POPs IN THE SURROUNDINGS OF E-WASTE SITES

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POPs IN THE SURROUNDINGS OF E-WASTE SITES

Jindrich Petrlik[1,2], Thitikorn Boontongmai[3], Nichchawan Bubphachat[3], Chutimon Thowsakul[3], Akarapon Teebthaisong[3], Penchom Saetang[3], Nikola Jelinek[1], Jitka Strakova[1,2], Valeriya Grechko[1], Punyathorn Jeungsmarn[3]

1 Arnika – Toxics and Waste Programme
2 International Pollutants Elimination Network (IPEN)
3 Ecological Alert and Recovery Thailand (EARTH)

Arnika – Toxics and Waste Programme,
Seifertova 327/85, 130 00 Prague 3, Czech Republic
Tel.: + 420 774 406 825
E-mail:toxik@arnika.org
Website: https://arnika.org

Ecological Alert and Recovery – Thailand (EARTH),
211/2 Ngamwongwan Rd., Soi 31, Bangkhen, Muang, Nonthaburi 11000, Thailand
Tel: +66 2 952 5061
E-mail: earth@EarthThailand.org
Website: https://www.earththailand.org

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EXECUTIVE SUMMARY

Electronic waste (e-waste) and its imports from abroad represent a big burden for the environment and human health in Thailand. This study is focused on mapping pollution by POPs (Persistent Organic Pollutants) in the vicinity of two facilities processing e-waste in Chachoengsao province, and one site affected by the disposal of sludge of unknown origin (Hat Nang Kaeo) in Prachinburi province. We focused on POPs which are used as additives in electronic equipment and plastic used for its casing, such as, for example, brominated flame retardants (BFRs), short-chain chlorinated paraffins (SCCPs), and others. We also focused on POPs produced unintentionally during the production of BFRs, and particularly during incineration and other thermal processes used for the disposal and recycling of plastics from e-waste.

For the sampling in this study, we chose two sites near factories which handle e-waste. They declare their focus to be recycling. However, the e-waste is mainly dismantled and only metal parts are recycled there in the factories. Residual waste, including plastic, is often burned in some kind of incineration operations.

We took samples of soils, sediments, dust, and free-range duck eggs. The widest range of samples was taken in the surroundings of the so-called "dioxin factory", the Supcharoen Recycle Co. Ltd. factory in Khao Hin Son. Soil and dust samples were also taken close to the CT Steel Co. Ltd. factory, one of the electronic waste recycling factories located in Moo 1 "Ban Muang Phrong" village, Khao Hin Son subdistrict, Phanom Sarakham district, Chachoengsao province.

Reference samples of dust, soil, and sediment were taken in a clean area of an organic farm in Na Somboon, Kalasin province. A reference sample of chicken eggs was obtained in a supermarket in Maha Sarakham in February 2022. These reference samples were also taken for another set of samples from Kalasin.

The results of the analyses for thirteen samples in total are evaluated in this study.

Contamination with POPs was revealed at all three locations researched in this study, Khao Hin Son Moo 9 - Nong Khok, Khao Hin Son Moo 1, and Hat Nang Kaeo. The highest levels were observed in the surroundings of the Supcharoen Recycle Co. Ltd. factory, in the village of Nong Khok, where contamination of the food chain was confirmed by high levels of some POPs in free-range duck eggs. The dismantling and incineration of e-waste is most likely to be the source of this serious contamination. The dumping of industrial sludge from a drum "donated" by a factory to villagers caused serious contamination with SCCPs.

Very high levels of unintentionally produced POPs were confirmed in the free-range duck eggs from Nong Khok. The level of PCDD/Fs is the tenth-highest level ever measured in poultry eggs in Asia, and the second-highest level measured in eggs from Thailand. The level of PBDD/Fs in the eggs from Nong Khok is the sixth highest measured in free-range poultry eggs from polluted sites globally. Also, the levels of PCDD/Fs and PBDD/Fs in the soil samples from this locality are many times higher compared to the reference site. The PeCB and HCB levels in these eggs belong among the highest measured in free-range egg samples in Thailand.

The level of PCDD/Fs and total TEQ level of PCDD/Fs and dl PCBs in the sample of duck eggs from Nong Khok exceed the maximum levels set in the EU by more than 24 and 14 times, respectively.

Serious contamination with SCCPs was discovered at Nong Khok, as well as Hat Nang Kaeo, most probably as a result of the dumping of industrial sludge at these sites. It also resulted in a high concentration of SCCPs measured in the free-range duck eggs at Nong Khok. A relatively high level of ndl PCBs was measured in the soil at Hat Nang Kaeo, in addition to contamination with SCCPs.

The levels of PBDD/Fs were most significant among the chemicals analysed in the samples from the Khao Hin Son Moo 1 locality, followed by PCDD/Fs, which shows that the burning of e-waste residues is the most important pathway of contamination at this locality.

1. INTRODUCTION

Thailand has become a destination for electronic waste and produces large volumes of this waste itself.

The burning of electronic waste as a major source of dioxins and other unintentionally produced persistent organic pollutants (POPs) is partly covered under the "Smouldering of Copper Cables" category listed in Part III of Annex C to the Stockholm Convention as one of the "*source categories that have the potential for comparatively high formation and release of these chemicals to the environment"* (Stockholm Convention 2010). Large quantities of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), "dioxins" in short, can also be released from the kind of waste incineration which occurs in e-waste "recycling" facilities as a way of disposing of residual plastics and other e-waste residues.

In this study we focused on research in the vicinity of two such facilities in Chachoengsao province, and one site affected by the disposal of sludge of unknown origin.

2. BASIC INFORMATION FOR THE STUDY

Since 2010, the volume of e-waste generated globally has been steadily rising. By 2019, approximately 53.6 million metric tons had been produced. This was an increase of 44.4 million metric tons in just five years. Of this, just 17.4 per cent was documented as having been collected and properly recycled (Tiseo 2022).

A comparison of e-waste generated per capita in Asian countries is presented in **Table 1**.

The amount of this type of waste has increased continually, with a high rate of 65% of total municipal hazardous waste states reported by EARTH from 2016 (EARTH 2016). The reason for the increased waste is related to changes around technological systems and the media. For example, previously original CRT televisions were replaced by digital flat-screen televisions, leading to an increase in e-waste made up of obsolete original televisions. In addition, tablets and mobile telephones are now widely used (EARTH 2016).

Similar trends are illustrated by statistics recorded in the Thai Ministry of Commerce database for electrical and electronic waste items such as used batteries, scrap electrical machinery, used computers and data processing machines, and old circuit boards, as well as used electronic circuits.

The Local Administrative Organisation, the Ministry of the Interior, is responsible for e-waste management. In 2020, about 1 per cent (4,000 tons) of domestic e-waste was collected by the Local Administration Organisation. Most of it went to the informal sector, in which about 1,000 informal concerns dismantle e-waste manually.

Used batteries and scrap electrical machinery are exported to Thailand in bulk volumes (recorded under the Harmonised System code 8548.9090) from several countries, including the USA, China, and Japan. In this case, in 2014, the USA shipped over 25,560 kg worth 330,000 USD (10.3 million THB), increasing to nearly 11.8 million kg, worth 3.1 million USD (101.4 million THB) to Thailand in 2018, with Japan sending 41,380 kg, worth 16.4 million USD (533.17 million THB) in 2014, increasing to over 1.64 million kg in 2018, valued at 11.6 million USD (377.8 million THB). Meanwhile, China sent nearly 1.4 million kg in 2014, valued at 24.49 million USD (796 million THB) to Thailand, increasing to 1.84 million kg in 2018, worth 14.93 million USD (484.3 million THB) (Roberts-Davis and Saetang 2019).

Table 1: Domestic e-waste generated per country in the Asian region in 2014. Source: (Balde 2015).

Country	E-waste generated (kg/capita)
Cambodia	1.0
China	4.4
India	1.3
Indonesia	3.0
Japan	17.3
Korea	15.9
Lao PDR	1.2
Malaysia	7.6
Thailand	6.4
Vietnam	1.3

In response to the high volume of e-waste imports and other types of plastic waste, including cases of illegal importation following China's ban, Thai civil society began campaigning for a ban on waste imports in 2018. This led to the establishment of a governmental subcommittee on the issue. Eventually, the Ministry of Commerce announced a ban on 428 types of e-waste in 2020. The ban considers waste under the statistical code "899" to be banned e-waste. "899" refers to "Electronic waste under the Basel Convention". The statistics for the import of e-waste, including illicit imports, showed that it was reduced in 2021 and 2022, following the ban (Piachan 2022). However, Ecological Alert and Recovery Thailand – EARTH's investigation through the Ministry of Commerce's database found continued imports of e-waste through customs codes not specifically singled out by the 2020 ban. One such code, 8548, saw more than 43 million kg of imports in 2021 and more than 11 million kg of imports between January and March 2022.

The Basel Action Network performed an extrapolation of e-waste exports from the EU: *"Extrapolation of the export rates to developing countries from our study from all of the 28 member states of the EU gives a total of 352,474 metric tonnes exported per annum"* (BAN 2018). It also stated that *"Europe's 6% exportation rate was far less than the 40% rate BAN found in the United States, which has no laws forbidding exports, two years earlier"* (BAN 2018).

The mismanagement of e-waste causes environmental pollution and affects human health. About 150 dismantling and recycling facilities were officially registered with the Department of Industrial Works (PCD-DIW 2021). However, including unregistered facilities would increase this number.

The report by the Basel Action Network documented how used electronics can get to countries like Thailand. It also showed that one of the used LCDs tracked from Germany ended up in the recycling factory owned by Supcharoen Recycle Co. Ltd. (BAN 2018). We have chosen this factory as one of the hot spots for our study, as it can be a potential source of contamination of the environment with POPs.

We focused on POPs, which are used as additives in electronic equipment and the plastic used for its casing, such as, for example, brominated flame retardants (BFRs), short-chain chlorinated paraffins (SCCPs), and others. We also focused on POPs produced unintentionally during the production of BFRs, and especially during incineration and other thermal processes used for the disposal and recycling of plastics from e-waste. The characteristics of both the intentionally used and unintentionally produced POPs which were analysed in the environmental samples for this study are described below.

