coordinates	Sampling Spot Description
SMS 1-9	Sediment	13°29'44.68"N 100°21'21.22"E	Fish farm
SMS 1-10	Sediment	13°30'6.65"N 100°16'22.96"E	Tha Chin River mouth
SMS 1-11	Sediment	13°33'31.16"N 100°18'46.55"E	Luang Sahakon Canal
SMS 1-14	Sediment	13°37'33.61"N 100°21'36.54"E	Residential area; Metal smelting factory
SMS 2-2	Sediment	13°37'37.26"N 100°21'48.36"E	Residential area; (Metal smelting facilities)
SMS 2-6	Sediment	13°36'23.2"N 100°21'00.4"E	Soi Kong Phanan Phon Alley; (metal smelting; small industrial facilities; open burning of waste)
SMS 2-7	Sediment	13°36'29.16"N 100°20'48.24"E	Soi Kong Phanan Phon Alley; (metal smelting; small industrial facilities; open burning of waste)
SMS 2-10	Sediment	13°37'8.28"N 100°20'37.38"E	Soi Talab Thong 3 Alley; (metal smelting; small industrial facilities; open burning of waste)
SMS 2-11	Sediment	13°36'36.60"N 100°20'35.64"E	Ekkachai canal; (Metal smelting; Small industrial facilities; Open burning of waste)
SMS 2-12	Sediment	13°36'25.56"N 100°21'31.26"E	Bang Nam Chued Canal; (Metal smelting; Small industrial facilities; Open burning of waste)
A1	Ash	13°37'59.5"N 100°21'09.3"E	Soi Choed Mahachai 1 Alley; (small-scale brass smelting facility)
A2	Soil	13°36'21.8"N 100°20'49.1"E	Soi Kong Phanan Phon Alley □ Taweesup Recycling company; (metal smelting; small industrial facilities; open burning of waste)
A3	Soil	13°36'21.8"N 100°20'49.1"E	Soi Kong Phanan Phon Alley □ Taweesup Recycling company; (metal smelting; small industrial facilities; open burning of waste)
Tha Tum hotspot area			

Name	Matrix	Coordinates	Sampling Spot Description
TT 1-1	Sediment	13°57'2.74"N 101°35'52.07"E	Effluent pond; (Chemical plant; Pulp and paper industry; Coal power plant)
TT 1-2	Sediment	13°57'3.16"N 101°35'50.34"E	Klong Tha Fuek Canal; (Chemical plant; Pulp and paper industry; Coal power plant)
TT 1-3	Sediment	13°57'7.47"N 101°36'0.10"E	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant)
TT 1-4	Sediment	13°56'57.71"N 101°36'2.81"E	Supply water pond
TT 1-5	Sediment	13°55'11.60"N 101°34'59.99"E	Discharge water near wood chip plant;
TT 1-6	Sediment	13°55'28.26"N 101°35'17.08"E	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant)
TT 1-7	Sediment	13°56'17.25"N 101°35'42.39"E	Downstream of Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant)
TT 1-8	Sediment	13°55'19.76"N 101°36'32.05"E	Nong Kla Canal
TT 1-9	Sediment	13°57'50.48"N 101°36'2.96"E	Water stream in cattle pasture; (Chemical plant; Pulp and paper industry; Coal power plant)
TT 1-10	Sediment	13°57'44.11"N 101°36'46.99"E	Upstream Bang Pakong River
TT 1-11	Sediment	13°58'5.63"N 101°35'8.64"E	Downstream Bang Pakong River
TT 2-1	Sediment	13°54'1.34"N 101°34'48.15"E	Upstream Chalongwang Canal
S1	Sediment	13°57'52.0"N 101°36'02.9"E	near TT 1-9
S2	Sediment	13°55'28.4"N	near TT 1-6

Name	Matrix	Coordinates	Sampling Spot Description
		101°35'17.0"E	
S3	Sediment	13°55'55.6"N 101°35'34.6"E	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant; Coal stock pile)
S4	Sediment	13°55'45.1"N 101°36'19.1"E	Canal; South from supply water pond for industry
S5	Ash	13°45'23.6"N 101°36'40.5"E	Eucalyptus field
Khon Kaen Hotspot Area			
KK 3	Sediment	16°40'44.9"N 102°43'58.1"E	Chot canal; upstream from Paper and pulp industry; Coal power plant
KK 4	Sediment	16°42'6.04"N 102°44'18.61"E	Paper and pulp industry; Coal power plant; Taken from outflow (30 m) of wasted water reservoir; Water red- coloured probably caused by soil particles
KK 7	Sediment	16°43'46.1"N 102°43'21.7"E	Phong river upstream from industry; (Paper and pulp industry; Coal power plant)
KK 8	Sediment	16°43'23.5"N 102°44'52.3"E	Chot canal downstream from industry; (Paper and pulp industry; Coal power plant)
KK 9	Sediment	16°43'23.33"N 102°44'52.70"E	Pond; (Paper and pulp industry; Coal power plant)
KK 10	Sediment	16°43'39.6"N 102°45'04.7"E	Chot reservoir before enter Phong river; (Paper and pulp industry; Coal power plant)
KK 11	Sediment	16°43'37.3"N 102°45'01.3"E	Rice paddy near Chot reservoir
KK 13	Sediment	16°43'56.02"N 102°45'38.12"E	Phong river; (Paper and pulp industry; Coal power plant)
KK 5	Ash		

Tab. 3: List of organic samples

Sample code	Type of organic samples	Coordinates	Sampled Fish Latin Name Number of Subjects (n)	Sampled Fish Common Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age
Map Ta Phut hotspot area Rayong Province						
MTP 1-10/1	Fish	12°40'09.6"N 101°09'29.1"E	Belonidae n=1	Tek Lang – Needle Fish Carnivore	Sea coast; (Chloralki plant; Chemical plant; Coal Power plant)	94.5 cm; 86.5 cm; 1349 g; -
MTP 1-10/2	Fish	12°40'09.6"N 101°09'29.1"E	Belonidae n=1	Tek Lang – Needle Fish Carnivore	Sea coast; (Chloralki plant; Chemical plant; Coal Power plant)	38.5 cm; 33 cm; 733 g; -
MTP 2-1/1	Fish	12°45'32.06"N 101° 9'46.65"E	Channa striata n=1	Pla Chorn – Snakehead Omnivore	Canal Kvai Phrao; (Chlor-alkali plant; Chemical plant; Coal Power plant; Open burning of waste)	30 cm; 24.5 cm; 265 g; 1 year
MTP 2-1/2	Fish	12°45'32.06"N 101° 9'46.65"E	Trichogaster pectoralis n=1	Pla Salid – Snakeskin Gourami Omnivore	Canal Kvai Phrao; (Chlor-alkali plant; Chemical plant; Coal Power plant)	18.5 cm; 15.5 cm; 124 g; 1 year
MTP 2-8	Fish	12°40'58.76"N 101° 9'17.79"E	Clarias batrachus n=3	Pla Dook – Walking Catfish Omnivore	(Chlor-alkali plant; Chemical plant; Coal Power plant)	31/27.5/32.8 cm; 29/25/29.5 m; 249/192/232 g; -
MTP 2-9	Fish	12°40'58.76"N 101° 9'17.79"E	Clarias batrachus n=3	Pla Dook – Walking Catfish Omnivore	(Chlor-alkali plant; Chemical plant; Coal Power plant)	34.7/32.5/36 m; 31.5/29.5/31.5 m; 257/247/423 g; -
MTP-2017-1A+1B	Fish	12°39'02.2"N 101°10'40.0"E	Lutjanus johnii n=2	Pla Kapong - John's snapper	Sea coast; (Coal power plant, Chemical industry)	41/34 cm; 34/29 cm; 857/654 g; 1/1 year
MTP-2017-2	Fish	12°39'02.2"N	Dasyatis pastinaca	Pla Kraben – Stingray	Sea coast; (Coal power plant,	51 cm; 175 cm;

Sample code	Type of organic samples	Coordinates	Sampled Fish Latin Name Number of Subjects (n)	Sampled Fish Common Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age
		101°10'40.0"E	n=1	Carnivore	Chemical industry)	4065 g; 1 year
MTP-2017-3	Fish	12°38'23.0"N 101°09'24.0"E	Acanthopagrus berda n=1	Pla E-klud – Goldsilk Seabream	Sea coast; (Coal power plant, Chemical industry)	43 cm; 38 cm; 1315 g; 1 year
MTP-2017-5	Fish	12°38'08.5"N 101°07'23.8"E	Pomadasys kaakan n=1	Pla Kapong Samea – Javelin Grunter Carnivore	Sea coast; (Coal power plant, Chemical industry)	43 cm; 38 cm; 1140 g; 1 year
MTP-2017-8	Fish	12°40'30.5"N 101°10'29.5"E	Channa striata n=1	Pla Chorn – Snakehead Omnivore	Sea coast; (Coal power plant, Chemical industry)	35 cm; 29 cm; 465 g; 1 year
MTP 1-4	Mollusc	12°40'11.0"N 101°10'46.7"E	Perna viridis n=1	Asian green mussel	Sea coast; (Chloralki plant; Chemical plant; Coal Power plant)	□
MTP 1-3	Crustacean	12°40'11.0"N 101°10'46.7"E	Scylla serrata n=3	Mud Crab/ Black Crab	Sea coast; (Chloralki plant; Chemical plant; Coal Power plant)	□
MTP 1-5	Crustacean	12°40'11.0"N 101°10'46.7"E	Thalamita crenata n=3	Spiny Rock Crab	Sea coast; (Chloralki plant; Chemical plant; Coal Power plant)	□
MTP 1-9	Crustacean		Scylla serrata n=3	Mud Crab/ Mangrove Crab/ Black Crab	Sea coast; (Chloralki plant; Chemical plant; Coal Power plant)	□
MTP 2-18	Egg	12°41'11.44"N 101° 6'56.74"E	n=3		Habitat; (Chloralki plant; Chemical plant; Coal Power plant)	□
MTP 2-19	Egg	12°41'9.64"N 101° 6'54.22"E	n=3		Habitat; (Chloralki plant; Chemical plant; Coal Power plant)	□

Sample code	Type of organic samples	Coordinates	Sampled Fish Latin Name Number of Subjects (n)	Sampled Fish Common Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age
MTP 1-11	Egg		n=4			□
Samut Sakhon hotspot area						
SMS1-12/1,2	Fish					
SMS 1-12/1-(1-2)	Fish	13°29'44.68"N 100°21'21.22"E	Polynemidae n=2	Pla Kulao - Threadfins	Fish farm;	
SMS 1-12/2-(1-2)	Fish	13°29'44.68"N 100°21'21.22"E	Ambassidae n=2	Pla Kao Mao - Asiatic glassfish	Fish farm;	
SMS 1-12/3	Fish	13°29'44.68"N 100°21'21.22"E	Sillago sihana n=1	Pla Sai - Silver Sillago	Fish farm;	
SMS 1-2/1-3	Fish	13°30'48.19"N 100°16'39.27"E	Mugilidae n=3	Pla Kra Bok - Mullets or Grey Mullets	Tha Chin river	
SMS 2F	Fish	13°35'42.82"N 100°19'55.17"E	Channa striata n=1	Pla Chorn – Snakehead Omnivore	Ekkachai canal; (Metal smelting; Small industrial facilities; Open burning of waste)	28 cm; 24 cm; 178 g; -
SMS 2-13	Egg	13°36'29.16"N 100°20'46.07"E	n=3		Residential area; (Metal smelting; Small industrial facilities; Open burning of waste)	□
Samut Sakhon	Egg	13°37'33.5"N 100°21'36.1"E	n=3		Residential area; (informal metal-scrap recycling and open burning)	□
Tha Tum hotspot area □ Prachinburi Province						
TT 2-8	Fish	13°57'51.0"N 101°36'03.2"E	Channa striata n=1	Pla Chorn – Snakehead Omnivore	Chalongwang Canal; (Chemical plant; Pulp and	29 cm; 25.5 cm; 211 g; 0-1 year

Sample code	Type of organic samples	Coordinates	Sampled Fish Latin Name Number of Subjects (n)	Sampled Fish Common Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age
					paper industry; Coal power plant)	
TT 2-6	Fish	13°55'17.57"N 101°35'10.12"E	Oreochromis niloticus n=3	Pla Nil – Nile Tilapia Omnivore	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant)	17.5/17/20 cm; 13.5/13.8/16.2 cm; 114/101/151 g; 0-1/0-1/0-1 year
TT 2-9	Mollusc	13°55'27.78"N 101°35'16.59"E	Phylloda foliacea	Hoi Karb - Clam	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant)	□
Tha Thum	Egg	13°56'01.9"N 101°35'45.2"E	n=4		Residential area; (Chemical plant; Pulp and paper industry; Coal power plant)	□
Khon Kaen hotspot area						
KK 12/1	Fish	16°43'16.61"N 102°45'4.36"E	*Barbonymus gonionotus* n=1	Pla Thapian – Silver Barb Omnivore	Canal; (Pulp and paper and pulp industry; Coal power plant)	19.2cm; 16.2 cm; 142 g; -
KK 14/1	Fish	16°43'16.61"N 102°45'4.36"E	*Hampala macrolepidota* n=2	Pla Kasoop Kit – Hampala Barb Omnivore	Reservoir; (Pulp and paper industry; Coal power plant)	20.5/21 cm; 17.1/17; 121/127 g; 1 year
KK 14/2	Fish	16°43'16.61"N 102°45'4.36"E	*Channa micropeltes* n=1	Pla Chado – Giant snakehead Carnivore	Reservoir; (Pulp and paper industry; Coal power plant)	16.8 cm; 14.9 cm; 49 g; 1 year
KK 1	Egg	16°41'38.61"N 102°44'14.66"E				□
KK 1/1	Egg		n=2			□
KK 1/2	Egg		n=3			□
Bangkok and Thap Lan National Park in Prachinburi Province						
PRN-2017-1	Fish	14°12'19.4"N 101°55'15.2"E	*Channa striata* n=1	Pla Chorn – Snakehead Omnivore	Water reservoir, Thap Lan National Park	44 cm; 38 cm; 586 g; 0-1 year