2.1 Comparison with previous studies

This report is not the first of its kind by EARTH and the Arnika team in Thailand. POPs were analysed in samples from localities affected by various industrial and waste disposal and recycling activities in a previous project between 2016 and 2019. So we can compare the results presented in this study with the data summarised in the report "Toxic Hot Spots in Thailand" (Petrlík, Dvorská et al. 2018), and several abstracts presented at Dioxin Conferences (Petrlik, Teebthaisong et al. 2018, Teebthaisong, Petrlik et al. 2018, Teebthaisong, Saetang et al. 2021). There is also a large number of studies looking at POPs levels at sites affected by e-waste dismantling in China (Zeng, Luo et al. 2016, Zeng, Huang et al. 2018), Vietnam (Anh, Tomioka et al. 2018, Nishimura, Suzuki et al. 2018, Anh, Tomioka et al. 2019), and Indonesia (Petrlik, Ismawati et al. 2020). We compared the results of the analyses in this study with these previous studies as well.

The sample of free-range duck eggs from Nong Khok is important for the investigation of potential food chain contamination. The results of its analyses for POPs can be compared with the data presented in two global studies recently: one was focused on sites affected by plastic waste management (Petrlik, Bell et al. 2021) and the other summarised levels of PCDD/Fs, dl PCBs, and PBDD/Fs in poultry eggs collected at various hot spots globally (Petrlik, Bell et al. 2022).

2.2 Persistent Organic Pollutants (POPs)

Persistent organic pollutants (POPs) represent a large group of chemicals which persist for a long time in the environment and bioaccumulate; mostly, they have potential for long-range environmental transport, and they also have adverse effects on human health or the environment (Stockholm Convention 2010). Thirty-one individual chemicals or groups are already listed under the Stockholm Convention (Stockholm Convention 2019). This covers some but not all chemicals that have the properties of POPs. Our report focuses on twelve POPs listed under the Stockholm Convention and also on seven additional chemicals, and one group of chemicals not yet listed under this convention. Their basic characteristics follow. We focused on both intentionally and unintentionally produced POPs.

2.2.1 Intentionally produced POPs

The intentionally produced POPs considered in our study were mainly technical chemicals and their mixtures used intentionally in electric and electronic equipment or the automotive industry, as well as those used as additives to plastics.

2.2.1.1 Non-dioxin-like polychlorinated biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) were produced until the 1980s in large volumes and they were used in industry as heat exchange fluids, in electric transformers and capacitors, and as additives in paint, carbonless copy paper, and plastics (Stockholm Convention 2019). Approximately 1.3 to 2 million tonnes of PCB were industrially produced in various countries from 1929 to the 1980s (Breivik, Sweetman et al. 2002, Weber, Herold et al. 2018). Twelve PCB congeners are considered as dioxin-like PCBs because of their effects and similar properties to PCDD/Fs (van den Berg, Birnbaum et al. 2006, European Commission 2012). These congeners are listed as unintentionally produced POPs in Annex C to the Stockholm Convention (Stockholm Convention 2010). Technical mixtures of PCBs are characterised by six,[1] sometimes seven[2] indicator PCB congeners. Maximum levels in food are set for six indicator PCB congeners in food in the EU (European Commission 2012, European Commission 2016).

2.2.1.2 Polychlorinated naphthalenes (PCNs)

Polychlorinated naphthalenes (PCNs) were produced for similar uses to PCBs, so they are their predecessors in some way. PCNs make effective insulating coatings for electrical wires. Others have been used as wood preservatives, as rubber and plastic additives, for capacitor dielectrics, and in lubricants. To date, intentional production of PCN is assumed to have ended (Stockholm Convention 2017). They are also unintentionally generated during high-temperature processes in the presence of chlorine, similarly to PCDD/Fs and dl PCBs.

The following PCN congeners were measured in the samples for this study: PCN 4, PCN 9, PCN 18, PCN 20, PCN 41, PCN 42, PCN 52, PCN 56, PCN 66, PCN 70, PCN 73, PCN 74, and PCN 75.

2.2.1.3 Short-chain chlorinated paraffins (SCCPs)

Short-chain chlorinated paraffins (SCCPs) are a group of POPs added by governments to the Stockholm Convention for global elimination in 2017. Chlorinated paraffins (CPs) are complex mixtures of certain organic compounds containing chloride: polychlorinated n-alkanes. SCCPs can be used as a plasticiser in rubber, paints, adhesives, and flame retardants for plastics as well as an extreme-pressure lubricant in metal-working fluids (Stockholm Convention 2017). SCCPs are toxic to aquatic organisms at low levels, disrupt endocrine function, and are suspected to cause cancer in humans (POP RC 2015). SCCPs are other additives in plastics that might also be expected in waste imported to and/or produced in Thailand. They were often used in the manufacture of wires and cables (POP RC 2009).

2.2.1.4 Brominated flame retardants (BFRs)

2.2.1.4.1 Polybrominated diphenyl ethers (PBDEs)

Polybrominated diphenyl ethers (PBDEs) are a group of brominated flame retardants that include substances listed in the Stockholm Convention for global elimination, such as PentaBDE (2009), OctaBDE (2009), and DecaBDE (2017). PBDEs are additives mixed into plastic polymers that are not chemically bound

1 PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
2 PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

to the material and therefore leach into the environment. They have already been identified in samples from other localities in Thailand (Petrlik, Kalmykov et al. 2017, Petrlík, Dvorská et al. 2018).

PBDEs have adverse effects on reproductive health as well as developmental and neurotoxic effects (POP RC 2006, POP RC 2007, POP RC 2014). DecaBDE and/or its degradation products may also act as endocrine disruptors (POP RC 2014).

PentaBDE has been used in polyurethane foam for car and furniture upholstery, and Octa- and DecaBDE have mainly been used in plastic casings for electronics. OctaBDE formed 10%-18% of the weight (Stockholm Convention 2016) of CRT television and computer casings and other office electronics made of acrylonitrile butadiene styrene (ABS) plastic. DecaBDE forms 7%-20% of the weight (POP RC 2014) of many different plastic materials, including high-impact polystyrene (HIPS), polyvinylchloride (PVC), and polypropylene (PP), used in electronic appliances. As this study examines samples from sites affected by the presence of electronic waste and/or by its incineration, all of the above-mentioned PBDEs were part of the main focus of our investigation.

2.2.1.4.2 Hexabromocyclododecane (HBCD)

Hexabromocyclododecane (HBCD) is a brominated flame retardant primarily used in polystyrene building insulation. HBCD is an additive mixed into plastic polymers that is not chemically bound to the material and therefore may leach into the environment. HBCD is highly toxic to aquatic organisms and has negative effects on reproduction, development, and behaviour in mammals, including transgenerational effects (POP RC 2010). HBCD is also found in packaging materials, video cassette recorder housings, and electric equipment.

HBCD was listed in Annex A of the Stockholm Convention for global elimination with a five-year specific exemption for use in building insulation that expired for most Parties in 2019 (Stockholm Convention 2013).

2.2.1.4.3 Tetrabromobisphenol A (TBBPA)

Tetrabromobisphenol A (TBBPA) is the largest-volume flame retardant used worldwide (Kodavanti and Loganathan 2019), covering around 60% of the total global BFR market (Law, Allchin et al. 2006). While the majority of TBBPA is chemically bonded to the polymer matrix of printed circuit boards, it is also used as an additive flame retardant in the manufacture of ABS resins and HIPs as an alternative to PBDEs and HBCD, and to banned OctaBDE mixtures in ABS plastic in particular (POP RC 2008, Abou-Elwafa Abdallah 2016). The main applications where plastic containing TBBPA may be used include TV set back-casings and business equipment enclosures (ECHA 2008).

TBBPA is a cytotoxicant, immunotoxicant, and thyroid hormone agonist with the potential to disrupt oestrogen signalling (Kitamura, Jinno et al. 2002, Birnbaum and Staskal 2004). It is also classified as very toxic to aquatic organisms and is on the OSPAR Commission's List of Chemicals for Priority Action because of its persistence and toxicity (OSPAR Commission 2011).

While earlier risk assessment studies concluded that there is no risk to human health associated with exposure to TBBPA (EFSA CONTAM 2011), recent studies have identified this chemical as "probably carcinogenic to humans" (Grosse, Loomis et al. 2016, IARC 2020).

TBBPA has been detected in almost all environmental compartments all over the world, rendering it a ubiquitous contaminant (Abou-Elwafa Abdallah 2016). It has been found to bioaccumulate in e.g. peregrine falcon eggs (Schwarz, Rackstraw et al. 2016). TBBPA was also measured in a soil sample from the Agbogbloshie e-waste scrapyard at a level of 149 ng/g dw, which was higher than the levels of nBFRs but lower than the level of PBDEs measured in the same sample. It was not found to accumulate in the eggs from that site (Petrlik, Adu-Kumi et al. 2019).

Human exposure studies have revealed dust ingestion and diet as the major pathways of TBBPA exposure in the general population.

There are no current restrictions on the production of TBBPA in the EU or worldwide.

2.2.1.4.4 Novel brominated flame retardants (nBFRs)

A group of six novel BFRs was chosen for the analyses in environmental samples from the localities studied in Thailand in addition to PBDEs, HBCD, and TBBPA.

Novel BFRs (nBFRs) are a group of chemicals that in many cases replaced the already restricted BFRs. Different sources list different chemicals among this group, but only a few of them are measured in the environment. Recent studies also show that nBFRs are becoming widespread in the environment, including in food, particularly in some Asian countries (Shi, Zhang et al. 2016). A review of the levels of BFRs in soil concluded that: *"Although further research is required to gain baseline data on NBFRs in soil, the current state of scientific literature suggests that NBFRs pose a similar risk to land contamination as PBDEs"* (McGrath, Ball et al. 2017).