Sample code	Type of organic samples	Coordinates	Sampled Fish Latin Name Number of Subjects (n)	Sampled Fish Common Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age
PRN-2017-2	Fish	14°14'24.9"N 101°53'02.8"E	*Oxyeleotris marmorata* n=2	Pla Boo – Marble Goby Carnivore	Klong Yang Canal	23/22 cm; 20/18 cm; 156/127 g; 0-1/0-1 year
PRN-2017-3A+3B	Fish	14°12'19.4"N 101°55'15.2"E	*Oreochromis niloticus* n=2	Pla Nil – Nile Tilapia Omnivore	Water reservoir, Thap Lan National Park	41/37 cm; 34/29 cm; 1349/1238 g; 1/1 year
Control group, supermarket	Egg		n=6			

3. Analysis

Inorganic samples - soil, sediment, and ash – were analysed for content of PCDD/Fs, dioxin-like PCBs (DL PCBs) seven indicate congeners of PCBs (∑ 7 PCBs), chlorobenzenes (HCB, TeClB, 1,2,3,4-TeClB, QClB), organochlorine pesticides (HCH, DDT, heptachlor, heptachlor epoxide, endosulfan, dieldrin, endrin, aldrin, octachlorstyrene, chlordan, oxychlordane, methoxychlor, mirex), and polycyclic aromatic hydrocarbons (PAHs). Organic samples – fish, mollusc, selfish, and chicken eggs – were analysed for content of PCDD/Fs, DL PCBs, ∑ 7 PCBs, chlorobenzenes (HCB, PeCB), hexachlorobutadiene (HCBD), organochlorine pesticides (HCH, DDT), polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD), and other brominated flame retardants (BFRs).

For content of PCDD/Fs and DL PCBs inorganic and organic samples were analysed by the high-resolution gas chromatography/high-resolution mass spectrometry at the accredited laboratories of Axys-Varilab,s.r.o. in Vrané nad Vltavou and at the State Veterinary Institute, both located in Prague, Czech Republic. Some organic samples (fish and shellfish) were analysed for PCDD/Fs and DL PCBs using the DR CALUX method. [20] These were sent to the Dutch ISO 17025 certified laboratory BioDetection Systems B.V. in Amsterdam, Netherlands. DR CALUX analysis results comply with EU requirements, as indicated in the Commission Regulation (EC) No 252/2012. Analysis for the content of ∑ 7 PCBs in inorganic and organic samples was conducted by high-resolution gas chromatography/high-resolution mass spectrometry at accredited laboratory Axys-Varilab, s.r.o. in Vrané nad Vltavou, and by gas chromatography coupled with tandem mass spectrometry in accredited laboratory of University of Chemistry and Technology, Department of Food Chemistry and Analysis, both located in Prague, Czech Republic.

Inorganic and organic samples were analysed for the content of chlorobenzenes (HCB and PeCB), HCBD, and organochlorine pesticides (HCH, DDT, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin) by gas chromatography coupled with tandem mass spectrometry at the accredited laboratory of the University of Chemistry and Technology, Department of Food Chemistry and Analysis in Prague, Czech Republic. Some inorganic samples were analysed for chlorobenzenes (HCB, TeClB, 1,2,3,4-TeClB, and QClB) and organochlorine pesticides (HCH, DDT, aldrin, oktachlorstyren, chlordan, oxychlordan, metoxychlor, and mirex) by gas chromatography with electron capture detector at the accredited laboratory of the State Veterinary Institute in Prague, Czech Republic.

In some organic samples (fish and chicken eggs) the content of PBDEs and other brominated flame retardants (BFRs) were analysed by gas chromatography coupled with tandem mass spectrometry and the content of HBCD was analysed by ultra-high-pressure liquid chromatography, coupled with tandem mass spectrometry both at the accredited laboratory of the University of Chemistry and Technology, Department of Food Chemistry and Analysis in Prague, Czech Republic. Content of PAHs in inorganic and organic samples was analysed by high-resolution gas chromatography/high-resolution mass spectrometry at the accredited laboratory of Axys-Varilab s.r.o. in Vrané nad Vltavou, Czech Republic. Some inorganic samples were analysed for PAHs by the high-resolution liquid chromatography with fluorescence detection at the accredited laboratory of the University of Chemistry and Technology, Department of Food Chemistry and Analysis in Prague, Czech Republic. One chicken egg sample was also analysed for content of polybrominated dibenzo-p-dioxins and polybrominated dibenzofurans (PBDD/Fs) by the high-resolution gas chromatography/high-resolution mass spectrometry analysis at the Dutch ISO 17025 certified laboratory BioDetection Systems B.V. in Amsterdam, Netherlands.

Tab. 4: Levels of detection in inorganic matrices (sediment, soil, and ash)

Compounds	**Level of detection**
PCBs (each of 7 indicating congeners)	0,05 µg/kg
PAHs (each of 16 homologues)	0,5 µg/kg
Organochlorine pesticides and chlorobenzenes (HCB, TeClB, 1,2,3,4-TeClB, QClB, HCH, DDT, heptachlor, heptachlor epoxide, endosulfan, dieldrin, endrin, aldrin, oktachlorstyren, chlordan, oxychlordan, metoxychlor, mirex)	0,05 µg/kg

4. Results

Results of chemical analyses of PCBs, organochlorine pesticides (HCB, HCH, DDT, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin), and naphthalene in sediments from the Map Ta Phut hotspot are presented in Table 5. Levels of all the contaminants in inorganic matrices except naphthalene are under the level of detection (<LOD). Table 6 shows results of chemical analyses of various POPs in organic samples (fish, mollusc, crustacean, and eggs) from the Map Ta Phut hotspot. There are measurable levels of PCDD/Fs, PCBs, chlorobenzenes (HCB, PeCB), HCBD, organochlorine pesticides (DDTs, HCH), brominated flame retardants (PBDEs, HBCD, and others), and PAHs in organic matrices from the hotspot.

Results of analytical measurement of PCBs, organochlorine pesticides (HCB, HCH, DDT, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin), and napthalene in sediments from the Samut Sakhon hotspot are presented in Table 7. All concentrations of the contaminants except naphthalene are under the level of detection (<LOD). Results of chemical analyses of various POPs in fish and eggs from the Samut Sakhon hotspot are shown in Table 8. There are measurable levels of PCDD/Fs, PCBs, DDTs, and PAHs in fish and eggs from this hotspot. Moreover, there are also measurable concentrations of PBDD/Fs, chlorobenzenes (HCB, PeCB), HCBD, HCH, and PBDEs in at least one sample of eggs from Samut Sakhon.

Table 9 shows results of chemical analyses of various POPs (PCDD/Fs, PCB, chlorobenzenes, organochlorine pesticides, and PAHs) in inorganic samples (sediment and ash) from the Tha Tum hotspot area. Measurable values of PCDD/Fs, PCBs, and PAHs are detected in some sediment samples. Few sediment samples show measurable values of HCB and/or DDTs and one sample of sediment shows measurable value of mirex. Results of chemical analyses of PCDD/Fs, PCBs, chlorobenzenes (HCB, PeCB), HCBD, and organochlorine pesticides (HCHs and DDTs) in organic matrices (two fish, one mollusc, and one egg) from Tha Tum are shown in Table 10. Concentrations of all measured POPs in the fish samples from Tha Tum are under the level of quantification (<LOQ). The egg sample has measurable concentrations of PCDD/Fs, PCBs, HCB, HCHs, and DDTs, while the mollusc sample has measurable concentrations of HCB and DDTs.

Results of chemical analyses of PCDD/Fs, PCBs, organochlorine pesticides (HCB, HCHs, DDTs, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin), and PAHs in samples of sediments and one sample of ash from the Khon Kaen hotspot area are presented in Table 11. All levels of the contaminants in sediment samples are under the level of detection (<LOD). The sample of ash has measurable concentrations of PCDD/Fs, PCBs, and PAHs. The table 12 shows results of chemical analyses of various POPs (PCDD/Fs, PCBs, HCB, PeCB, HBCD, HCHs, DDTs, PAHs) in organic samples (fish and eggs) from the Khon Kaen hotspot. The fish samples only show measurable levels of DDTs. The egg samples show measurable levels of PCDD/Fs, PCBs, HCB, HCHs, DDTs, and PAHs.

In Tables 6, 8, and 10, show the results of CALUX bioassays to specify effects of PCDD/Fs and PCDD/Fs + DL PCBs in organic samples from the Map Ta Phut, the Samut Sakhon, and the Tha Tum hotspot areas. All treated samples are compliant and some of them are also under the level of quantification (<LOQ).

Tab. 5: Results of inorganic samples from Map Ta Phut hotspot area. Complete results are listed in the annex.

Name	Matrix	∑ 7 PCBs[1)] [µg/kg DW]	HCB [µg/kg DW]	∑ 3 HCHs[2)] [µg/kg DW]	∑ DDTs[3)] [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide[4)] [µg/kg DW]	Endosulfan[5)] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	Napthalene [µg/kg DW]
MTP 1-13	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.5**
MTP 1-16	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.5**
MTP 1-17	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**1.7**
MTP 2-3	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.6**
MTP 2-5	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.7**
MTP 2-6	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.6**

[1)] ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.
[2)] ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[3)] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.
[4)] Heptachlor epoxide is sum of isomers cis and trans.
[5)] Endosulfan is sum of isomers α-endosulfan and β-endosulfan.

Tab. 6: Results of organic samples from Map Ta Phut hotspot area

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg fat]	DL PCBs [ng WHO-TEQ/kg fat]	PCDD/Fs DR CALUX [ng BEQ/kg]	PCDD/Fs + DL PCBs DR CALUX [ng BEQ/kg]	∑ 6 PCBs[1] [µg/kg fat]	∑ 7 PCBs[2] [µg/kg fat]	HCB [µg/kg fat]	PeCB [µg/kg fat]	HCBD [µg/kg fat]	∑ 3 HCHs[3] [µg/kg fat]	∑ DDTs[4] [µg/kg fat]	∑ 16 PBDEs[5] [µg/kg fat]	∑ HBCDs[6] [µg/kg fat]	∑ 6 BFRs[7] or ∑ 5 BFRs[8] [µg/kg fat]	∑ 16 PAHs[9] or ∑ 12 PAHs[10] [µg/kg fat]
MTP 1-10/1	fish	NA	NA	NA	**0.12**	**550.06**	**550.06**	<LOQ	**9.62**	<LOQ	<LOQ	**176.67**	**646.77**	**36.0**	<LOQ[7]	NA
MTP 1-10/2	fish	**0.1**	**0.001**	NA	NA	<LOQ	<LOQ	<LOQ	**20.16**	<LOQ	<LOQ	**52.67**	<LOQ	**86.6**	<LOQ[7]	**104**[9]
MTP 2-1/1	fish	NA	NA	NA	**0.15**	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	**292.3**	<LOQ	**54.2**	<LOQ[7]	NA
MTP 2-1/2	fish	NA	NA	NA	**0.15**	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	**113.54**	**36.49**	**19.6**	<LOQ[7]	NA
MTP 2-8	fish	NA	NA	NA	**1.9**	**19.57**	**19.57**	**45.84**	**2.47**	**2.47**	**3.04**	**27.58**	**49.88**	**9.8**	<LOQ[7]	NA
MTP 2-9	fish	**0.4**	**0.28**	NA	NA	**59.67**	**59.67**	**64.7**	**29.08**	**2.68**	**5.34**	**24.90**	**94.28**	**7.1**	<LOQ[7]	**77**[9]
MTP-2017-1A+1B	fish	NA	NA	NA	NA	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	**20**	NA	NA	NA	**14.67**[10]
MTP-2017-2	fish	NA	NA	NA	NA	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	**31.62**	<LOQ	**34.19**[7]	**5.98**[10]

MTP-2017-3	fish	NA	NA	NA	NA	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	**11.94**	<LOQ	<LOQ	<LOQ[7)]	**19.4**[10)]
MTP-2017-5	fish	NA	NA	NA	NA	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ[7)]	**375**[10)]
MTP-2017-8	fish	NA	NA	NA	NA	NA	NA	NA	**4.55**	<LOQ	NA	NA	NA	NA	NA	**33.33**[10)]
MTP 1-4	mollusc	**0.7**	**0.05**	NA	NA	<LOQ	<LOQ	<LOQ	**0.6**	<LOQ	<LOQ	**2.55**	NA	NA	NA	**1710**[9)]
MTP 1-3	crustacean	<LOQ	**8**	0.3 (<LOQ)	0.6 (<LOQ)	**15.17**	**17.57**	NA	NA	NA	NA	NA	NA	NA	NA	**1210**[9)]
MTP 1-5	crustacean	<LOQ	**0.2**	0.1 (<LOQ)	0.2 (<LOQ)	**17.2**	**20.1**	NA	NA	NA	NA	NA	NA	NA	NA	**4900**[9)]
MTP 1-9	crustacean	**12.2**	**51.69**	**0.56**	**0.67**	**30.4**	**35.5**	NA	NA	NA	NA	NA	NA	NA	NA	**2310**[9)]
MTP 2-18	egg	**0.8**	**0.73**	NA	NA	**0.95**	**1.11**	**4.01**	<LOQ	<LOQ	**1.77**	**19.25**	**1.09**	**40.68**	**0.34**[8)]	**280**[9)]
MTP 2-19	egg	**2.3**	**0.95**	NA	NA	**3.54**	**4.46**	**6**	<LOQ	<LOQ	**1.68**	**8.43**	**3.3**	**166.81**	**0.27**[8)]	**198**[9)]
MTP 1-11	egg	**0.5**	**1.61**	NA	NA	**0.5**	**0.64**	**4.43**	<LOQ	<LOQ	**6.25**	**8.35**	**44.95**	**185.55**	**0.76**[8)]	**1152**[9)]

[1)] ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
[2)] ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.
[3)] ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[4)] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.
[5)] ∑ 16 PBDEs is sum of BDE 28, BDE 47, BDE 49, BDE 66, BDE 85, BDE 99, BDE 100, BDE 153, BDE 154, BDE 183, BDE 196, BDE 197, BDE 203, BDE 206, BDE 207, and BDE 209.
[6)] ∑ HBCDs is sum of isomers α-HBCD, β-HBCD, and γ-HBCD.
[7)] ∑ 6 BFRs is sum of BTBPE, DBDPE, HBB, OBIND, PBEB, and PBT.
[8)] ∑ 5 BFRs is sum of BTBPE, DBDPE, HBB, OBIND, and PBEB.

[9] ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.
[10] ∑ 12 PAHs is sum of phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

Tab. 7: Results of inorganic samples from Samut Sakhon hotspot area. Complete results are listed in the annex.

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 6 PCBs[1] [µg/kg DW]	∑ 7 PCBs[2] [µg/kg DW]	HCB [µg/kg DW]	∑ 3 HCHs[3] [µg/kg DW]	∑ DDTs[4] [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide[5] [µg/kg DW]	Endosulfan[6] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	Napthalene [µg/kg DW]	∑ 16 PAHs[7] [µg/kg DW]
SMS 1-11	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**1.4**	NA
SMS 1-14	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.5**	NA
A3	soil	**35.2**	**5.72**	**1.2**	**7.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA	**1747**
A2	soil	**12.8**	**0.001**	**1.06**	**1.06**	NA	NA	NA	NA	NA	NA	NA	NA	NA	**488**
A1	ash	**1.9**	**0.27**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**3210**

[1] ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
[2] ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.
[3] ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[4] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.
[5] Heptachlor epoxide is sum of isomers cis and trans.
[6] Endosulfan is sum of isomers α-endosulfan and β-endosulfan.
[7] 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

Tab. 8: Results of organic samples from Samut Sakhon hotspot area

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg fat]	PBDD/Fs [ng WHO-TEQ/kg fat]	DL PCBs [ng WHO-TEQ/kg fat]	PCDD/Fs + DL PCBs DR CALUX [ng BEQ/kg]	∑ 6 PCBs[1] [µg/kg fat]	∑ 7 PCBs[2] [µg/kg fat]	HCB [µg/kg fat]	PeCB [µg/kg fat]	HCBD [µg/kg fat]	∑ 3 HCHs[3] [µg/kg fat]	∑ DDTs[4] [µg/kg fat]	∑ 16 PBDEs[5] [µg/kg fat]	∑ 5 BFRs[6] [µg/kg fat]	∑ 16 PAHs[7] [µg/kg fat]	∑ 4 PAHs[8] [µg/kg fresh] EU
SMS1-12/1,2	fish	NA	NA	NA	0.1 (<LOQ)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SMS 1-12/1-(1-2)	fish	NA	NA	NA	NA	**112.21**	**112.21**	<LOQ	NA	NA	<LOQ	**81.87**	NA	NA	NA	NA
SMS 1-12/2-(1-2)	fish	NA	NA	NA	NA	**31.02**	**31.02**	<LOQ	NA	NA	<LOQ	**37.35**	NA	NA	NA	NA
SMS 1-12/3	fish	NA	NA	NA	NA	**43.25**	**43.25**	<LOQ	NA	NA	<LOQ	**39.12**	NA	NA	NA	NA
SMS 1-2/1-3	fish	**0.2**	NA	**0.05**	NA	**6.77**	**6.77**	<LOQ	NA	NA	<LOQ	**17.28**	NA	NA	**48**	NA
SMS 2F	fish	<LOQ	NA	**0.08**[9]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**1.3**
SMS 2-13	egg	**6.2**	NA	**6**	NA	**7.08**	**8.07**	NA	**1.49**	<LOQ	NA	NA	NA	NA	**2730**	NA
Samut Sakhon	egg	**84.04**	**15.8**	**11.67**	NA	**11.4**	**12.97**	**4.21**	NA	NA	**0.31**	**2.85**	**3.1**	<LOQ	NA	NA

[1] ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
[2] ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.
[3] ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[4] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

[5] ∑ 16 PBDEs is sum of BDE 28, BDE 47, BDE 49, BDE 66, BDE 85, BDE 99, BDE 100, BDE 153, BDE 154, BDE 183, BDE 196, BDE 197, BDE 203, BDE 206, BDE 207, and BDE 209.
[6] ∑ 5 BFRs is sum of BTBPE, DBDPE, HBB, OBIND, and PBEB.
[7] ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene , indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, dibenzo(a,h)anthracene.
[8] ∑ 4 PAHs is sum of benzo(a)anthracene, chrysene, benzo(b)fluoranthene, and benzo(a)pyrene.
[9] Value is in ng WHO-TEQ/kg fresh weight.

Tab. 9: Results of inorganic samples from Tha Tum hotspot area. Complete results are listed in the annex.

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 6 PCBs[1] [µg/kg DW]	∑ 7 PCBs[2] [µg/kg DW]	HCB [µg/kg DW]	TeClB [µg/kg DW]	1,2,3,4-TeClB [µg/kg DW]	QClB [µg/kg DW]	∑ 3 HCHs[3] [µg/kg DW]	∑ DDTs[4] [µg/kg DW]	Heptachlor [µg/kg DW]	Aldrin [µg/kg DW]	Oktachlorstyren [µg/kg DW]	Heptachlor epoxide[5] [µg/kg DW]	Chlordan[6] [µg/kg DW]	Oxychlordan [µg/kg DW]	Metoxychlor [µg/kg DW]	Mirex [µg/kg DW]	Endosulfan[7] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	∑ 16 PAHs[8] [µg/kg DW]
TT1-11	sediment	NA	NA	**0.28**	**0.28**	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
S1	sediment	**1.6**	**0.013**	<LOD	<LOD	**0.23**	<LOD	<LOD	<LOD	<LOD	**0.44**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA	**137**
S2	sediment	**1.27**	**0.026**	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA	**631**
S3	sediment	**3.76**	**0.022**	NA	NA	**0.22**	<LOD	<LOD	<LOD	<LOD	**0.14**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.32**	NA	NA	NA	**576**
S4	sediment	**0.22**	**0.048**	NA	NA	**0.30**	<LOD	<LOD	<LOD	<LOD	**2.2**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA	**85**
S5	ash	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**6683**

[1] ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
[2] ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.
[3] ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[4] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.
[5] Heptachlor epoxide is sum of isomers cis and trans.
[6] Chlordan is sum of isomers cis and trans.
[7] Endosulfan is sum of isomers α-endosulfan and β-endosulfan.

[8)] 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

Tab. 10: Results of organic samples from Tha Tum hotspot area

Name	**Matrix**	**PCDD/Fs [ng WHO-TEQ/kg fat]**	**DL PCBs [ng WHO-TEQ/kg fat]**	**PCDD/Fs + DL PCBs DR CALUX [ng BEQ/kg]**	**∑ 6 PCBs[1)] [µg/kg fat]**	**∑ 7 PCBs[2)] [µg/kg fat]**	**HCB [µg/kg fat]**	**PeCB [µg/kg fat]**	**HCBD [µg/kg fat]**	**∑ 3 HCHs[3)] [µg/kg fat]**	**∑ DDTs[4)] [µg/kg fat]**
TT 2-8	Fish	NA	NA	0.1 (<LOQ)	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
TT 2-6	Fish	NA	NA	NA	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
TT 2-9	mollusc	NA	NA	NA	<LOQ	<LOQ	**2**	**0.8**	<LOQ	<LOQ	**4.35**
Tha Thum	Egg	**4.27**	**3.94**	NA	**0.39**	**0.39**	**1.51**	NA	NA	**0.23**	**0.83**

[1)] ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
[2)] ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.
[3)] ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[4)] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

Tab. 11: Results of inorganic samples from Khon Kaen hotspot area. Complete results are listed in the annex.

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 6 PCBs[1)] [µg/kg DW]	∑ 7 PCBs[2)] [µg/kg DW]	HCB [µg/kg DW]	∑ 3 HCHs[3)] [µg/kg DW]	∑ DDTs[4)] [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide[5)] [µg/kg DW]	Endosulfan[6)] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	∑ 16 PAHs[7)] [µg/kg DW]
KK 5	ash	**0.9**	**1.04**	**0.29**	**0.33**	NA	NA	NA	NA	NA	NA	NA	NA	**310**

[1)] ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
[2)] ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.
[3)] ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[4)] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.
[5)] Heptachlor epoxide is sum of isomers cis and trans.
[6)] Endosulfan is sum of isomers α-endosulfan and β-endosulfan.
[7)] ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

Tab. 12: Results of organic samples from Khon Kaen hotspot area

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg fat]	DL PCBs [ng WHO-TEQ/kg fat]	∑ 6 PCBs[1)] [µg/kg fat]	∑ 7 PCBs[2)] [µg/kg fat]	HCB [µg/kg fat]	PeCB [µg/kg fat]	HCBD [µg/kg fat]	∑ 3 HCHs[3)] [µg/kg fat]	∑ DDTs[4)] [µg/kg fat]	∑ 16 PAHs[5)] [µg/kg fat]
KK 12/1	Fish	NA	NA	<LOQ	<LOQ	<LOQ	NA	NA	<LOQ	<LOQ	NA
KK 14/1	Fish	NA	NA	<LOQ	<LOQ	<LOQ	NA	NA	<LOQ	**9.08**	NA
KK 14/2	Fish	NA	NA	<LOQ	<LOQ	<LOQ	NA	NA	<LOQ	**18.61**	NA
KK 1	Egg	**1.5**	**0.83**	**1**	**1.16**	NA	NA	NA	NA	NA	**3985**
KK 1/1	Egg	NA	NA	NA	NA	**5.52**	<LOQ	<LOQ	**1.53**	**10.06**	NA
KK 1/2	Egg	NA	NA	NA	NA	**5.24**	<LOQ	<LOQ	**2.34**	**20.43**	NA

[1)] ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
[2)] ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.
[3)] ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[4)] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.
[5)] ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene , indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, dibenzo(a,h)anthracene.

Tab. 13: Results of background organic samples (supermarket in Bangkok and Thap Lan National Park)

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg fat]	DL PCBs [ng WHO-TEQ/kg fat]	PCDD/Fs + DL PCBs DR CALUX [ng BEQ/kg]	∑ 6 PCBs[1)] [µg/kg fat]	∑ 7 PCBs[2)] [µg/kg fat]	HCB [µg/kg fat]	PeCB [µg/kg]	HCBD [µg/kg]	∑ 3 HCHs[3)] [µg/kg]	∑ DDTs[4)] [µg/kg fat]	∑ 16 PBDEs[5)] [µg/kg fat]	∑ HBCDs[6)] [µg/kg fat]	∑ 6 BFRs[7)] [µg/kg]	∑ 16 PAHs[8)] or ∑ 12 PAHs[9)] [µg/kg fat]
PRN-2017-1	Fish	NA	NA	NA	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	**51.28**	<LOQ	<LOQ	<LOQ	**28.21[9)]**
PRN-2017-3A+3B	Fish	NA	NA	NA	NA	NA	<LOQ	NA	NA	<LOQ	**47.62**	<LOQ	<LOQ	<LOQ	NA
PRN-2017-2	Fish	NA	NA	NA	<LOQ	<LOQ	NA	<LOQ	<LOQ	NA	NA	NA	NA	NA	NA
Control group, supermarket	Egg	**0.1**	**0.001**	**9.04**	**0.22**	**0.22**	<LOQ	<LOQ	<LOQ	**0.52**	<LOQ	**3.1**	<LOQ	<LOQ	**233[8)]**

[1)] ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
[2)] ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.
[3)] ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[4)] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.
[5)] ∑ 16 PBDEs is sum of BDE 28, BDE 47, BDE 49, BDE 66, BDE 85, BDE 99, BDE 100, BDE 153, BDE 154, BDE 183, BDE 196, BDE 197, BDE 203, BDE 206, BDE 207, and BDE 209.
[6)] ∑ HBCDs is sum of isomers α-HBCD, β-HBCD, and γ-HBCD.
[7)] ∑ 6 BFRs is sum of BTBPE, DBDPE, HBB, OBIND, PBEB, and PBT.
[8)] ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.
[9)] ∑ 12 PAHs is sum of phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

5. Discussion

The POPs concentrations determined in the samples could be compared with background levels and pollution criteria. These values could be helpful to discuss and evaluate our results. The measured background levels of POPs in fish and eggs are presented in Table 13, as background levels can be instrumental, as well as literature data of POPs. In the report conducted at the large brackish Songkhla Lake and the Gulf of Thailand concentrations of DDTs (sum of p,p'-DDT, p,p'-DDE, and p,p'-DDD) were measured in 113 fish of four species (*Scatophagus argus*, *Protosus canius*, *Channa striata*, and *Zonichthys nigrofasciata*). The mean DDTs concentrations at different locations in the analysed fish species ranged from 33 to 170 µg/kg fat. [21] Levels of HCB, HCHs, DDTs, and PCBs in foodstuffs were investigated in Bangkok in 1991 [22]. Levels of these contaminants in five fish species from the investigation are shown in Table 14. Levels of organochlorine pesticides and PCBs in sediments collected from the east coast of Thailand were reported in 2014. [23] The mean concentrations of contaminants from nine sampling sites are shown in Table 15.