The scientific panel of the EFSA evaluated 17 "emerging"[3] and 10 "novel"[4] BFRs in 2012 and suggested that: *"There is convincing evidence that tris(2,3-dibromopropyl) phosphate (TDBPP) and dibromoneopentyl glycol (DBNPG) are genotoxic and carcinogenic, warranting further surveillance of their occurrence in the environment and in food. Based on the limited experimental data on environmental behaviour, 1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE) and hexabromobenzene (HBB) were identified as compounds that could raise a concern for bioaccumulation"* (EFSA CONTAM 2012). EFSA's panel also stated that for most of the BFRs that were evaluated, there was not sufficient data about their presence in the environment for meaningful conclusions to be drawn.

Decabromodiphenyl ethane (DBDPE) was introduced in the early 1990s as an alternative to DecaBDE in plastic and textile applications (Ricklund, Kierkegaard et al. 2010). It was used mainly in wire coatings and polystyrene, in both cases as a replacement for DecaBDE. This widespread contaminant is a highly hydrophobic compound (with a log Kow of 11.1); (Covaci, Harrad et al. 2011). DBDPE has been identified in sewage sludge (De la Torre, Concejero et al. 2012), indoor dust (Julander, Westberg et al. 2005, Ali, Harrad et al. 2011) outdoor dust (Muenhor, Harrad et al. 2010, Anh, Tomioka et al. 2018), chicken eggs (Tlustos, Fernandes et al. 2010), and food in general (Tlustos, Fernandes et al. 2010, Shi, Zhang et al. 2016).

BTBPE was first produced in the 1970s and is used as a replacement for OctaBDEs (Hoh, Zhu et al. 2005). It has been identified in various abiotic media (dust, the atmosphere, sediment, water) and biotic media (zooplankton, mussels, fish, aquatic birds' eggs, honey, chicken eggs, or food in general) (Hoh, Zhu et al. 2005, Julander, Westberg et al. 2005, Ali, Harrad et al. 2011, Wu, Guan et al. 2011, Mohr, García-Bermejo et al. 2014, Poma, Volta et al. 2014, Petrlik 2016, Petrlik, Kalmykov et al. 2017, Anh, Tomioka et al. 2018).

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3 The group of emerging BFRs included: BEH-TEBP – Bis(2-ethylhexyl) tetrabromophthalate, BTBPE – 1,2-Bis(2,4,6-tribromophenoxy) ethane, DBDPE – Decabromodiphenyl ethane, DBE-DBCH – 4-(1,2-Dibromoethyl)-1,2-dibromocyclohexane, DBHCTD – 5,6-Dibromo-1,10,11,12,13,13-hexachloro-11-tricyclo[8.2.1.02,9]tridecene, EH-TBB – 2-Ethylhexyl 2,3,4,5-tetrabromobenzoate, HBB – 1,2,3,4,5,6-Hexabromobenzene, HCTBPH – 1,2,3,4,7,7-Hexachloro-5-(2,3,4,5-tetra-bromophenyl)- bicyclo[2.2.1]hept-2-ene, OBTMPI – Octabromotrimethylphenyl indane (OBIND in this study), PBB-Acr – Pentabromobenzyl acrylate, PBEB – Pentabromoethylbenzene, PBT – Pentabromotoluene, TBNPA – Tribromoneopentyl alcohol, TDBP-TAZTO – 1,3,5-Tris(2,3-dibromopropyl)-1,3,5-triazine-2,4,6-trione, TBCO – 1,2,5,6-Tetrabromocyclooctane, TBX – 1,2,4,5-Tetrabromo-3,6-dimethylbenzene, and TDBPP – Tris(2,3-dibromopropyl) phosphate.

4 The group of novel BFRs included: BDBP-TAZTO – 1,3-Bis(2,3-dibromopropyl)-5-allyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione, DBNPG – Dibromoneopentyl glycol, DBP-TAZTO – 1-(2,3-Dibromopropyl)-3,5-diallyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione, DBS – Dibromostyrene, EBTEBPI – N,N'-Ethylenebis(tetrabromophthalimide), HBCYD – Hexabromocyclododecane (HBCD or HBCDD are more of the abbreviations used for this chemical, already listed in Annex A to the Stockholm Convention), HEEHP-TEBP – 2-(2-Hydroxyethoxy)ethyl 2-hydroxypropyl 3,4,5,6-tetrabromophthalate, 4'-PeBPO-BDE208 – Tetradecabromo-1,4-diphenoxybenzene, TTBNPP – Tris(tribromoneopentyl) phosphate, and TTBP-TAZ – Tris(2,4,6-tribromophenoxy)-s-triazine.

This compound has the ability to bioaccumulate and to biomagnify in aquatic food webs (Law, Halldorson et al. 2006, Wu, Guan et al. 2011). Similarly, to DecaBDE, a commercial mixture of BTBPE was found to contain brominated dioxins (PBDD/Fs) and/or to support their formation during the treatment of ABS plastic (Tlustos, Fernandes et al. 2010, Ren, Zeng et al. 2017, Zhan, Zhang et al. 2019). BTBPE has been measured in increased concentrations in Indonesia during passive air sampling conducted in 2005–2006 (Lee, Sverko et al. 2016).

HBB has commonly been used for the manufacture of paper, wood, textiles, plastics, and electronic goods (Yamaguchi, Kawano et al. 1988, Watanabe and Sakai 2003) and it is *"likely widely distributed, as verified both by chemical analysis and estimated properties"* (Arp, Møskeland et al. 2011).

The laboratory at the Department of Food Chemistry and Analysis of the University of Chemistry and Technology, Prague, routinely measures six nBFRs in environmental samples, including the egg samples for this study: 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE), decabromodiphenyl ethane (DBDPE), hexabromobenzene (HBB), octabromo-1,3,3-trimethylpheny-1-indane (OBIND), 2,3,4,5,6-pentabromoethylbenzene (PBEB), and pentabromotoluene (PBT).

Out of this group, BTBPE, DBDPE, and HBB are monitored more often in environmental samples (Munschy, Héas-Moisan et al. 2011, Mohr, García-Bermejo et al. 2014, Poma, Volta et al. 2014, Vorkamp, Bossi et al. 2015).

2.2.2 Unintentionally produced POPs

There is a large group of POPs which were not produced intentionally and added to any products but they occurred as unintentional by-products at any phase of the production of chemicals or disposal of waste containing halogenated compounds. These POPs are listed in Annex C to the Stockholm Convention (Stockholm Convention 2010). We have also added polybrominated dioxins (PBDD/Fs), which are not yet listed in Annex C, to our study.

2.2.2.1 Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs)

Dioxins belong to a group of 75 polychlorinated dibenzo-p-dioxin (PCDD) congeners and 135 polychlorinated dibenzofuran (PCDF) congeners, of which 17 are of toxicological concern. Levels of PCDD/Fs and dl PCBs are expressed in total WHO-TEQ, calculated according to toxic equivalency factors (TEFs) set by a WHO expert panel in 2005 (van den Berg, Birnbaum et al. 2006). These WHO TEFs were used to evaluate dioxin-like toxicity in the pooled samples of chicken eggs, soils, sediments, and dust samples in this study.

Chlorinated dioxins (PCDD/Fs) are known to be extremely toxic. Numerous epidemiological studies have revealed a variety of human health effects linked to chlorinated dioxin exposure, including cardiovascular disease, diabetes, cancer, porphyria, endometriosis, early menopause, alteration of testosterone and thyroid hormones, and an altered immune system response, among others (White and Birnbaum 2009, Schecter 2012). Laboratory animals given dioxins suffered a variety of effects, including an increase in birth defects and stillbirths. Fish exposed to these substances died shortly after the exposure ended. Food (particularly from animals) is the major source of exposure for humans (BRS 2017).

Chlorinated dioxins became known to the public in the 1970s as a result of contamination with Agent Orange, a defoliant pesticide mixture sprayed by the U.S. during the Vietnam War.[5] The production of 2,4,5 T pesticide as a basic ingredient for Agent Orange left one of the most seriously contaminated sites in Europe (Zemek and Kocan 1991, Kubal, Fairweather et al. 2004, Weber, Gaus et al. 2008) and workers sick with

5 According to estimates provided by the Government of Vietnam, 400,000 people were killed or maimed by the pesticide; 500,000 children were born with birth defects ranging from retardation to spina bifida, and an additional two million people have suffered cancers or other illnesses, which also can be related to dioxins as impurities in the Agent Orange mixture. It is estimated that in total, the equivalent of at least 366 kilograms of pure dioxin were dropped. (York and Mick 2018) many symptoms of exposure to the most toxic of dioxin congeners, 2,3,7,8-TCDD (Pelclová, Urban et al. 2006, Bencko and Foong 2013).

2.2.2.2 Dioxin-like polychlorinated biphenyls (dl PCBs)

Polychlorinated biphenyls (PCBs) are a group of 209 different congeners that can be divided into two groups according to their toxicological properties: 12 congeners exhibit toxicological properties similar to dioxins and are often referred to as "dioxin-like PCBs" (dl PCBs). They are suggested to be a part of the total TEQ levels (van den Berg, Birnbaum et al. 2006), and this study includes their levels in total PCDD/Fs + dl PCBs TEQ concentrations in all samples except HNK-SOIL-01.

The other PCB congeners do not exhibit dioxin-like toxicity but have a different toxicological profile and are referred to as "non-dioxin-like PCBs" (ndl PCBs) (European Commission 2011).

2.2.2.3 Polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs)

There are also other unintentionally produced POPs that are not yet listed in the Stockholm Convention. With the broad use of brominated flame retardants, the question has arisen about the presence of polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs)[6] in the food chain, as they are found in different environmental compartments (Kannan, Liao et al. 2012). The WHO expert panel has concluded that polybrominated dibenzo-p-dioxins (PBDDs), dibenzofurans (PBDFs), and some dioxin-like polybrominated biphenyls (dl PBBs) may contribute significantly to daily human background exposure to the total dioxin toxic equivalencies (TEQs) (van den Berg, Denison et al. 2013).