Tab. 14: Levels of organochlorine pesticide and PCBs in fish bought at fish markets in Bangkok [22].

	n	Fat [%]	Σ PCBs [µg/kg fat]	Σ 4 HCHs[1)] [µg/kg fat]	Σ 4 DDTs[2)] [µg/kg fat]	HCB [µg/kg fat]
Red-tail finfoil barb (*Puntius altus*)	3	8.5	27	9.8	110	11
Catfish (*Clarias batrachus*)	3	11	18	7.9	130	0.91
Sneak-head fish (*Ophiocephalus striatus*)	3	1.9	110	18	150	3.3
Nile tilapia (*Tilapia nilotica*)	3	1.6	63	88	140	1.3
Climbing perch (*Anabas testudineus*)	3	3.3	30	20	70	1.8

[1)] Σ 4 HCHs is sum of isomers α-HCH, β-HCH, γ-HCH, and δ-HCH.
[2)] Σ 4 DDTs is sum of p,p'-DDT, o,p'-DDT, p,p'-DDE, and p,p'-DDD.

Tab. 15: Range of organochlorine pesticide and PCBs levels in sediment samples from nine sampling sites at the east coast of Gulf of Thailand in 2013 [23]. "ND" means not detected.

Σ PCBs[1)] [µg/kg DW]	Σ 3 HCHs[2)] [µg/kg DW]	Σ 4 DDTs[3)] [µg/kg DW]	HCB [µg/kg DW]
0.04-3.03	ND-0.78	0.11-2.6	0.02-0.22

[1)] ∑ PCBs is sum of 22 PCBs congeners.
[2)] Σ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[3)] Σ 4 DDTs is sum of p,p'-DDT

The pollution criteria of POPs for sediments and soils are presented in Table 16. Aside from Thai pollution criteria, American and Czech pollution criteria were used for the comparison and as a substitution for missing criteria of some contaminants. There are two types of pollution criteria for sediments in Thailand. The first one is for the purpose of benthic animals' protection and the second for the purpose of human health protection. As the second one is expressed only in units of microgram per kilogram of total organic carbon, we did not measure the content of organic carbon in sediment samples, only the first one's criteria expressed in micrograms per kilogram of dry weight of sediment can be used in discussion. Different Thai pollution criteria for soils are used for agricultural and habitat soils rather than for soils with other purposes. Since soil samples were not collected from agricultural soil or from wildlife habitats, the pollution criteria for soils with other purposes were applied. Pollution criteria for sediments and soils in the Czech Republic and for soils in the USA are also of two area types - residential and industrial. As sediment and soil samples were collected mostly at borderline communities and not located directly in industrial areas, pollution criteria for residential areas were applied.
, o,p'-DDT, p,p'-DDE, and p,p'-DDD.

Tab. 16: Pollution criteria for sediments and soils in Thailand, United States, and Czech Republic.

Chemical compound	Sediments				Soils			
	Thai[10)]		Czech[11)]		Thai[12)]		Czech/USA[11)]	
	For the protection of benthic animals	To protect humans via the food chain	Resident area	Industrial area	Agricultural and Habitat	Other purposes	Resident soil	Industrial soil
2,3,7,8-TCDD[1)]	none	none	4,5 ng/kg DW	18 ng/kg DW	none	none	4,5 ng/kg DW	18 ng/kg DW
∑ HxCDDs[2)]	none	none	94 ng/kg DW	390 ng/kg DW	none	none	94 ng/kg DW	390 ng/kg DW
∑ PCBs[3)]	60 µg/kg DW	none	none	None	2200 µg/kg DW	10 000 µg/kg DW	none	none
Single congener of PCB	none	none	110 µg/kg DW	380 µg/kg DW	none	none	110 µg/kg DW	380 µg/kg DW
∑ 6 PCBs[4)]	none	none	220 µg/kg DW	740 µg/kg DW	none	none	220 µg/kg DW	740 µg/kg DW
Chlordane	3 µg/kg DW	35 µg/kg TOC	none	None	16 000 µg/kg DW	110 000 µg/kg DW	none	none
Dieldrin	2 µg/kg DW	16.5 µg/kg TOC	30 µg/kg DW	110 µg/kg DW	300 µg/kg DW	1500 µg/kg DW	30 µg/kg DW	110 µg/kg DW
∑ DDTs[5)]	5 µg/kg DW	24 µg/kg TOC	none	None	17 000 µg/kg DW	120 000 µg/kg DW	none	none
DDTs[6)]			1 700 µg/kg DW	7 000 µg/kg DW			1 700 µg/kg DW	7 000 µg/kg DW
DDEs[7)]	none	none	1 400 µg/kg DW	5 100 µg/kg DW	none	none	1 400 µg/kg DW	5 100 µg/kg DW
DDDs[8)]	none	none	2 000 µg/kg DW	7 200 µg/kg DW	none	none	2 000 µg/kg DW	7 200 µg/kg DW
Endrin	2 µg/kg DW	360 µg/kg TOC	18 000 µg/kg DW	180 000 µg/kg DW	none	none	18 000 µg/kg DW	180 000 µg/kg DW
Heptachlor epoxide	2.5 µg/kg DW	1.5 µg/kg TOC	53 µg/kg DW	190 µg/kg DW	500 µg/kg DW	2700 µg/kg DW	53 µg/kg DW	190 µg/kg DW
α-HCH	none	none	77 µg/kg DW	270 µg/kg DW	none	none	77 µg/kg DW	270 µg/kg DW

β-HCH	none	none	270 µg/kg DW	960 µg/kg DW	none	none	270 µg/kg DW	960 µg/kg DW
γ-HCH	2.5 µg/kg DW	11 µg/kg TOC	520 µg/kg DW	2100 µg/kg DW	4400 µg/kg DW	29 000 µg/kg DW	52 µg/kg DW	2100 µg/kg DW
Aldrin	none	10 µg/kg TOC	29 µg/kg DW	100 µg/kg DW	none	none	29 µg/kg DW	100 µg/kg DW
Endosulfan	none	2900 µg/kg TOC	370 000 µg/kg DW	3 700 000 µg/kg DW	none	none	370 µg/kg DW	3700 µg/kg DW
Heptachlor	none	3 µg/kg TOC	110 µg/kg DW	380 µg/kg DW	1100 µg/kg DW	5500 µg/kg DW	110 µg/kg DW	380 µg/kg DW
Mirex	none	0.5 µg/kg TOC	27 µg/kg DW	96 µg/kg DW	none	none	27 µg/kg DW	96 µg/kg DW
Metoxychlor	none	none	310 000 µg/kg DW	3 100 000 µg/kg DW	none	none	310 000 µg/kg DW	3 100 000 µg/kg DW
HCB	none	490 µg/kg TOC	300 µg/kg DW	1100 µg/kg DW	none	none	300 µg/kg DW	1100 µg/kg DW
∑ PAHs[9)]	1600 µg/kg DW	none	none	None	none	none	none	none
Naphthalene	none	none	3600 µg/kg DW	18000 µg/kg DW	none	none	3600 µg/kg DW	18000 µg/kg DW
Acenaphthene	none	none	3400000 µg/kg DW	33000000 µg/kg DW	none	none	3400000 µg/kg DW	33000000 µg/kg DW
Fluorene	none	none	2300000 µg/kg DW	22000000 µg/kg DW	none	none	2300000 µg/kg DW	22000000 µg/kg DW
Anthracene	none	none	17000000 µg/kg DW	170000000 µg/kg DW	none	none	17000000 µg/kg DW	170000000 µg/kg DW
Fluoranthene	none	none	2300000 µg/kg DW	22000000 µg/kg DW	none	none	2300000 µg/kg DW	22000000 µg/kg DW
Pyrene	none	none	1700000 µg/kg DW	17000000 µg/kg DW	none	none	1700000 µg/kg DW	17000000 µg/kg DW
Benz(a)antracene	none	1080 µg/kg TOC	150 µg/kg DW	2100 µg/kg DW	none	none	150 µg/kg DW	2100 µg/kg DW
Chrysene	none	108000 µg/kg TOC	15000 µg/kg DW	210000 µg/kg DW	none	none	15000 µg/kg DW	210000 µg/kg DW
Benzo(b)fluoranthene	none	none	150 µg/kg DW	2100 µg/kg DW	none	none	150 µg/kg DW	2100 µg/kg DW

Benzo(k)fluoranthene	none	none	1500 µg/kg DW	21000 µg/kg DW	none	none	1500 µg/kg DW	21000 µg/kg DW
Benzo(a)pyrene	none	110 µg/kg TOC	15 µg/kg DW	210 µg/kg DW	600 µg/kg DW	2900 µg/kg DW	15 µg/kg DW	210 µg/kg DW
Indeno(1,2,3,-c,d)pyrene	none	none	150 µg/kg DW	2100 µg/kg DW	none	none	150 µg/kg DW	2100 µg/kg DW
Dibenz(a,h)anthracene	none	none	15 µg/kg DW	210 µg/kg DW	none	none	15 µg/kg DW	210 µg/kg DW

[1)] 2,3,7,8-TCDD is 2,3,7,8-tetrachlorodibenzodioxin.
[2)] ∑ HxCDDs is sum of dibenzo-p-dioxin congeners with six chlorine atoms.
[3)] ∑ PCB is sum of all 209 congeners of PCB.
[4)] ∑ 6 PCB is sum of PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
[5)] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.
[6)] ∑ DDTs is sum of p,p'-DDT and o,p'-DDT.
[7)] ∑ DDEs is sum of p,p'-DDE and o,p'-DDE.
[8)] ∑ DDDs is sum of p,p'-DDD and o,p'-DDD.
[9)] ∑ PAHs is sum of benz(a)anthracene, benzo(a)pyrene, and chrysene.
[10)] Sediment in Surface Water Quality Criteria in Thailand (Draft Regulation)
[11)] Methodical instruction of Czech Ministry of Environmental Affairs: Indicators of contamination 2013.
[12)] Notification of National Environmental Board No. 25, B.E. (2004) issued under the Enhancement and Conservation of National Environmental Quality Act B.E.2535 (1992) published in the Royal Government Gazette No. 121 Special Part 119 D dated October 20, B.E.2547(2004).

Maximum residue limits of organochlorine pesticides and maximum levels of PCBs and PCDD/Fs for organic samples are presented in Table 17. In addition to Thai maximum limits of POPs, the European and Czech maximum limits were used for the comparison and as a substitution for missing limits of some contaminants. Thai maximum limits of POPs in foodstuffs are established just for some organochlorine pesticides and not for other contaminants such as PCBs and PCDD/Fs, but they are applicable for all kinds of organic samples designated as foodstuff. According to the Thai Agricultural Standard (TAS 9003 – 2004) extraneous maximum residue limits is issued just as a voluntary standard. European and Czech legislation introduced legally-mandated obligatory maximum levels of PCBs and PCDD/Fs in eggs, fish, and crustaceans and maximum residue levels of organochlorine pesticides in eggs. Unfortunately, maximum levels of organochlorine pesticides in fish and crustaceans are missing in the European Union. There are only voluntary maximum residue levels of organochlorine pesticides in fish in the Czech Republic. In the European Union and the Czech Republic, maximum levels of POPs in molluscs are not established at all[1].

1 There is only a maximum level of PAHs for smoked molluscs in the European Union.

Tab. 17: Maximum residue limits of organochlorine pesticides and maximum levels of PCB and PCDD/F for eggs, fish, molluscs, and crustaceans in Thailand, European Union, and Czech Republic.

Chemical compound	Eggs		Fish			Molluscs		Crustaceans	
	Thai	EU/Czech	Thai	EU	Czech	Thai	EU/Czech	Thai	EU/Czech
PCDD/F	none	2.5 ng WHO-TEQ/kg fat[4)]	none	3.5 ng/kg fresh[4)]		none	none	none	3.5 ng/kg fresh[4)]
PCDD/F + DL PCB	none	5 ng WHO-TEQ/kg fat[4)]	none	6.5 ng/kg fresh[4)]		none	none	none	6.5 ng/kg fresh[4)]
∑ 6 PCB[1)]	none	40 µg/kg fat[4)]	none	marine 75 µg/kg fresh[4)] freshwater 125 µg/kg fresh[4)]		none	none	none	75 µg/kg fresh[4)]
∑ 4 DDTs[2)]	100 µg/kg fresh[3)]	50 µg/kg fresh[5)]	1000 µg/kg fat[3)]	none	500 µg/kg fresh or 5000 µg/kg fat[7)]	1000 µg/kg fat[3)]	none	1000 µg/kg fat[3)]	none
HCB	<LOD[6)]	20 µg/kg fresh[5)]	<LOD[6)]	none	50 µg/kg fresh or 500 µg/kg fat[7)]	<LOD[6)]	none	<LOD[6)]	none
α-HCH	none	20 µg/kg fresh[5)]	none	none	none	none	none	none	none
β-HCH	<LOD[6)]	10 µg/kg fresh[5)]	<LOD[6)]	none	none	<LOD[6)]	none	<LOD[6)]	none
γ-HCH	<LOD[6)]	10 µg/kg fresh[5)]	<LOD[6)]	none	50 µg/kg fresh or 500 µg/kg fat[7)]	<LOD[6)]	none	<LOD[6)]	none
HCH (β + α)	none	none	none	none	20 µg/kg fresh or 200 µg/kg fat[7)]	none	none	none	none

[1)] ∑ 6 PCB is sum of PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
[2)] ∑ 4 DDTs is sum of p,p'-DDT, o,p'-DDT, p,p'-DDE, and p,p'-DDD.
[3)] Thai: Pesticide Residues: Extraneous Maximum Residue Limits (EMRL), Thai Agricultural Standard (TAS 9003 – 2004).
[4)] EU: Commission Regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs.