PBDD/Fs are the most relevant group of unintentionally produced POPs in the sites that were sampled with e-waste and/or plastic waste which may contain brominated flame retardants, like those in Agbogbloshie, Ghana, and Samut Sakhon, Thailand, respectively (Teebthaisong, Petrlík et al. 2018, Hogarh, Petrlik et al. 2019).

PBDD/Fs have been known to be potential by-products of commercial PBDE mixtures since 1986 (Buser 1986). They were also found to be by-products of some novel BFRs such as DBDPE (Brenner and Knies 1990) or BTBPE (Ren, Zeng et al. 2017, Zhan, Zhang et al. 2019). This is similar to the chlorinated dioxins that have been observed as impurities in PCBs and other chlorinated chemicals. PBDFs have also been found to be formed by sunlight exposure during normal use, as well as during the disposal/recycling processes of flame-retarded consumer products (Kajiwara, Noma et al. 2008). Some studies found PBDD/Fs in copper metal recycling (Mei, Guorui et al. 2015), in the air around a waste incinerator plant (Gao, Zhang et al. 2014), around an open burning site (Gullett, Wyrzykowska et al. 2010), and, recently, in children's toys (Budin, Petrlik et al. 2020). PBDD/Fs are similar to PCDD/Fs; however, they have been studied less extensively than their chlorinated analogues.

PBDD/Fs have been found to exhibit similar toxicity and health effects to their chlorinated analogues (PCDD/Fs) (Mason, Denomme et al. 1987, Behnisch, Hosoe et al. 2003, Birnbaum, Staskal et al. 2003, Kannan, Liao et al. 2012, Piskorska-Pliszczyńska and Maszewski 2014). They can, for example, affect brain development, damage the immune system and foetus, or induce carcinogenesis (Kannan, Liao et al. 2012). *"Both groups of compounds show similar effects, such as induction of aryl hydrocarbon hydroxylase (AHH)/EROD activity, and toxicity, such as induction of wasting syndrome, thymic atrophy, and liver toxicity"* (Behnisch, Hosoe et al. 2003).

In general, brominated dioxins are less regulated than chlorinated dioxins. For example, PBDD/Fs are not currently listed under the Stockholm Convention (Stockholm Convention 2010), although there is clear evidence that they display very similar properties to PCDD/Fs, which have been listed in Annex C of the

6 The synonym "brominated dioxins" is used for this group of chemicals as well, while "dioxins" applies for PCDD/Fs. We use both these shorter synonyms in this report.

Convention since its origin in 2001. In 2010, the Stockholm Convention POPs Review Committee recommended further assessment of PBDD/Fs, including *"releases from smelters and other thermal recovery technologies, including secondary metal industries, cement kilns and feedstock recycling technologies"* (POP RC 2010).

2.2.2.4 Hexachlorobenzene (HCB), pentachlorobenzene (PeCB), hexachlorobutadiene (HCBD)

Pentachlorobenzene (PeCB) and hexachlorobenzene (HCB) are primarily produced unintentionally during combustion, as well as during thermal and industrial processes. They also occur as a by-product during the production of chlorinated hydrocarbons such as perchloroethylene, trichloroethylene, carbon tetrachloride, or pesticides. In the past, they were produced intentionally as pesticides or technical substances. Perchloroethylene is widely used in dry cleaning, and trichloroethylene and carbon tetrachloride have been used extensively as degreasing agents and as solvents for other chlorine-containing compounds. PeCB was used as a component in PCB products, in dyestuff carriers, as a fungicide, as a flame retardant, and as a chemical intermediate for the production of the pesticide quintozene (POP RC 2008).

In high doses, HCB is lethal to some animals and, at lower levels, adversely affects their reproductive success. Researchers also found out that HCB, similarly to other organochlorinated compounds, has a transplacental transfer (Sala, Ribas-Fitó et al. 2001). HCB has been found in food of all types (BRS 2017).

Although globally, the consumption of HCB-contaminated food is the primary source of HCB exposure, other potential exposure pathways include the inhalation of HCB-contaminated air, skin contact, in utero exposure, and from breast milk (Reed, Büchner et al. 2007). The study also found that in addition to cancer, the human health effects associated with HCB exposure encompass systemic impairment (thyroid, liver, bone, skin) and damage to the kidneys and blood cells, as well as the immune and endocrine systems. It also causes a teratogenic effect, and impairs nervous systems.

PeCB is very toxic to aquatic organisms and may cause long-term adverse effects in the aquatic environment (POP RC 2007).

Hexachlorobutadiene (HCBD) occurs as a by-product during the production of the same chlorinated hydrocarbons as PeCB and HCB, as a part of the so-called "hexa-residues". It is also formed unintentionally during the incineration processes of such substances as acetylene and chlorine residues. HCBD is very toxic to aquatic organisms, and has been shown to cause kidney damage and cancer in animal studies as well as chromosomal aberrations in occupationally exposed humans (Pohl, McClure et al. 2001, POP RC 2012, Balmer, Hung et al. 2019). Systemic toxicity following exposure via oral, inhalation, and dermal routes may include fatty liver degeneration, epithelial necrotising nephritis, potentially causing chronic inflammation, central nervous system depression, and cyanosis (BRS 2017, Balmer, Hung et al. 2019).

3. SAMPLING AND ANALYTICAL METHODS

3.1 Sampling

For sampling in this study, we chose two sites near factories which handle electronic waste. They declare their focus to be recycling. However, the e-waste is mainly dismantled and only metal parts are recycled there in the factories. Residual waste, including plastic, is often burned in some kind of incineration operations. The Basel Action Network (BAN) which visited inside one of these factories, *"observed it mass melting/burning circuit boards and belching out dioxin-laden, carcinogenic smoke over the dairy farms in the area"* (BAN 2018).

We took samples of soils, sediments, dust, and free-range duck eggs. The widest range of samples was taken in the surroundings of a so-called "dioxin factory", belonging to Supcharoen Recycle Co. Ltd. located in Khao Hin Son, Phanom Sarakham, Chachoengsao province in the western part of the community. Reference samples of dust, soil, and sediment were taken in a clean area of an organic farm in Na Somboon, Don Somboon subdistrict, Yang Talat District, Kalasin province. A reference sample of chicken eggs was obtained in a supermarket in Maha Sarakham in February 2022.

All samples were collected as pooled samples composed of multiple individual samples. Pooled samples of soil were composed from three to ten point samples; the specification for each sample is given in Table 2. Soil was taken at a depth of 2 to 10 cm from the surface with a stainless steel shovel. Sediment samples were also taken with a stainless steel shovel since core sampling was not an appropriate tool for sampling at the Khao Hin Son locations. However, a core plastic tube was used for the sampling of a reference sample in Na Somboon. Samples of soil and sediment were homogenised in a stainless steel bowl. Pooled samples of sediment were composed of three to five point samples; the specification for each sample is given in Table 2. The quartering was done in case the composite sample was too large.

Dust samples were collected using brushes, always in several strips on a surface area between 2.25 and 9 m^2, depending on the individual circumstances at the sample site. Individual strips are considered here as individual samples of dust. The number of individual samples is specified in Table 2. Sampling equipment was cleaned with distilled water and technical alcohol (shovel and bowl) and/or used for one composite sample only (brushes). Brushes were checked for potential total bromine or chlorine content with handheld XRF before they were used for sampling. None of them contained any brominated or chlorinated compounds, according to the results. Only brushes with wooden handles were used.

The eggs were collected into typical plastic egg packaging and were boiled for approximately seven minutes. The homogenates from the edible parts of the eggs were used for the analyses in the laboratories. The numbers of individual eggs in the pooled samples are specified in Table 2 and ranged from five to six eggs in each pooled sample.

Sediment samples were transported in 250-ml PE plastic containers, and soil and dust samples were transported to the laboratory in PE plastic ziplock bags. All samples were kept in cool conditions during storage and transportation.

We also report in this study about the results of the analyses from the Hat Nang Kaeo site, where unknown waste sludge or similar waste was observed being dumped. One pooled sample of potentially contaminated soil next to the dumping area was taken and analysed for some POPs.

A brief overview of the samples is given in **Table 2**.

Table 2: Overview of samples taken for this study in November 2019 and February 2022 respectively.

Locality	Sample ID	Matrix	Sampling date	No of individual samples in pooled sample
Near Supcharoen Recycle Co. Ltd. factory	KH-S-1	soil	11 Nov 2019	10
Khao Hin Son - Nong Khok	SCN-DUST-01	dust	04 Feb 2022	6
	SCN-DUST-02	dust	04 Feb 2022	4
	SCN-SED-01	sediment/waste sludge	04 Feb 2022	3
	SCN-SED-02	sediment	04 Feb 2022	5
	SCN-EGG-01/22	duck eggs	04 Feb 2022	6
Khao Hin Son Moo 1	CT-KHS-SOIL-1	soil	03 Feb 2022	5
	CT-KHS-DUST-1	dust	03 Feb 2022	6
Hat Nang Kaeo	HNK-SOIL-01	soil	03 Feb 2022	3
Na Somboon	NS-S-01 (ref)	soil	11 Feb 2022	5
	NSD-02 (ref)	dust	11 Feb 2022	6
	NS-SED-01 (ref)	sediment	11 Feb 2022	5
Maha Sarakham	TH-REF-EGG 2022	chicken eggs	11 Feb 2022	5

3.2 Analytical methods

Thirteen samples in total were analysed for this study. All samples were analysed for their content of seven indicator PCB congeners, hexachlorobutadiene (HCBD), pentachlorobenzene (PeCB), hexachlorobenzene (HCB), 16 PBDE congeners, three HBCD isomers, six novel BFRs[7] (nBFRs), and tetrabromobisphenol A (TBBPA). All samples except KH-S-1 were also analysed for 13 PCN congeners.[8]

The analytes were extracted by a mixture of organic solvents, hexane: dichloromethane (1:1). The extracts were cleaned by means of gel permeation chromatography (GPC). The identification and quantification of the analyte were conducted by gas chromatography coupled with tandem mass spectrometry detection in electron ionisation mode for the analyses of PCBs, HCBD, PeCB, HCB, and PCNs.

The identification and quantification of PBDEs and nBFRs were performed using gas chromatography coupled with mass spectrometry in negative ion chemical ionisation mode (GC-MS-NICI). The identification and quantification of HBCD isomers and TBBPA were performed by liquid chromatography interfaced with tandem mass spectrometry, with electrospray ionisation in negative mode (UHPLC-MS/MS-ESI).

Four reference samples, two sediments and duck eggs from Nong Khok, and a soil sample from Hat Nang Kaeo were also analysed for short chain chlorinated paraffins (SCCPs).

The extract, which was prepared in the same way as for the other analyses, was transferred into cyclohexane and diluted. The identification and quantification of SCCPs were performed via gas chromatography/time-of-flight high resolution mass spectrometry (GC/TOF-HRMS) in the mode of negative chemical ionisation (NCI).

7 This group of chemicals is represented by the following chemicals: 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE), decabromodiphenyl ethane (DBDPE), hexabromobenzene (HBB), octabromo-1,3,3-trimethylpheny-1-indan (OBIND), 2,3,4,5,6-pentabromoethylbenzene (PBEB), and pentabromotoluene (PBT).

8 PCN 4, PCN 9, PCN 18, PCN 20, PCN 41, PCN 42, PCN 52, PCN 56, PCN 66, PCN 70, PCN 73, PCN 74, and PCN 75.

All of the above-mentioned analyses were conducted in a Czech-certified laboratory (University of Chemistry and Technology, Department of Food Chemistry and Analysis).

All samples except the soil sample from Hat Nang Kaeo were analysed for their content of individual PCDD/Fs, twelve dioxin-like PCB congeners, and for polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs) by HRGC-HRMS in the MAS laboratory, Münster, Germany. The accredited MAS_PA002, ISO/IEC 17025:2005 method was used to determine PBDD/Fs. The basic steps of the analyses can be summarised as follows:

1. addition of $^{13}C_{12}$-labelled PBDD/F internal standards to the sample extract
2. multi-step chromatographic clean-up of the extract
3. addition of $^{13}C_{12}$-labelled PBDD/F recovery standards
4. HRGC/HRMS analysis

Quantification was performed according to the internal labelled PBDD/F standards (isotope dilution technique and internal standard technique).

All the results are summarised in **Tables 2-4**.

4. DESCRIPTION OF SAMPLED LOCALITIES AND RESULTS OF THE ANALYSES

4.1 Khao Hin Son Moo 9 – Nong Khok

Nong Khok is a village in Moo 9, Khao Hin Son subdistrict, Phanom Sarakham district, Chachoengsao province, located in the eastern region of Thailand. It is located south of the so-called "dioxin factory" (see Photos 1 – 3), which is a synonym chosen in the BAN report for the electronic waste dismantling facility (BAN 2018). It is located in the neighbourhood of a Buddhist temple. Nong Khok is located approximately 400 metres southwest of the "dioxin factory". Two samples of dust, two sediment samples, and one pooled sample of free-range duck eggs were taken in Nong Khok in February 2022. One sediment sample was taken in a pond where ducks forage and another sediment sample was taken from a little wetland on the edge of the pond. It was contaminated with a kind of waste sludge residue dumped here (see Photo 8). The dust samples were taken near the open space living area of the family (SCN-DUST-01; see Photos 4-5) and on the edge of the village at the border with a field (SCN-DUST-02; Photo 6) on a small pathway on the wall of the local pond. One pooled soil sample from the edge of the forest at a distance of 50 metres from the factory and ten metres from the fenced area respectively was taken in November 2019 (KH-S-1).

The results of the analyses for this site are summarised in **Table 3**.

Photo 1: So called "dioxin factory" Supcharoen Co. Ltd., November 2019. *Photo by Jindrich Petrlik, Arnika.*

Photo 2: Aerial view at "dioxin factory", e-waste recycling plant near Nong Khok village, which is partly visible on the top at this view, October 2019. Sample KH-S-1 was taken in one line on the edge of the forest on left side of this picture.
Photo by © Karnt Thassanaphak, EARTH.

Photo 3: Aerial view at "dioxin factory", e-waste recycling plant near Nong Khok village, closer view at part with technology, where residues from e-waste are incinerated.
Photo by © Karnt Thassanaphak, EARTH.

Table 3: Summarised results of the analyses of the samples from Nong Khok. The results are in ng/g of dry matter for dust, soil, and sediment and in ng/g of fat for eggs respectively if not specified otherwise.

Locality	Khao Hin Son - Nong Khok					
Sample ID	KH-S-1	SCN-DUST-01	SCN-DUST-02	SCN-SED-01	SCN-SED-02	SCN-EGG-01/22
Matrix	Soil	Dust	Dust	Sediment	Sediment	Eggs
Fat content (%)	/	/	/	/	/	16.30%
PCDD/Fs (pg WHO-TEQ/g)	19	14.6	14.4	<27.9	2.5	61
DL PCBs (pg WHO-TEQ/g)	1.06	1.43	1.04	10.7	<0.41	11
Total PCDD/F + DL PCBs (pg WHO-TEQ/g)	21	16	15.4	10.7	2.5	72
PBDD/Fs	18	10.2	3.9	NA	3.1	8.4
HCBD	<0.02	<0.02	<0.02	<0.02	<0.02	<0.10
HCB	0.42	0.17	0.10	<0.02	<0.02	6.1
PeCB	0.28	0.24	0.06	<0.02	<0.02	8.7
6 iPCB	0.19	0.20	0.33	<0.02	<0.02	2.9
7 iPCB	0.23	0.20	0.33	<0.02	<0.02	3.4
13 PCN cong.	NA	0.028	0.059	<0.02	<0.02	0.96
SCCPs	NA	NA	NA	8,215,913	60	1189
sum HBCD	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75
PBDE 209	16.5	<5.0	<5.0	<5.0	<5.0	4.0
sum of PBDEs	21	2.7	0.84	<LOQ	0.10	4.2
BTBPE	0.48	<0.01	<0.01	<0.01	<0.01	<0.30
DBDPE	52	<10.0	<10.0	<10.0	<10.0	<3.3
HBBz	0.91	<0.01	<0.01	0.43	0.20	<0.20
OBIND	<0.1	<0.10	<0.10	<0.10	<0.10	<4.2
PBEB	<0.01	<0.01	<0.01	<0.01	<0.01	<4.2
PBT	<0.01	<0.01	<0.01	0.031	0.022	<4.2
sum of nBFRs	53	<10.0	<10.0	0.46	0.22	<4.2
TBBPA	<1.5	<1.5	<1.5	<1.5	<1.5	<4.2

Photo 4: Sampling of the dust in Nong Khok village, February 2022. *Photo by Jindrich Petrlik, Arnika.*

Photo 5: Lines after dust sampling, SCN-DUST-01, February 2022. *Photo by Jindrich Petrlik, Arnika.*

Photo 6: Dust sample SCN-DUST-02 shown by samplers from EARTH and Arnika, February 2022. “Dioxin factory” is a chimney visible next to head of one of samplers. *Photo by Jindrich Petrlik.*

Photo 7: Free-range duck in Nong Khok, near area with sediment contaminated with industrial sludge. *Photo by Jindrich Petrlik.*

Photo 8: Sampling of contaminated sediment in Nong Khok, February 2022. *Photo by Jindrich Petrlik.*

4.2 Khao Hin Son Moo 1

CT Steel Co. Ltd. is the name of a factory that conducts melting of metal parts from electronic wastes. It is located in Moo 1 "Ban Muang Phrong" village, Khao Hin Son subdistrict, Phanom Sarakham district, Chachoengsao province (see Photos 9–11). The factory is located close to the southern edge of the BB Green farm, in the middle of agricultural land with many ponds.

The factory received a permit for recycling e-waste in 2020, but locals stated that the factory has been operating since 2019. Locals have complained of bad smells and dust in the area. There was also a fire in the factory in April 2021.

Our sampling sites were about 100 metres to the north of the fence of the factory. We took one pooled sample of dust (see Photo 12) and one pooled sample of soil (see Photo 14).

The results of the analyses for this site are summarised in **Table 4**.

Photo 9: View at factory of CT Steel company in Khao Hin Son, February 2022. *Photo by Jindrich Petrlik,* Arnika.

Photo 10: Aerial view at CT Steel Co. Ltd., one of the electronic waste recycling factories located in Moo 1 "Ban Muang Phrong" *Photo by © Karnt Thassanaphak, EARTH.*

Photo 11: Aerial view at CT Steel Co. Ltd., one of the electronic waste recycling factories located in Moo 1 "Ban Muang Phrong" village, Khao Hin Son subdistrict, Phanom Sarakham district, Chachoengsao province. *Photo by © Karnt Thassanaphak, EARTH.*

Photo 12: Sampling of dust near CT Steel factory, February 2022. *Photo by Jindrich Petrlik, Arnika.*

Photo 13: Experts from EARTH measure VOCs in the area near CT Steel factory, February 2022. *Photo by Jindrich Petrlik, Arnika.*

Photo 14: Soil sampling near CT Steel factory. *Photo by Jindrich Petrlik, Arnika.*

4.3 Hat Nang Kaeo

In a patch of land surrounded by cassava fields and near rice fields in Moo 6 village, Hat Nang Kaeo sub-district, Kabin Buri district, Prachinburi province, eastern region of Thailand, an unknown industrial waste sludge was dumped over an 24 000 metre square area. Regional environmental agencies investigated the area in January 2022. Interviews with people in the area suggest the illegal dumping may have occurred earlier in 2021.

The results of the analyses for this site are summarised in **Table 4** below.