[5)] EU: Commission Regulation (EC) No 149/2008 of 29 January 2008 amending Regulation (EC) No 396/2005 of the European Parliament and of the Council by establishing Annexes II, III and IV setting maximum residue levels for products covered by Annex I.
[6)] Thai: Pesticide Residues: Maximum Residue Limits (MRL), Thai Agricultural Standard (TAS 9002 – 2016).
[7)] Czech: Edict no. 381/2007 about assignation of Maximum Residue Limits of pesticides in food and feedstock.

5.1 Map Ta Phut industrial complex

Levels of PCBs and organochlorine pesticides (HCB, HCHs, DDTs, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin) in all sediment samples from the Map Ta Phut area are under the level of detection. This conclusion indicates generally low residue levels of organochlorine pesticides and PCBs in sediments from the Map Ta Phut area and is also consistent with very low or zero PCBs and pesticide (DDTs, HCB, and HCHs) concentrations found in sediments along the east coast of Gulf of Thailand in 2013 (table 15). Contrary to our conclusion, research conducted by Greenpeace Research Laboratories found trace levels of highly chlorinated compounds, such as PeCB and HCB, in the water streams flowing through the industrial complex in 2004. These chlorinated compounds can be formed as by-products of industrial processes involving chlorine compounds. They are highly persistent in the environment and many of them are able to accumulate in the bodies of animals and humans. [14] Six samples (MTP 1-13, MTP 1-16, MTP 1-17, MTP 2-3, MTP 2-5, MTP 2-6) showed relatively low levels of naphthalene (from 0.5 to 1.7 μg/kg DW) and were collected from water canals flowing through the industrial complex. The naphthalene concentrations were safely under the criteria for sediments at residential areas in the Czech Republic.

Ten fish samples collected in the hotspot area (MTP 1-10/1, MTP 1-10/2, MTP 2-1/1, MTP 2-1/2, MTP 2-8, MTP 2-9, MTP-2017-1, MTP-2017-2, MTP-2017-3, MTP-2017-5) were analysed for content of HCBD and organochlorine pesticides (HCB, PeCB, HCHs, and DDTs) and one more fish sample (MTP-2017-8) was analysed for content of HCBD and PeCB. Concentrations of HCB, PeCB, HCBD, and HCHs in fish samples from the hotspot area are higher than background levels in fish from Thap Lan National Park (Table 13) in two, four, two, and two cases, respectively. Two fish samples (MTP 2-8 and MTP 2-9) have HCB and HCHs concentrations higher than the Thai maximum residue limits[2]. The occurrence of HCB, PeCB, HCBD, and HCHs is probably caused by industrial facilities operated in the hotspot area, particularly by several chlorine production plants.

Only two fish samples have DDTs concentrations under the level of quantification. Three fish samples (MTP 1-10/1, MTP 2-1/1, and MTP 2-1/2) have one order of magnitude higher DDTs concentrations (176.67, 292.3, 113.54 μg/kg fat) than the background DDTs levels in fish from Thap Lan National Park (51.28 and 47.62 μg/kg fat), but have same order of magnitude as certain fish samples from the large brackish Songkhla Lake (up to 170 μg/kg fat) [21] and fish bought at fish markets in Bangkok (up to 150 μg/kg fat) [22]. All fish samples from the hotspot area are safely under the maximum residue limits in Thailand and the Czech Republic. The occurrence of DDTs is probably residue of pesticide usage in the past. This assumption is supported by the fact that the most common DDT isomer (metabolite) residue in the samples is p.p'-DDE. The ratio of p,p´-DDE /DDT is an indicator of whether the DDT observed was recently released, or had been emitted into the environment in the past. [24]

Ten fish samples collected in the hotspot area (MTP 1-10/1, MTP 1-10/2, MTP 2-1/1, MTP 2-1/2, MTP 2-8, MTP 2-9, MTP-2017-1, MTP-2017-2, MTP-2017-3, MTP-2017-5) were analysed for content of indicator congeners of PCBs (I-PCBs) and two of them (MTP 1-10/2, MTP 2-9) for content of PCDD/Fs and DL PCBs. Just three fish samples (MTP 1-10/1, MTP 2-8, and MTP 2-9) have measurable concentrations of I-PCBs (550.06, 19.57, and 59.67 μg/kg fat) that are also higher than PCBs levels in fish from Thap Lan National Park (under the level of quantification). Measurable but relatively low concentrations of PCDD/Fs and DL PCBs were found in both of the analysed samples. After the conversion on fresh weight, the concentrations of six indicate PCBs congeners, PCDD/Fs, and PCDD/Fs + DL PCBs in the analysed fish samples are under the maximal levels for fish in the European Union and the Czech Republic (Table 17). Dioxins can be formed as

2 Thai maximum residue levels of HCB, β-HCH, and γ-HCH in fish are levels of detection.

an unintentional by-product in chlor-alkali and VCM plants. This assumption is supported by the fact that the fish with measurable PCDD/Fs levels were caught in the Chak Mak Canal or in its mouth to the sea. The canal is flowing around two factories producing chlorine, whose waste waters are probably discharged into the canal. All the fish samples with measurable PCBs levels in the hotspot area were caught in the Chak Mak Canal; therefore, there is probably a source of PCBs around the canal.

Brominated compounds (PBDEs, HBCDs, and BFRs) were analysed in nine fish samples from the hotspot area (MTP 1-10/1, MTP 1-10/2, MTP 2-1/1, MTP 2-1/2, MTP 2-8, MTP 2-9, MTP-2017-2, MTP-2017-3, MTP-2017-5). Concentrations of PBDEs, HBCDs, and BFRs in the fish samples from the hotspot area are measurable and also higher than the levels in the fish from Thap Lan National Park (under the level of quantification) in five, six, and one case respectively. Seven fish samples collected in the hotspot area (MTP 1-10/2, MTP 2-9, MTP-2017-1, MTP-2017-2, MTP-2017-3, MTP-2017-5, and MTP-2017-8) were analysed for content of PAHs. All the samples have PAHs concentrations in the same order of magnitude or the one order of magnitude higher than the sample from the background locality in Thap Lan National Park (28.21 µg/kg fat). A significant PAHs contamination was not found in the fish from the Map Ta Phut.

The one sample of mussels (***Perna viridis***) from the hotspot area (MTP 1-4) was analysed for content of PCDD/Fs, PCBs, organochlorine pesticides (HCB, PeCB, HCHs, DDTs), HCBD, and PAHs. The temporal comparison of PCBs and organochlorine pesticide levels in mussels from coastal areas of Thailand is summarized in Table 18. The levels of PCBs and organochlorine pesticides in mussels in our study are lower than those found in previous studies. Moreover, according to the literature, the levels of organochlorine pesticides in mussels from Thailand are relatively lower than those in developed nations. [25] The mussel sample complies to Thai maximum residue limits for organochlorine pesticides. From that reasons, organochlorine pesticides in the hotspot area does not represent significant contamination of mussels. The mussel sample has measurable levels of PCDD/Fs, DL PCBs, and PeCB indicating certain contamination by chlorinated compounds. It can be caused by pollution from industrial sources, especially from the chlorine- using or producing plants in the industrial complex. Concentrations of PAHs were measured in molluscs (***Ostrea pliculata***, ***Perna viridis***, and ***Amusium pleuronectes***) collected in the Upper Gulf of Thailand in 1982. The concentrations reported in the cited study indicated the presence of low levels of PAHs in water of the Upper Gulf. PAHs detected included: acenaphthylene, benzo(a)pyrene, fluoranthene, phenanthrene, methylphenanthrene, and triphenylene. Benzo(a)pyrene was present in all species, at concentrations varying from 1.0 to 8.2 µg/kg fresh. [26] Concentrations of PAHs in the mussel sample from the Map Ta Phut hotspot area were mostly under the level of quantification with exception of naphthalene and phenanthrene. The benzo(a)pyrene concentration in our sample (less than 10 µg/kg fresh) does not significantly exceed the level from the cited study.

Tab. 18: Concentrations of organochlorine pesticides and PCBs in mussels (Perina viridis) from coastal areas of Thailand. "NA" means not analysed.

Year of sampling	Number of sampling sites	∑ PCBs[1)] [µg/kg fresh]	∑ DDTs[2)] [µg/kg fresh]	∑ 3 HCHs[3)] [µg/kg fresh]	HCB [µg/kg fresh]	Reference
1979	4	2 - 43	32 - 42	NA	NA	[27]
1989	9	NA	0.39–7.41	< 0.02–0.19[4)]	< 0.02–0.31	[28]
1994 – 1995	16	< 0.01 - 20	1.2 - 38[5)]	< 0.01 - 0.33	< 0.01 - 0.12	[26]
2002 – 2003	8	1.69 (0.32 - 3.7)	2.55 (1.17 - 3.86)	0.3 (< 0.01 - 0.49)	0.06 (< 0.01 - 0.10)	[29]
2016	1	< 0.35[6)]	0.13	< 0.15	< 0.05	This study

[1)] ∑ PCBs is sum of all PCB congeners.
[2)] ∑ 6 DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.
[3)] ∑ 3 HCHs is sum of α-HCH, β-HCH, and γ-HCH.
[4)] This value is sum of α-HCH and γ-HCH.
[5)] This value is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, and p,p'-DDD.
[6)] This value is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

Contents of PCDD/Fs, PCBs, and PAHs were determined in three samples of crustaceans collected in the hotspot area (MTP 1-3, MTP 1-5, and MTP 1-9). Measurable levels of PCBs, and PAHs have been found in all three samples, but only one sample shows measurable level of PCDD/Fs. After the conversion on fresh weight, the concentrations of six indicate PCBs congeners, PCDD/Fs, and PCDD/Fs + DL PCBs in the analysed crustacean samples are under the maximal levels in the European Union and the Czech Republic (Table 17). Dioxins and PCBs pollution can be caused by industry sources, particularly by the chlorine-using or producing plants in the industrial complex.

Three egg samples from the vicinity of the industrial complex (MTP 2-18, MTP 2-19, and MTP 1-11) were analysed for content of PCDD/Fs, PCBs, organochlorine pesticides (HCB, PeCB, HCHs, and DDTs), HCBD, PAHs, and brominated compounds (PBDEs, HBCDs, and BFRs). Concentrations of PCDD/Fs, PCBs, HCB, HCHs, DDTs, HBCDs, and BFRs in all the egg samples from the hotspot area are higher than the levels in the background egg sample bought in the supermarket in Bangkok (Table 13). Concentrations of PBDEs and PAHs in egg samples significantly exceed the background levels in one sample (MTP 1-11). Concentrations of PeCB and HCBD in the egg samples are under level of quantification, as well as the background levels. Concentrations of HCB in all three egg samples are higher than the maximum residue limit in Thailand[3]. All the egg samples have lower concentrations of PCDD/Fs, PCBs, DDTs, HCB, and HCHs than maximal levels in eggs tolerable for the European market (table 17), but concentrations of PCDD/Fs and DL PCBs are relatively high in all three egg samples. One egg sample (MTP 2-19) has more than 90 % of the maximum level of PCDD/Fs in the European Union and the Czech Republic. Dioxins and PCBs can be formed as an unintentional by-product in industries producing and using chlorine that are located in the industrial complex.

5.2 Samut Sakhon hotspot area

Levels of PCBs and organochlorine pesticides (HCB, HCHs, DDTs, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin) in all sediment samples from Samut Sakhon are under the level of detection. This conclusion indicates generally low residue levels of organochlorine pesticides and PCBs in sediments collected in the area. Two samples (SMS 1-11 and SMS 1-14) showed relatively low levels of naphthalene (1.4 and 0.5 µg/kg DW) and were collected from a water canal and from a dried pond near metal smelting factories. The naphthalene concentrations were safely under the criteria for sediments at residential areas in the Czech Republic.

Two soil samples (A2 and A3) collected form the hotspot area were analysed for content of PCDD/Fs, PCBs, and PAHs. Concentrations of PCDD/Fs, PCBs, and PAHs indicate contamination from some industrial source. The PCDD/Fs and PCBs levels in the samples are under the pollution criteria for soils in Thailand, the United States, and the Czech Republic, but concentration of the most toxic dioxin 2,3,7,8-TCDD at locality A3 (1.5 ng/kg DW) reaches up to 33 % of pollution criteria for soils on resident area in the United States and the Czech Republic. Both samples have also relatively high concentrations of PAHs with levels of benzo(a)pyrene (23 and 27 µg/kg DW) higher than the pollution criteria for soils in the United States and the Czech Republic (15 µg/kg DW). The ash sample (A1) from the hotspot area contains measurable concentrations of PCDD/Fs (1.9 ng WHO-TEQ/kg DW), DL PCB (0.27 ng WHO-TEQ/kg DW), and PAHs (3210 µg/kg DW) indicating industrial source of contamination. Soil and ash sample contamination is likely caused due to a vicinity of “recycling” factories.

Four fish samples from the hotspot area (SMS 1-12/1, SMS 1-12/2, SMS 1-12/3, SMS 1-2) analysed for content of organochlorine pesticides expose HCHs and HCB concentrations lower than level of quantification and measurable levels of DDTs. Fish samples from the background locality

3 Thai maximum residue level of HCB in eggs is a level of detection.

(Thap Lan National Park in Table 13) show same pattern: HCB and HCHs concentrations lower than level of quantification and measurable levels of DDTs. Moreover, the DDTs levels in the fish samples from the hotspot area (17.28 – 81.87 μg/kg fat) are in the same order of magnitude as fish samples from the background locality (47.62 – 51.28 μg/kg fat). In comparison with concentrations of organochlorine pesticide in fish bought at fish markets in Bangkok in 1991 (table 14), the levels of organochlorine pesticides in fish from the hotspot area are lower. Concentrations of DDTs in fish samples from the hotspot area are safely under the maximum residue limits in Thailand and the Czech Republic. These findings mean that organochlorine pesticide burden in the hotspot area does not expose considerable contamination.

The same four fish samples were analysed for content of six I-PCBs. Levels of these PCBs congeners in fish samples from the hotspot area (6.77 – 112.21 μg/kg fat) were considerably higher than in fish samples from the background locality (under the level of quantification), but were in a similar range as PCB concentrations in fish samples bought at fish markets in Bangkok in 1991 (27 – 110 μg of unspecified PCBs congeners /kg fat). Detected PCBs contamination in the fish samples could be explained by residues from PCBs usage before its ban in 2004, and partially by unintentional PCBs production by combustion sources (small metallurgical plants, and open burning of waste at some locations) in the hotspot area. The analysed fish samples were collected from the Tha Chin River and from ponds on the seashore, and not in a direct vicinity of small facilities handling waste, therefore the influence of industries cannot be directly responsible for the contamination. Levels of six indicate PCBs congeners in the fish samples (0.13 – 0.38 μg/kg fresh after the conversion) were safely under the maximal PCBs level in the European Union and the Czech Republic (40 μg/kg fresh). Two fish samples (SMS 1-2 and SMS 2F) were analysed for content of PCDD/Fs and one of them (SMS 1-2) has a measurable PCDD/Fs level (0.2 ng WHO-TEQ/kg fat). The positive sample collected from the Tha Chin River was under the maximum PCDD/Fs level in the European Union and the Czech Republic (3.5 ng WHO-TEQ/kg fat). PCDD/Fs contamination of sample can be explained by unintentional production in a factory using chlorine and dumping waste water in Tha Chin River near the sampling point.

Two egg samples collected in the hotspot area contain unsafe levels of POPs. The first egg sample (SMS 2-13) was analysed for content of PCDD/Fs, PCBs, PeCB, HCBD, and PAHs. Concentrations of all the analysed contaminants in the sample except a concentration of HCBD (under the level of quantification) exceed levels in the background egg sample bought in the supermarket in Bangkok (Table 13). Both the concentrations of PCDD/Fs (6.2 ng WHO-TEQ/ kg fat) and PCDD/Fs + DL PCBs (12.2 ng WHO-TEQ/ kg fat) are two folds higher than the maximal levels in eggs tolerable for the European market (Table 17). The contamination of the egg sample by PCDD/Fs and DL PCBs could originate from waste burning in small waste “recycling” facilities placed nearby a household where the hens are kept. This conclusion is supported by presence of other contaminants such as PeCB and PAHs that could be produced by waste burning and/or small metallurgical facilities. Furthermore, this hypothesis is supported by fact that residues of burned waste were found on a courtyard of the household. The second egg sample (notation: Samut Sakhon) was analysed for content of PCDD/Fs, polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs), PCBs, HCB, HCHs, DDTs, PBDEs, and BFRs. Concentrations of HCHs, PBDEs, and BFRs in the sample are lower or same as levels in the background egg sample bought in the supermarket in Bangkok (table 13) and other contaminants (PCDD/Fs, PCBs, HCB, and DDTs) in the sample exceed these levels. Concentrations of β-HCH (0.31 μg/kg fat) and HCB (4.21 μg/kg fat) are higher than the maximum residue limits for eggs in Thailand[4]. The concentrations of PCDD/Fs (84.04 ng WHO-TEQ/kg fat) and PCDD/Fs + DL PCBs (95.71 ng WHO-TEQ/kg fat) are 33 folds and 19 folds higher, respectively, than the maximal egg levels tolerable for the European market (Table 17). Additionally, the concentration of PBDD/Fs (15.8 ng

4 Thai maximum residue levels of HCB and β-HCH in eggs are levels of detection.

WHO-TEQ/kg fat) without the maximal tolerable levels at all poses additional risk for human health. The contamination of the second egg sample can be caused by breeding hens around a small a waste “recycling” facility placed nearby burning waste, including e-waste. Both the egg samples are seriously unsafe for human consumption due to the content of PCDD/Fs, DL PCBs, and PBDD/Fs.

5.3 Tha Tum industrial complex

The first group of twelve sediment samples (TT 1-1, TT 1-2, TT 1-3, TT 1-4, TT 1-5, TT 1-6, TT 1-7, TT 1-8, TT 1-9, TT 1-10, TT 1-11, and TT 2-1) collected in the hotspot area in February 2016 were analysed for content of PCBs and organochlorine pesticides (HCHs, DDTs, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin). All samples from the first group have concentrations of all measured contaminants are under the level of detection, except for one sample (TT 1-11) that has a very low level of the I-PCBs (0.28 µg/kg DW). The pollution criteria for sediments in Thailand and the Czech Republic are not exceeded in any of the sediment samples from the group.

The second group of four sediment samples (S1, S2, S3, and S4) collected in the hotspot area in February 2015 were analysed for content of PCDD/Fs, PCBs, PAHs, organochlorine pesticides (HCHs, DDTs, heptachlor, heptachlor epoxide, aldrin, oktachlorstyren, chlordan, oxychlordan, metoxychlor, and mirex), and chlorobenzenes (HCB, TeClB, 1,2,3,4-TeClB, QClB). Concentrations of organochlorine pesticides and chlorobenzenes were mostly under the levels of detection, but three samples (S1, S3, and S4) show measurable levels of HCB and DDTs and one sample (S3) shows measurable levels of mirex (0.32 µg/kg DW). The occurrence of HCB and mirex is surprising, because these pesticides have never been imported or used in Thailand according to the National Implementation Plan. The presence of HCB in the sediments can be explained by unintentional production from the industrial facilities in the hotspot area. This assumption is supported by content of PCDD/Fs and DL PCBs in same samples. All these contaminants are produced unintentionally in chemical processes (bleaching of paper) or during incineration of fuels, including coal containing chlorine (power plants). Concentrations of PAHs in soil samples were in a common range, but one sample (S3) has a concentration of dibenzo(a,h)anthracene (37 µg/kg DW) higher than the Czech pollution criteria for sediments in a residential area (15 µg/kg DW).

The only ash sample (S5) collected 30 km south from the Tha Tum industrial area at a eucalyptus plantation was analysed for content of PAHs. Concentrations of PAHs in the ash sample were in a common range typical for ash, but has a relatively high concentration of benzo(a)pyrene (76 µg/kg DW).

Concentrations of PCBs, HCB, PeCB, HBCD, HCHs, and DDTs in two fish samples collected in water canals in the hotspot area (TT 2-8 and TT 2-6) are under the levels of quantification and both the fish samples comply with the Thai, Czech, and European maximal residue levels. One sample of freshwater mussels was collected in a water canal in the hotspot area. Concentrations of PCBs, HCBD, and HCHs in the mussel sample are under the levels of quantifications and the concentrations of HCB, DDTs, and PeCB in this sample are measurable. Moreover, the HCB concentration in mussels exceeds the maximal residue level in Thailand[5]. While occurrence of DDTs is probably residue of pesticide usage in the past, the presence of HCB and PeCB could be caused by variety of industrial facilities operated in the industrial area, particularly by bleaching of paper in the pulp and paper plant.

5 Thai maximum residue level0 of HCB in eggs is a level of detection.

The one egg sample (notation: Tha Thum) collected in the hot spot area contains dangerous levels of POPs. The sample was analysed for content of PCDD/Fs, PCBs, and organochlorine pesticides (HCB, HCHs, DDTs). While concentrations of I-PCBs (0.39 µg/kg fat) and HCHs (0.23 µg/kg fat) in the sample are the same order of magnitude as levels in the background egg sample bought in the supermarket in Bangkok (Table 13), the concentrations of PCDD/Fs, DL PCBs, HCB, and DDTs in the sample exceed background levels. Concentrations of β-HCH (0.23 µg/kg fat) and HCB (1.51 µg/kg fat) in the egg sample are higher than the maximum residue limits for eggs in Thailand[6]. Both the concentrations of PCDD/Fs (4.27 ng WHO-TEQ/ kg fat) and PCDD/Fs + DL PCBs (8.21 ng WHO-TEQ/ kg fat) are significantly higher than the maximal levels for eggs tolerable in the EU (table 17). The egg sample is unsafe for human consumption due to the content of PCDD/Fs and DL PCBs.

5.4 Pulp and Paper industrial area near Khon Kaen

According to the literature, the occurrence of organochlorine pesticides and PCBs in sediments is not common in the broader region of the Mekong Basin. In 2014, a survey of 21 organochlorine pesticides and PCBs in sediments was conducted on the wetlands of the Mekong Basin, which is part of the Phong River. Only a few organochlorine pesticides measured in 531 sediment samples occurred in high concentrations. Aldrin, heptachlor, and mirex were not detected in any samples. Chlordane, dieldrin, HCHs, and metoxychlor were detected infrequently and at low concentrations. DDTs, endosulfan, HCB, and endrin were most commonly detected in the study. Only 4 from 61 analysed samples contained PCBs. [30] The study conducted at the Phong River around the industrial area near Khon Kaen found low levels of organochlorine pesticides and PCBs in sediments in 2005. Concentrations of organochlorine pesticides and PCBs found in the study are displayed in Table 19. The range of concentrations of PCBs in sediments from the hotspot area was 0.18–47 µg/kg DW. According to the study, higher concentrations of PCBs were found in the area of the eucalyptus plantation (Project Green) than in the mainstream of the Phong River. The pulp and paper plant started operation in 1982, while Project Green, which receives irrigation from treated waste water of the plant, was initiated in 1994. Higher concentration of PCBs in this location suggests main exposure sources from the plant activity. [31]

6 Thai maximum residue levels of HCB and β-HCH in eggs are levels of detection.

Tab. 19: Concentrations of organochlorine pesticides and PCBs in sediments at Phong River around the industrial area near Khon Kaen in 2005. [31]

	∑ PCBs [µg/kg DW]	**∑ 3 DDTs [µg/kg DW]**	**∑ 3 HCHs [µg/kg DW]**	**HCB [µg/kg DW]**
Upstream Pong River	6.6	0.59	9.9	0.066
Discharge point, Pong River	0.18	0.211	0.015	0.003
Discharge point, Pong River	0.78	0.77	0.199	0.018
Project Green, Paper factory	5.0	0.027	0.005	0.001
Project Green, Paper factory	47	0.8	0.01	0.015
Downstream Pong River	0.55	0.13	0.28	0.005

[1)] ∑ PCBs is sum of all PCB congeners.
[2)] ∑ 3 DDTs is sum of residues p,p'-DDT, p,p'-DDE, and p,p'-DDD.
[3)] ∑ 3 HCHs is sum of α-HCH, β-HCH, and γ-HCH.

Contrary to the study mentioned above, all levels of organochlorine pesticides and PCBs in our sediment samples are under the level of detection. It can be explained by declining use of pesticides and PCBs levels in the Phong River and other water bodies due to negligible or zero increase of contaminants, and fluvial transport of sediments accelerated by the vertical erosion of river beds on this section of the Phong River (a result of the Ubolratana Dam). Moreover, we did not sample the particular spots of the eucalyptus plantation where the highest concentration of PCBs was found in 2005. All sediment samples collected in the hotspot area comply with criteria for organochlorine pesticides and PCBs of Thailand, the United States, and the Czech Republic. The only ash sample (KK 5) has measurable concentrations of PCDD/Fs, PCBs, and PAHs. This sample was found around a road near the power plant in the industrial area and is probably fly or bottom ash from the power plant or other industrial plant in the area. If this assumption is true, there is a significant source of PCDD/Fs and PCBs from the combustion processes in the industrial area.

Fish samples meet the requirements for maximal content of organochlorine pesticides and PCBs. All three fish samples collected in the hotspot area were analysed for content of PCBs, HCHs, HCB, and DDTs, but in just two fish samples (KK 14/1 and KK 14/2) only the DDTs content was above level of quantification. Concentrations of DDTs in these two samples (9.08 and 18.61 μg/kg fat) were few fold under the background level of DDTs in fish from Thap Lan National Park and also were well below the maximum residue limit for fish in Thailand, the European Union, and the Czech Republic.

Egg samples collected in the hotspot area have significantly higher concentrations of PCDD/Fs, PCBs, PAHs, and organochlorine pesticides (HCHs, HCB, DDTs) than levels in the background egg sample bought in supermarket in Bangkok (table 13). Two egg samples (KK 1/1 and KK 1/2) exceed Thai maximum residue limit of HCB[7]. The presence of HCB at the hotspot area could be explained by unintentional production from the chlorine production facilities in the pulp and paper plant. Hexachlorobenzene was also used as a pesticide, but according to the Thai National Implementation Plan it has never been imported or used in Thailand. The egg sample (KK 1) mixed from the two eggs shows measurable levels of PCDD/Fs, PCBs, and PAHs. Concentrations of PCDD/Fs and PCBs in the egg sample were under the maximum levels of these contaminants in the European Union and the Czech Republic, but the level of PCDD/Fs (1.5 ng WHO-TEQ/kg fat) reaches up 60 % of the maximal level and the level of PCDD/Fs + DL PCBs (2.33 ng WHO-TEQ/kg fat) reaches up 47 % of the maximal level. This PCDD/Fs and PCBs concentration in the egg sample indicate that there is a contamination source in the hotspot area. PCDD/Fs can be produced as by-products during chlorine bleaching in pulp and paper mills. The EPA's national dioxins source assessment reported that bleached pulp and paper production was ranked 4th overall as a source of dioxins contamination. [32] A scientific survey conducted around the pulp and paper plant near Khon Kaen found high PCDD/Fs concentrations in sediments in 2006. Dioxins levels in sediments at the hotspot area ranged from 36 to 130 ng TEQ/kg with a mean value of 76.5 ng TEQ/kg. The highest concentration of PCDD/Fs (130 ng TEQ/kg) was found in a sediment sample collected from the discharge point of the pulp and paper plant, which indicated PCDD/Fs contamination from the plant's operations. [16] Our results show that PCDD/Fs contamination from the plant can persist and is present in the food chain. For a better understanding of the PCDD/Fs contamination and its proliferation in the area, more measurements of organic and inorganic matrices are needed.