Photo 15: Sampling of contaminated soil in Hat Nang Kaeo, February 2022. *Photo by Jindrich Petrlik, Arnika.*

Photo 16: Visible contamination of the soil with industrial sludges in Hat Nang Kaeo. *Photo by Jindrich Petrlik, Arnika.*

Table 4: **Summarised results of the analyses of the samples from the Hat Nang Kaeo and Khao Hin Son Moo 1 sites. The results are in ng/g of dry matter if not specified otherwise.**

Locality	**Hat Nang Kaeo**	**Khao Hin Son Moo 1**	
Sample ID	HNK-SOIL-01	CT-KHS-SOIL-1	CT-KHS-DUST-1
Matrix	Soil	Soil	Dust
PCDD/Fs (pg WHO-TEQ/g)	NA	1.15	2.33
DL PCBs (pg WHO-TEQ/g)	NA	0.41	0.43
Total PCDD/F + DL PCBs (pg WHO-TEQ/g)	NA	1.56	2.76
PBDD/Fs	NA	3.32	4.32
HCBD	<0.02	<0.02	<0.02
HCB	<0.02	<0.02	0.17
PeCB	<0.02	<0.02	0.075
6 iPCB	51	<0.02	0.022
7 iPCB	51	<0.02	0.022
13 PCN cong.	<0.02	<0.02	0.031
SCCPs	45,299	NA	NA
sum HBCD	<0.02	<0.02	<0.02
PBDE 209	<5.0	<5.0	<5.0
sum of PBDEs	<5.0	<5.0	0.3
BTBPE	<0.01	<0.01	<0.01
DBDPE	<10.0	<10.0	<10.0
HBBz	<0.01	<0.01	<0.01
OBIND	<0.10	<0.10	<0.10
PBEB	<0.01	<0.01	<0.01
PBT	<0.01	<0.01	<0.01
sum of nBFRs	<10.0	<10.0	<10.0
TBBPA	<1.5	<1.5	<1.5

4.4 Na Somboon – organic farm, reference site

The organic farm used for the reference site is located in Na Somboon village, Don Somboon subdistrict, Yang Talat district, Kalasin province, in Northeastern Thailand. The organic farm raises buffalo, cows, and chicken, as well as planting a number of crops. The sample of dust included in this study (NSD-02) comes from the road located near the open space living area (kitchen and dining space) but not from the living area itself, where another sample (NSD-01) not suitable for comparison with the samples in this study was taken.

The soil sample was taken in a meadow near to housing for buffaloes (see Photo 23) on the organic farm (see Photos 18 and 19). It was a composite sample from five point samples in a square 3x3 metres. A composite sample of sediment from five individual samples taken with a core tube device was taken in a small backyard pond on the organic farm (see Photo 20).

The results of the analyses of reference samples, including eggs from a supermarket in Maha Sarakham, are summarised in **Table 5**.

Table 5: Summarised results of the analyses of the reference samples from the Na Somboon organic farm (dust, soil, and sediment) and a supermarket in Maha Sarakham (chicken eggs). The results are in ng/g of dry matter for dust, soil, and sediment and in ng/g of fat for eggs, respectively, if not specified otherwise.

Locality	Na Somboon – organic farm – reference site			Reference egg
Sample ID	NSD-02	NS-S-01	NS-SED-01	TH-REF-EGG 2022
Matrix	Dust	Soil	Sediment	Eggs
Fat content (%)	/	/	/	11.4%
PCDD/Fs (pg WHO-TEQ/g)	<0.63	<0.63	0.64	0.53
DL PCBs (pg WHO-TEQ/g)	<0.41	<0.41	<0.41	0.15
Total PCDD/F + DL PCBs (pg WHO-TEQ/g)	<LOQ	<LOQ	0.64	0.68
PBDD/Fs	<2.99	<2.76	<2.99	<1.2
HCBD	<0.02	<0.02	<0.02	<0.10
HCB	0.755	<0.02	<0.02	<0.10
PeCB	1.62	0.037	<0.02	0.578
6 iPCB	<0.02	<0.02	<0.02	<0.20
7 iPCB	<0.02	<0.02	<0.02	<0.20
13 PCN cong.	<0.02	<0.02	<0.02	<0.20
SCCPs	68	26	<5.0	641
sum HBCD	<0.75	<0.75	<0.75	<4.2
PBDE 209	<5.0	<5.0	<5.0	<1.5
sum of PBDEs	<5.0	<5.0	<5.0	<LOQ
BTBPE	<0.01	<0.01	<0.01	<0.30
DBDPE	<10.0	<10.0	<10.0	<3.3
HBBz	<0.01	<0.01	<0.01	<0.20
OBIND	<0.10	<0.10	<0.10	<4.2
PBEB	<0.01	<0.01	<0.01	<4.2
PBT	<0.01	<0.01	<0.01	<4.2
sum of nBFRs	<10.0	<10.0	<10.0	<4.2
TBBPA	<1.5	<1.5	<1.5	<4.2

Photo 17: Research team of EARTH and Arnika on visit at organic farm in Na Somboon, February 2022. *Photo by Jindrich Petrlik, Arnika.*

Photo 18: Organic farm Na Somboon, view at a meadow where a reference sample of soil was taken. *Photo by Jindrich Petrlik, Arnika.*

Photo 19: Reference sample of soil from Na Somboon, view at homogenization of the sample. *Photo by Jindrich Petrlik, Arnika.*

Photo 20: A small pond in Na Somboon, a site of reference sample of sediment. *Photo by Jindrich Petrlik, Arnika.*

Photo 21: Gecko at organic farm Na Somboon. *Photo by Jindrich Petrlik, Arnika.*

Photos 22 and 23: Animals at organic farm Na Somboon. *Photos by Jindrich Petrlik, Arnika.*

5. RESULTS AND DISCUSSION

5.1 Intentionally produced POPs

5.1.1 Non-dioxin-like PCBs (ndl PCBs)

The non-dioxin-like PCBs represented by indicator congeners in this study were measured at the relatively high level of 51 ng/g dw in a sample from Hat Nang Kaeo. This shows the potential contamination of the site with hazardous industrial waste, oils, or sludge.

The levels of ndl PCBs were either below the level of quantification (LOQ) and/or 1 ng/g dw in all the other samples in this study. They were measured at the level of 2.9 ng/g fat for six PCB indicator congeners in the pooled sample of duck eggs from Nong Khok, which is less than one-tenth of the limit value of 40 ng/g fat set for eggs in the EU (European Commission 2016). It is also a level comparable to what was measured in pooled samples of free-range chicken eggs in Saraburi, in the vicinity of the Praeksa landfill, or in the Map Ta Phut area (Petrlik, Teebthaisong et al. 2018). It is lower in comparison to the levels between 7 and 11 ng/g fat measured in the egg samples from Samut Sakhon, and much lower in comparison with the samples from contaminated sites in Kazakhstan (Petrlik, Teebthaisong et al. 2018) or levels in the range of 9-42 ng/g fat in the samples from a contaminated site in the Czech Republic (Mach, Petrlík et al. 2016)

5.1.2 PCNs

In most of the samples the levels of PCNs were below LOQ; only two dust samples and the pooled sample of duck eggs from Nong Khok and one dust sample from Khao Hin Son Moo 1 had concentrations above LOQ but they were not very high anyway, being several times lower than in samples from the e-waste site in Agbogbloshie, Ghana (Petrlik, Adu-Kumi et al. 2019).

The level in the duck eggs of 0.955 ng/g fat is comparable to the lower levels measured in eggs from the UK or Ireland in 2007–08 (Fernandes, Rose et al. 2017).

5.1.3 SCCPs

SCCPs were measured in a contaminated soil sample from Hat Nang Kaeo and two sediments and the duck eggs from Nong Khok, as well as in the reference samples. The level of SCCPs in contaminated soil from Hat Nang Kaeo of more than 45 mg/kg dw is quite high and shows the potential contamination of the site with some industrial sludge waste. The level in one of the sediment samples from Nong Khok of more than 8,200 mg/kg dw is actually 5.5 times higher than the new low POPs content level of 1,500 mg/kg dw introduced in the EU this year (European Parliament 2022). It means that the sediment sample SCN-SED-01 would be considered as POPs waste in the EU and would have to be treated by some of the technologies for the destruction of POPs as they are listed in the General Technical Guidelines for POPs Waste of the Basel Convention (Basel Convention 2022). The sediment sample was contaminated with some sludge brought to the place in a barrel from the recycling factory in Moo 9. It is sixteen times higher than the highest level of 554 ng/g dw measured in soil inside a chlorinated paraffins factory in China (Wang, Zhao et al. 2018).

The other sediment sample SCN-SED-02 from the little pond in Nong Khok had a much lower level of SCCPs but it was still much higher in comparison to the reference sediment from Na Somboon, which was below the LOQ of 5 ng/g dw. It reached the lower ends of the levels observed near areas where chlorinated paraffins were produced (Guida, Capella et al. 2020).

The concentration of SCCPs in the sample of duck eggs was quite high, 1,189 ng/g fat. It reached more than half of the level of 2,067 ng/g fat measured in eggs from the Agbogbloshie e-waste scrap yard (Petrlik, Adu-Kumi et al. 2019) or the level of 1,950 ng/g fat in eggs from the vicinity of the Baskuduk landfill (Adu-Kumi, Petrlik et al. 2019), and it is close to the median level in home-grown eggs in Longtang (926 ng/g fat), an e-waste site in China (Zeng, Huang et al. 2018). The levels of SCCPs in free-range eggs from Guiyu, another e-waste site in China (Zeng, Luo et al. 2016), were measured at much higher levels (between 2,300 and 150,000 ng/g fat) than in the duck eggs from Nong Khok.

Also, the level of SCCPs in the reference egg sample from a supermarket in Maha Sarakham, of 641 ng/g fat, is the highest measured level among the reference egg samples from supermarkets and/or local stores compared to e.g. the level of 62 ng/g fat in eggs from a supermarket in Accra (Adu-Kumi, Petrlik et al. 2019) or to the level of 135 ng/g fat in eggs from a supermarket in Jakarta (Petrlik, Bell et al. 2021), and it is a higher level than in some egg samples from contaminated sites such as e.g. some dumpsites and/or Samut Sakhon, where the level of SCCPs of 173 ng/g fat was measured in a sample of free-range chicken eggs (Adu-Kumi, Petrlik et al. 2019).