7 Thai maximum residue level of HCB in eggs is a level of detection.

5.5 Comparison of hotspots

For comparison, samples of fish and eggs were used, because they were collected from all the hotspot areas and background locality, and they were analysed for some POPs with detectable values. Concentrations of I-PCBs and DDTs in fish samples from different hotspot areas are plotted in Figures 1 and 2, respectively. The highest concentration of I-PCBs in fish was found in sample MTP 1-10/1 from Map Ta Phut. The sample is determined as a needlefish (family *Belonidae*) which is a group of carnivorous fish. Concentrations of I-PCBs are higher than the level of quantification in some other fish samples from Map Ta Phut and Samut Sakhon hotspot areas, while fish samples from Tha Tum, Khon Kaen, and Thap Lan National Park were under the level of quantification. Concentrations of DDTs in the four fish samples exceeded the values found in fish samples from Thap Lan National Park. These are from Map Ta Phut (three samples) and Samut Sakhon (one sample).

Fig. 1: Comparison of 7 I-PCBs concentrations in the fish samples from the hotspot areas and from the background locality

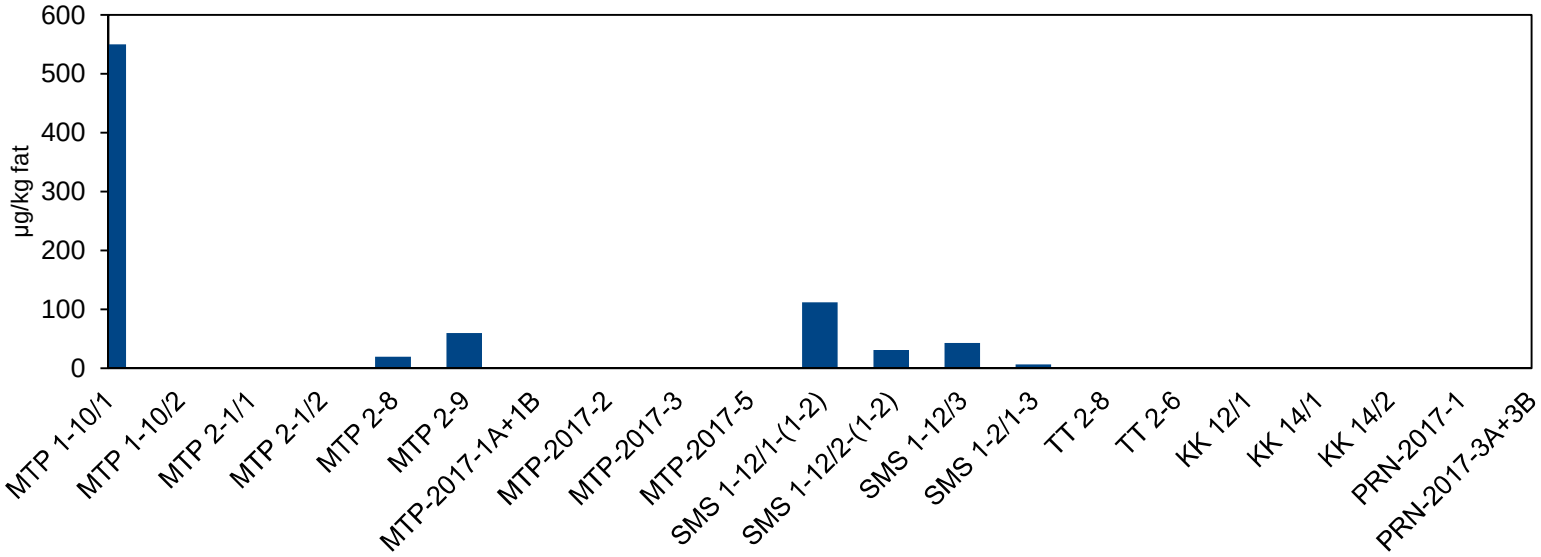
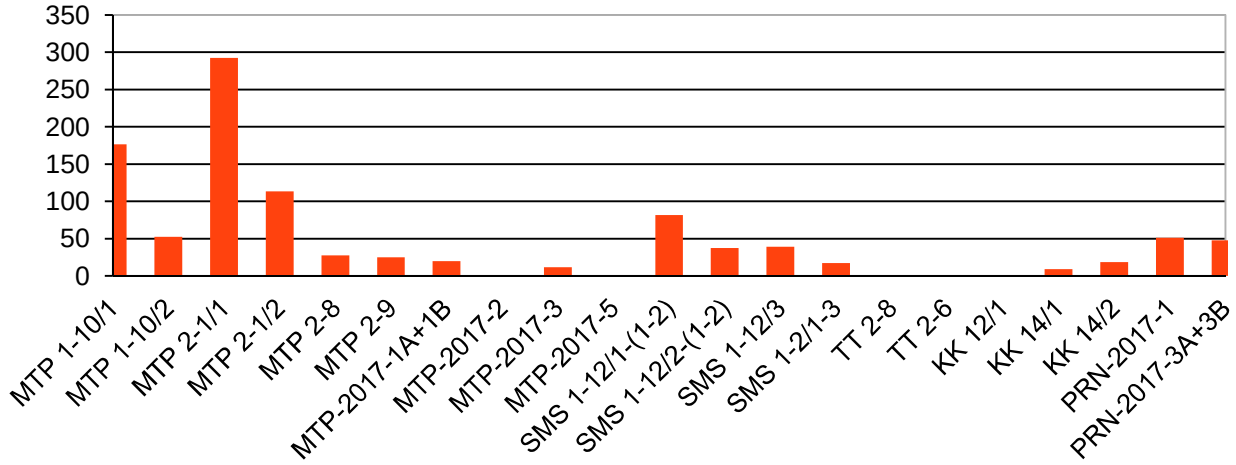


Fig. 2: Comparison of DDTs concentrations in the fish samples from the hotspot areas and from the background locality



Concentrations of PCDD/Fs and DL PCBs, I-PCBs, and PAHs in egg samples from different hotspot areas are plotted in Figures 3, 4, and 5, respectively.. Concentrations of PCDD/Fs and DL PCBs in all the egg samples from the hotspot areas are higher than levels of these contaminants in the sample from the supermarket in Bangkok. The highest values of PCDD/Fs and DL PCBs were found in the two egg samples from Samut Sakhon. The same pattern was found for I-PCBs concentrations in egg samples: all samples from hotspot areas are higher than the egg sample from the supermarket, and the highest values are in the two eggs samples from Samut Sakhon. Concentrations of PAHs in most egg samples from the hotspot areas are higher than the value in the sample from the supermarket in Bangkok, except for one egg sample from Map Ta Phut (MTP 2-19). The highest values of PAHs were found in the egg sample from the Khon Kaen hotspot area (KK 1) and the second highest value was found in the egg sample from Samut Sakhon hotspot area (SMS 2-13).

Fig. 3: Comparison of PCDD/Fs and DL PCBs concentrations in the egg samples from the hotspot areas and from the background locality

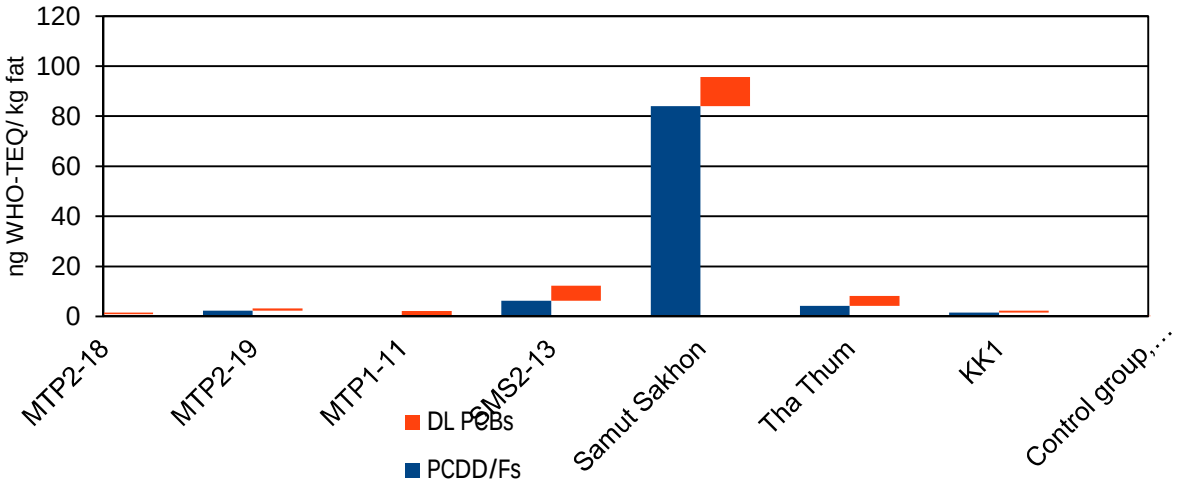


Fig. 4: Comparison of 7 I-PCBs concentrations in the egg samples from the hotspot areas and from the background locality

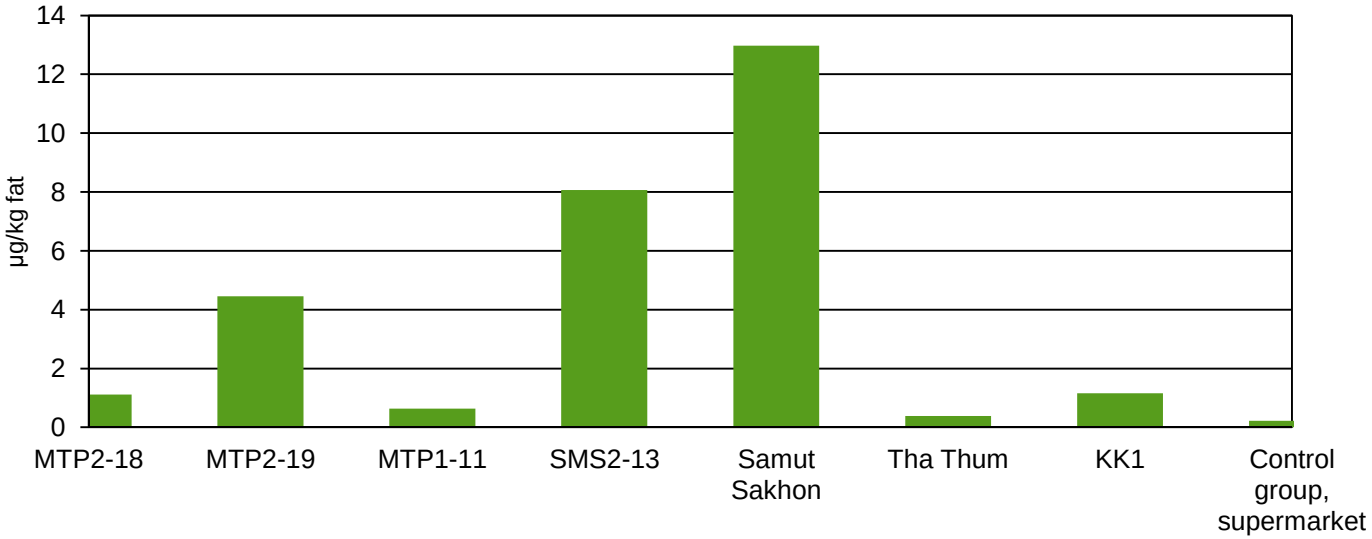
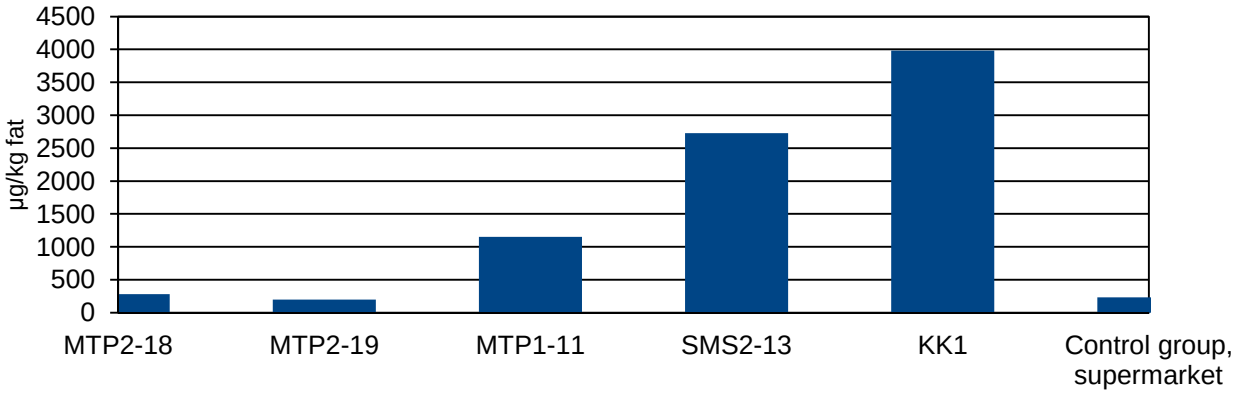


Fig. 5: Comparison of 16 PAHs concentrations in the egg samples from the hotspot areas and from the background locality



5.6 General assessment of persistent organic pollutant distribution in Thailand

Organochlorine pesticides, mainly DDTs, were commonly used in Thailand in the past and their levels in the environment are still decreasing. The monitoring of organochlorine pesticides in Thailand conducted in the 1970s showed that organochlorine pesticides persisted in a majority of the samples, roughly 50 % in water, 90 % in sediments and aquatic animals, and 90 % in soil samples. Aside from the most common compounds, such as DDTs, the other organochlorine pesticides frequently found in environmental samples were α-HCH, endrin, aldrin, dieldrin, and heptachlor. After the evidences that all these organochlorine compounds had widely distributed in the food chain and the environment, they were progressively banned. During 1987-1989, there was a nationwide monitoring program for residue levels of organochlorine pesticides in the environment to observe levels of these chemicals after their uses had been decreasing. The results revealed that organochlorine pesticides were found to have been distributed in all agricultural areas and ended up in living organisms, such as fish and shellfish; same situation as it was ten years ago, only the amounts of accumulation were not alarming and had a tendency to decline. [8] The results from our monitoring of organochlorine pesticides showed relatively low levels and confirm continuous tendency to decline as we found generally lower level than were presented in the cited literature [21] [22] [23].