5.1.4 BFRs

Surprisingly, not very high levels of PBDEs were measured in the samples from the sites that were studied, although they are affected by e-waste dismantling processes. The levels of PBDEs in the soil and dust samples decreased with an increase in the distance from the Supcharoen Co. Ltd. factory. The highest level of 21 ng/g dw of the sum of PBDEs was measured in a sample of soil from close to the fence of the factory. DecaBDE showed the highest concentration among all the BDE congeners measured in that sample. Also, the level of 4.2 ng/g fat of PBDEs measured in the duck eggs from Nong Khok belongs among the rather low levels in comparison with samples from other sites, including e.g. Samut Sakhon (Petrlik, Kalmykov et al. 2017, Petrlik, Bell et al. 2021).

The levels of TBBPA and the sum of three HBCD isomers did not exceed LOQ in any of the measured samples included in this study.

The levels of nBFRs were not very high either. They were above the LOQ levels only in samples from the vicinity of the Supcharoen Recycle factory, and the highest level, 53 ng/g dw, was measured in a soil sample taken from close to the fence of the "dioxin factory". DBDPE was the main contributor to that level, with 52 ng/g dw, which is a higher level than the 16 ng/g dw measured for DecaBDE in the same sample (KH-S-1). The levels of nBFRs were above LOQ only in two sediment samples from Nong Khok but did not reach the level of 1 ng/g dw apart from the above-mentioned sample of soil. The levels of PBEB and OBIND were below LOQ in all samples in this study.

5.2 Unintentionally produced POPs

5.2.1 PCDD/Fs and dl PCBs

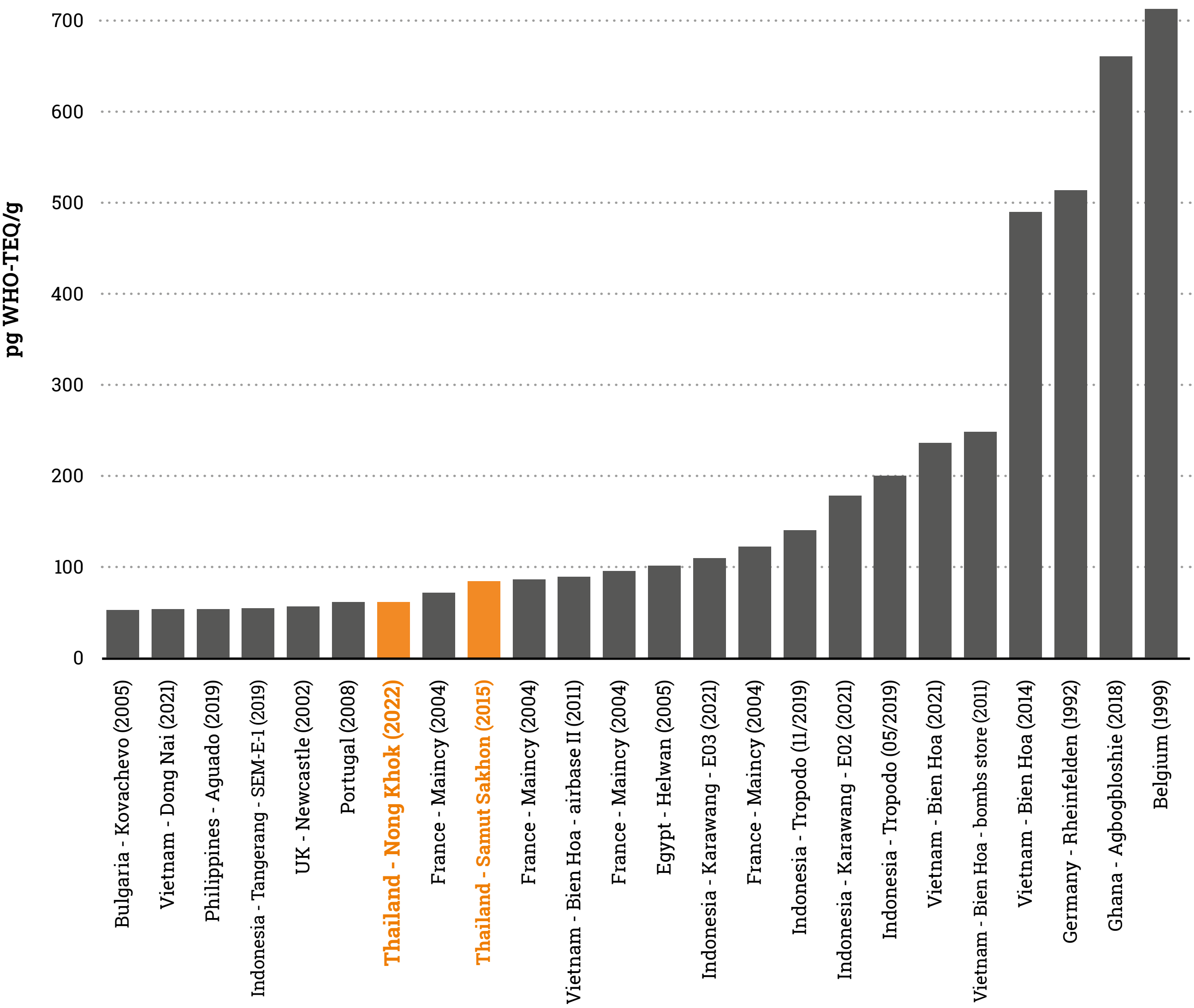
Dioxins and dioxin-like PCBs were analysed in all the samples in this study except the soil sample HNK-SOIL-01. They were measured below LOQ in the dust and soil samples from the Na Somboon reference site. Dioxins were slightly above LOQ in the sample of sediment from the reference site, but dl PCBs were also below LOQ in this sample as well as in the dust and soil samples. The levels in the reference sample of chicken eggs from a supermarket were low, at levels comparable to other egg reference samples, e.g. from Beijing or Accra (Petrlik, Teebthaisong et al. 2018, Hogarh, Petrlik et al. 2019) but higher than in supermarket eggs from Bangkok or Jakarta (Petrlik, Teebthaisong et al. 2018, Ismawati, Petrlik et al. 2021).

The highest levels were observed in the samples from Nong Khok and the vicinity of the Supcharoen factory in general. They are fifteen to twenty and two to three times higher in comparison with the reference samples in the soil and dust samples from Nong Khok and Khao Hin Son Moo 1, respectively. The levels of PCDD/Fs prevail in all the samples in comparison to dl PCBs.

The comparison of the sediment samples from Nong Khok is a little problematic since PCDD/Fs could not be analysed properly because of the high level of interference of dioxin congeners with other chemicals in one of the samples (SCN-SED-01) during the analysis and therefore LOQ was established much higher, at a level of almost 28 pg TEQ/g dw, which is 44 times higher than for the analysis in other samples. The level in another sediment sample from Nong Khok (SCN-SED-02) was not as high as in the dust or soil.

However, the level of 61 pg TEQ/g fat of PCDD/Fs in the pooled sample of free-range duck eggs from Nong Khok was very high. The level of PCDD/Fs in these eggs is the tenth-highest level ever measured in Asia, and the second-highest level measured in eggs from Thailand after the sample from Samut Sakhon, from a site where e-waste and other wastes were burned. The comparison is visible in **Figure 1**.

Figure 1: The graph shows the highest levels of PCDD/Fs measured in poultry eggs globally. The EU maximum is set at the level of 2.5 pg TEQ/g fat (European Commission 2016), which is twenty times lower compared to 50 pg TEQ/g fat which is the minimum level for a sample to be included in this graph. The levels from other sites come from a global study on PCDD/Fs and dl PCBs in eggs (Petrlik, Bell et al. 2022).