Contrary to the information from the Thai National Implementation Plan of the Stockholm Convention saying that mirex and HCB were never imported and used in Thailand, we found one sediment sample containing mirex and relatively frequent presence of HCB mainly in organic samples. Hexachlorobenzene contamination can be originated from the usage of fungicides or as an impurity in pesticide formations and other chemicals, but it is also formed as a by-product of various chlorinating processes and the combustion of industrial and municipal wastes. The occurrence of HCB found in our study is consistent with previous studies [22] [23].

There are some factors that have an influence on the distribution of POPs in Thailand and in tropical zones in general. Seasonal variation and effect of temperature are some of these factors. The effect of seasonal variation on the accumulation of POPs in aquatic animals was studied on spot barb (***Puntius bimaculatus***) widely found across the Thailand**.** [33] For the study, spot barbs were collected in both dry and wet seasons for measurement of accumulated pollutants. The results indicated that both PCBs and organochlorine compound concentrations in freshwater fish collected in the dry season were higher than that in the wet season due to lipid content. Since we had taken samples in the dry season, it is acceptable lower levels of POPs in freshwater fish during a wet season than is presented in our study.

Temperature has a much wider effect on distribution of POPs in the environment. Increasing temperatures provide thermodynamic forcing to drive POPs out of reservoirs, like soil, vegetation and water, and into the atmosphere where they can be transported rapidly by winds and then redistributed among environmental media to reach locations where lower temperatures prevail. A widely-cited hypothesis to explain why some POPs are found in remote, cold environments at concentrations that are a cause for concern is the effect of low temperatures on physiochemical properties that enhance deposition within such environments. This process has been termed “global fractionation” or “cold trapping” [34] According to this flux model, emission to air will tend to occur primarily in “global source areas” where POPs are used or released. POPs can potentially migrate from warmer to colder areas and become “fractionated” on latitudinal or altitudinal gradients. The polar regions will become “global sinks” for POPs released or used elsewhere on Earth. For example, DDTs usage has been extensive through the tropics, and the high temperatures in the tropics will mean greater volatilisation rates of DDTs than locations in a cooler climate. [35]

Temperature can significantly affect the distribution of POPs between different phases, and promote POPs to migrate from the land surface to the atmosphere. Consequently, in the tropical environment there are more POPs dispersed through air and retained less in sediments. The ratios of organochlorine concentrations in sediment and water phases were positively correlated with the latitude of sampling. [36] Moreover, the presence of organochlorine compounds in aquatic ecosystems was less significant, and its residence time was quite short, whereas its transfer to the atmosphere was much larger due to the high temperature. It is probably the reason why we found relatively low levels of POPs in the sediment samples in all hotspot areas in Thailand, because high temperature cause volatilization of POPs from the soils and sediments.

Higher temperature in tropical zones can also influence the toxicity of POPs. Numerous studies have concluded that the bioavailability and toxicity of POPs in organisms increases with the increase of temperature. Possible mechanisms for this are as follows: 1) the dynamic toxicity effect of compounds increases with the increasing temperature, 2) warming gives rise to a weak immune ability of wildlife to POPs, which results in increasing toxicity of POPs. [37] For this reason, more rigorous maximal allowed levels in foodstuffs, in comparison with European Union, is necessary for tropical countries such as Thailand, because relatively low levels found in the organic samples can have a stronger toxic effect on human health.

6. Conclusions

Our results show that there are residues of organochlorine pesticides still present in the environment of Thailand. The most common organochlorine pesticide is DDT and its residues, which is in agreement with literature information and amounts of used pesticides according to the National Implementation Plan of Thailand. Contrary to the information from the National Implementation Plan of Thailand, we found residues of mirex.

The most problematic POPs found in the hotspot areas are unintentionally produced contaminants as PCDD/Fs, HCB, PeCB, PCBs, HBCD, HCHs. These contaminants are unintentionally produced by industrial processes, such as the bleaching of paper, small metallurgical facilities used as waste recycling operations, open burning of waste and e-waste in particular (e.g. for purpose of collecting remaining metals from wastes), chlor-alkali production, and the production of plastics or waste incineration.

The most contaminated matrix are eggs, because most of the egg samples exceed the maximum residue limits of HCB or HCH for Thailand or maximum levels of PCB and PCDD/F for the European Union and the Czech Republic. Two egg samples collected in the Samut Sakhon hotspot area contain unsafe levels of unintentionally produced POPs. One of the two egg samples from Samut Sakhon has concentrations of PCDD/Fs (84.04 ng WHO-TEQ/kg fat) and PCDD/Fs + DL PCBs (95.71 ng WHO-TEQ/kg fat) that are 33 folds and 19 folds higher than the maximal levels in eggs tolerable for the European market. Moreover, this egg sample also contains a concentration of PBDD/Fs (15.8 ng WHO-TEQ/kg fat) without the maximal tolerable levels at all. The contamination of the egg samples from Samut Sakhon can be caused by breeding hens around a small a waste “recycling” facility located near a waste burning facility, including e-waste.

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8. Annex I

Tab. 20: Complete results of inorganic samples from Map Ta Phut hotspot area

Name	Matrix	∑ 7 PCBs[1)] [µg/kg DW]	HCB [µg/kg DW]	∑ 3 HCHs[2)] [µg/kg DW]	∑ DDTs[3)] [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide[4)] [µg/kg DW]	Endosulfan[5)] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	Napthalene [µg/kg DW]
MTP 1-1	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
MTP 1-6	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
MTP 1-7	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
MTP 1-8	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
MTP 1-12	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
MTP 1-13	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.5**
MTP 1-14	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
MTP 1-15	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
MTP 1-16	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.5**
MTP 1-17	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**1.7**
MTP 2-2	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
MTP 2-3	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.6**
MTP 2-5	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.7**
MTP 2-6	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.6**
MTP 2-6 (1)	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
MTP 2-14	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
MTP 2-15	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA

[1)] ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.
[2)] ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[3)] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.
[4)] Heptachlor epoxide is sum of isomers cis and trans.
[5)] Endosulfan is sum of isomers α-endosulfan and β-endosulfan.

Tab. 21: Complete results of inorganic samples from Samut Sakhon hotspot area

Name	Matrix	**PCDD/Fs [ng WHO-TEQ/kg DW]**	**DL PCBs [ng WHO-TEQ/kg DW]**	**∑ 6 PCBs[1)] [µg/kg DW]**	**∑ 7 PCBs[2)] [µg/kg DW]**	**HCB [µg/kg DW]**	**∑ 3 HCHs[3)] [µg/kg DW]**	**∑ DDTs[4)] [µg/kg DW]**	**Heptachlor [µg/kg DW]**	**Heptachlor epoxide[5)] [µg/kg DW]**	**Endosulfan[6)] [µg/kg DW]**	**Dieldrin [µg/kg DW]**	**Endrin [µg/kg DW]**	**Napthalene [µg/kg DW]**	**∑ 16 PAHs[7)] [µg/kg DW]**
SMS 1-1	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-3	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-5	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-6	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-8	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-8	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-9	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-10	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-11	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**1.4**	NA
SMS 1-14	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.5**	NA
SMS 2-2	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 2-6	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA

SMS 2-7	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 2-10	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 2-11	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 2-12	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
A3	soil	**35.2**	**5.72**	**1.2**	**7.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA	**1747**
A2	soil	**12.8**	**0.001**	**1.06**	**1.06**	NA	NA	NA	NA	NA	NA	NA	NA	NA	**488**
A1	ash	**1.9**	**0.27**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**3210**

[1)] ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
[2)] ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.
[3)] ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[4)] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.
[5)] Heptachlor epoxide is sum of isomers cis and trans.
[6)] Endosulfan is sum of isomers α-endosulfan and β-endosulfan.
[7)] 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

Tab. 22: Complete results of inorganic samples from Tha Tum hotspot area

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 6 PCBs[1] [µg/kg DW]	∑ 7 PCBs[2] [µg/kg DW]	HCB [µg/kg DW]	TeClB [µg/kg DW]	1,2,3,4-TeClB [µg/kg DW]	QClB [µg/kg DW]	∑ 3 HCHs[3] [µg/kg DW]	∑ DDTs[4] [µg/kg DW]	Heptachlor [µg/kg DW]	Aldrin [µg/kg DW]	Oktachlorstyren [µg/kg DW]	Heptachlor epoxide[5] [µg/kg DW]	Chlordan[6] [µg/kg DW]	Oxychlordan [µg/kg DW]	Metoxychlor [µg/kg DW]	Mirex [µg/kg DW]	Endosulfan[7] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	∑ 16 PAHs[8] [µg/kg DW]
TT 1-1	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-2	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-3	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-4	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-5	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-6	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-7	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-8	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-9	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-10	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA

TT 1-11	sediment	NA	NA	**0.28**	**0.28**	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 2-1	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
S1	sediment	**1.6**	**0.013**	<LOD	<LOD	**0.23**	<LOD	<LOD	<LOD	<LOD	**0.44**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA	**137**
S2	sediment	**1.27**	**0.026**	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA	**631**
S3	sediment	**3.76**	**0.022**	NA	NA	**0.22**	<LOD	<LOD	<LOD	<LOD	**0.14**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.32**	NA	NA	NA	**576**
S4	sediment	**0.22**	**0.048**	NA	NA	**0.30**	<LOD	<LOD	<LOD	<LOD	**2.2**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA	**85**
S5	ash	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**6683**

[1)] ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
[2)] ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.
[3)] ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[4)] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.
[5)] Heptachlor epoxide is sum of isomers cis and trans.
[6)] Chlordan is sum of isomers cis and trans.
[7)] Endosulfan is sum of isomers α-endosulfan and β-endosulfan.
[8)] 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

Tab. 23: Complete results of inorganic samples from Khon Kaen hotspot area

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 6 PCBs[1)] [µg/kg DW]	∑ 7 PCBs[2)] [µg/kg DW]	HCB [µg/kg DW]	∑ 3 HCHs[3)] [µg/kg DW]	∑ DDTs[4)] [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide[5)] [µg/kg DW]	Endosulfan[6)] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	∑ 16 PAHs[7)] [µg/kg DW]
KK 3	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 4	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 7	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 8	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 9	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 10	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 11	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 13	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 5	ash	**0.9**	**1.04**	**0.29**	**0.33**	NA	NA	NA	NA	NA	NA	NA	NA	**310**

[1)] ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
[2)] ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.
[3)] ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.
[4)] ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.
[5)] Heptachlor epoxide is sum of isomers cis and trans.
[6)] Endosulfan is sum of isomers α-endosulfan and β-endosulfan.
[7)] ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

9. Annex II – Pictures

Samut Sakhon 1

Samut Sakhon 2

Samut Sakhon 3

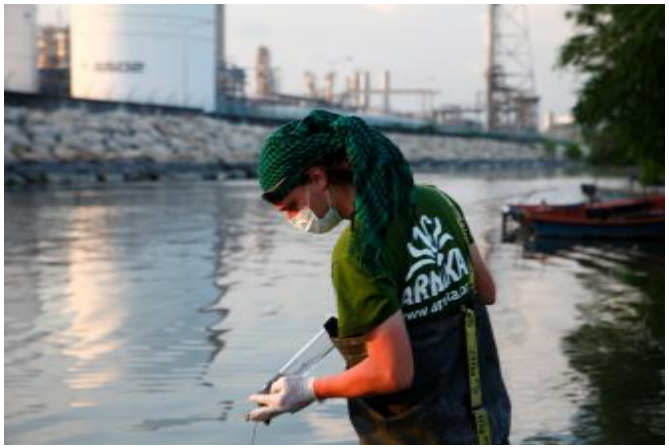
Samut Sakhon 4

Samut Sakhon 5

Map Ta Phut 1

Map Ta Phut 2

Map Ta Phut 3



Map Ta Phut 4

EUROPEAN UNION

The European Union (EU) is made of 28 Member States who have decided to gradually link together their know-how, resources and destinies. Together, during a period of enlargement of 50 years, they have built a zone of stability, democracy and sustainable development whilst maintaining cultural diversity, tolerance and individual freedoms. The European Union is committed to sharing its achievements and its values with countries and peoples beyond its borders. The European Commission is the EU's executive body.

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