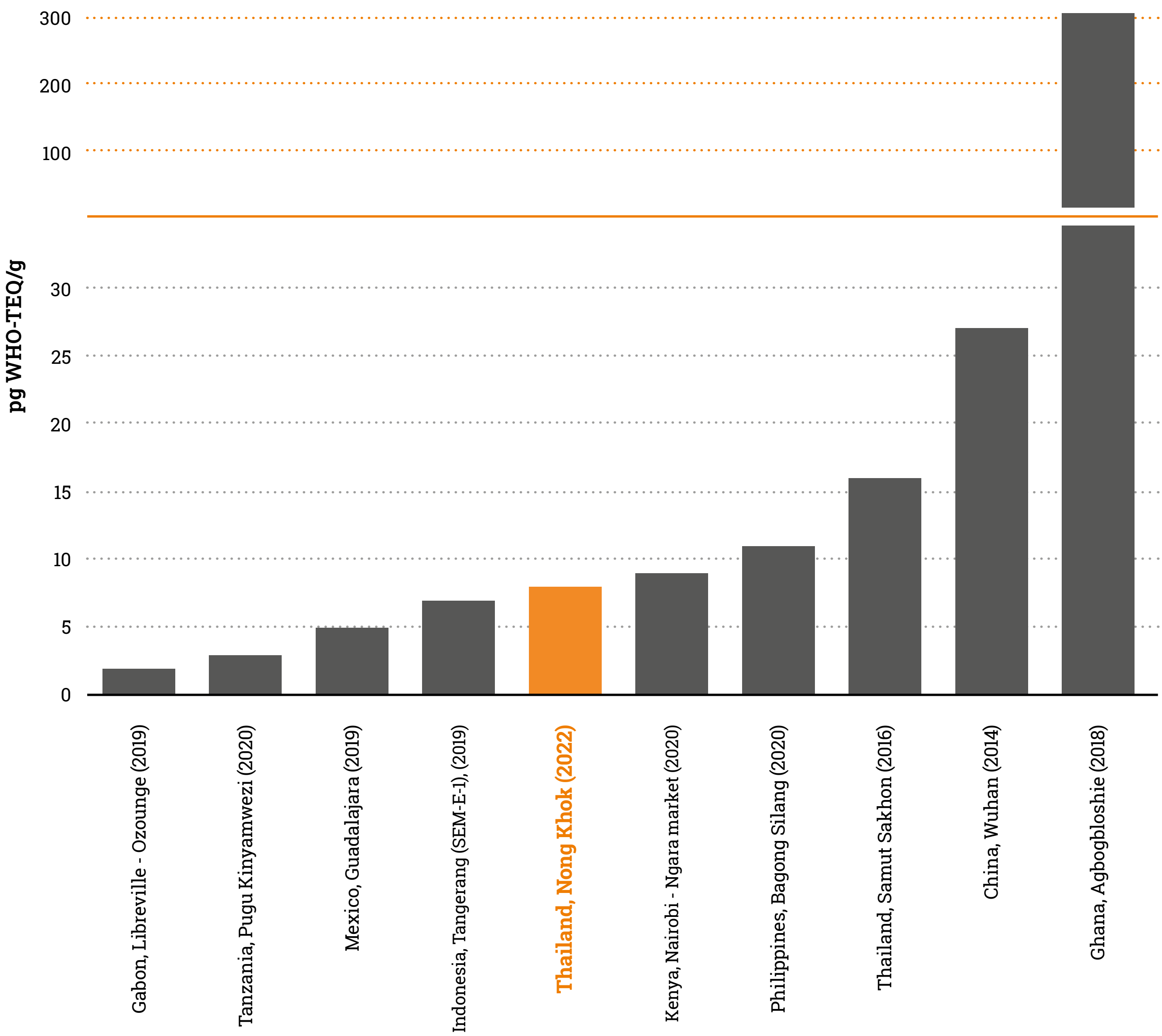


The level of PCDD/Fs and total TEQ level of PCDD/Fs and dl PCBs in the sample of duck eggs from Nong Khok exceed the maximum levels of 2.5 and 5 pg TEQ/g fat set in the EU (European Commission 2016) by more than 24 and 14 times respectively.

5.2.2 PBDD/Fs

The levels of brominated dioxins (PBDD/Fs) were also relatively high in soil from the vicinity of the Supcharoen Recycle Co. Ltd. and in one dust sample from Nong Khok (SCN-DUST-01). Their levels in the other dust and soil samples in this study were approximately at half of their levels in the previously mentioned two samples. It was impossible to conduct their analysis in the contaminated sediment sample from Nong Khok. The level of PBDD/Fs of 8.4 pg TEQ/g fat in the duck eggs from Nong Khok is the sixth-highest measured in free-range eggs from polluted sites globally (Petrlik, Bell et al. 2022); see **Figure 2**.

Figure 2: Highest levels of PBDD/Fs measured in poultry eggs globally. The sources of information about PBDD/Fs from other sites are global studies focused on PBDD/Fs in eggs (Teebthaisong, Saetang et al. 2021, Petrlik, Bell et al. 2022).



It reached half of the level measured in the sample of free-range chicken eggs from Samut Sakhon and is at almost the same level as in the eggs from the Ngara market in Nairobi, where electronic waste is dismantled.

There is no limit value set for PBDD/Fs in food. However, we can see that even the value of PBDD/Fs in the duck eggs from Nong Khok would exceed by more than three times the limit of 2.5 pg TEQ/g fat set in the EU regulation for the content of PCDD/Fs. We should take into account that PBDD/Fs are considered to have similar toxicity as their chlorinated analogues (van den Berg, Denison et al. 2013).

5.2.3 HCB, PeCB, and HCBD

Levels of HCB and PeCB below those measured in the reference samples were found in the dust samples from Nong Khok. The levels in the soil and sediment were above the levels at the reference site. Among the samples in this study the highest levels of HCB and PeCB, 6.1 and 8.7 ng/g fat respectively, were measured in the duck eggs from Nong Khok. Both these chemicals may occur as unintentionally produced POPs during the burning of chlorinated wastes, so we consider the Subcharoen Recycle Co. Ltd. factory to be a major potential source of HCB and PeCB at Nong Khok. High levels of chlorobenzenes (CBzs) were also observed at an e-waste site in Vietnam in a study from 2018 (Nishimura, Suzuki et al. 2018). However, it is hard to compare the data in this study with that study, since the samples there were analysed for a total of 11 CBzs.

The PeCB level in the sample from Nong Khok is the highest level in comparison with other free-range egg samples from Thai hot spots for POPs. The level in eggs from Samut Sakhon was 1.5 ng/g fat (Petrlík, Dvorská et al. 2018), and it is also higher than the level of 3.2 ng/g fat measured in a sample of free-range chicken eggs in the vicinity of a metallurgical complex at Balkhash, Kazakhstan (Petrlik, Kalmykov et al. 2016). A higher level of 16.6 ng/g fat of PeCB was recently measured in free-range chicken eggs from Ciobanovca, Moldova, near a municipal waste dumpsite and a site suspected of being contaminated with obsolete pesticides, but levels at two other sites affected by municipal waste dumping or by the pyrolysis of used tires were lower, at levels of 0.60 and 0.42 respectively (Petrlik, Strakova et al. 2022). A PeCB level of 0.578 ng/g fat was measured in the reference sample in this report.

The level of 6.1 ng/g fat of HCB in the duck eggs from Nong Khok is slightly lower compared to the 6.8 ng/g fat in a pooled sample of free-range chicken eggs from Map Ta Phut (Petrlik, Dvorska et al. 2018) and it is higher than in e.g. eggs from some unpolluted Russian sites, where a maximum level of 4.85 ng/g fat was measured (Shelepchikov, Revich et al. 2006), although the levels observed at polluted sites in Russia were much higher in 2005–2006 (DiGangi and Petrlik 2005, Shelepchikov, Revich et al. 2006). A more comprehensive list for the comparison of HCB levels in free-range poultry eggs can be found in Table 6. It is visible that higher levels were observed in samples taken rather before the year 2010, with the exception of very high levels in the vicinity of the Wuhan municipal waste incinerator in China (Petrlik 2016) and in eggs from the Agbogbloshie e-waste and car wreck scrapyard in Ghana (Petrlik, Adu-Kumi et al. 2019). In that comparison the level of HCB measured in the duck eggs from Nong Khok belongs to the rather higher levels in comparison with those observed at different locations after 2010.

Table 6: Overview of HCB levels measured in poultry eggs worldwide. The eggs from other sites than supermarkets are free-range chicken eggs.

Country	Locality	Year	HCB in ng/g fat	Potential source of contamination	Reference
Thailand	Maha Sarakham	2022	<0.10	Supermarket – reference eggs	This study
Thailand	Bangkok	2016	<0.18	Supermarket – reference eggs	(Petrlík, Dvorská et al. 2018)
Montenegro	Pljevlja	2015	0.43	Coal power plant	(Petrlik and Behnisch 2015, Petrlik, Arkenbout et al. 2019)
Philippines	Aguado	2005	1.7	Hazardous waste incinerator	(Calonzo, Petrlik et al. 2005, DiGangi and Petrlik 2005)
Armenia	Alaverdi	2018	1.7	Metallurgical industry	(Petrlik and Strakova 2018)
Senegal	Mbeubeuss	2005	1.7	Municipal and hazardous waste dumpsite	(DiGangi and Petrlik 2005, Petrlik, Diouf et al. 2005)
Thailand	Koh Samui	2016	1.8	Municipal waste landfill	(Petrlík, Dvorská et al. 2018)
Bosnia and Herzegovina	Zenica	2015	2.7	Metallurgical industry	(Petrlik and Behnisch 2015, Petrlik, Arkenbout et al. 2019)
Belarus	Gatovo	2014	2.9	Car shredder	(Petrlik, Kalmykov et al. 2016, Petrlik, Arkenbout et al. 2019)
Uzbekistan	Kanlikul	2003	3.0	Use of pesticides	(Muntean, Jermini et al. 2003)
China	Beijing	2014	3.5	Supermarket – reference eggs	(Petrlik 2016)
Thailand	Map Ta Phut	2016	3.6	Chemical industry	(Petrlík, Dvorská et al. 2018)
Thailand	Samut Sakhon	2015	4.2	Metallurgical industry	(Petrlík, Dvorská et al. 2018)
Kazakhstan	Balkhash	2014	4.4	Metallurgical industry	(Petrlik, Kalmykov et al. 2016)
Ukraine	Kryvyi Rih	2018	4.5	Metallurgical industry	(Petrlik, Straková et al. 2018, Petrlik, Arkenbout et al. 2019)
Thailand	Map Ta Phut	2016	4.8	Mixed industrial sources	(Petrlík, Dvorská et al. 2018)
Russia	Volsky district, Saratov region	2006	4.9	None	(Shelepchikov, Revich et al. 2006)
Turkey	Izmit	2005	5.3	Hazardous waste incinerator	(DiGangi and Petrlik 2005, Petrlik, Yarman et al. 2005)
Serbia	Obrenovac	2015	5.4	Coal power plant/ stockpile of obsolete pesticides	(Petrlik and Behnisch 2015, Petrlik, Arkenbout et al. 2019)
Thailand	Khon Kaen	2016	5.5	Mixed industrial sources	(Petrlík, Dvorská et al. 2018)
Thailand	**Nong Khok**	**2022**	**6.1**	**E-waste site**	**This study**
Kazakhstan	Shabanbai Bi	2014	6.3	Unknown	(Petrlik, Kalmykov et al. 2016)
Kazakhstan	Shetpe	2016	6.3	Cement kiln	(Petrlik, Kalmykov et al. 2016)
Thailand	Map Ta Phut	2016	6.8	Chemical industry	(Petrlík, Dvorská et al. 2018)
Cameroon	Yaounde – Etetak Quart.	2018	7.1	Municipal waste dumpsite	(Petrlik, Adu-Kumi et al. 2019).
India	Eloor	2005	7.7	Chemical industry	(DiGangi and Petrlik 2005, Petrlik, Jayakumar et al. 2005)
Czech Rep.	Pitárne	2018	8.0	PVC recycling plant	(Petrlik, Arkenbout et al. 2019)
Slovakia	Kokshov - Baksha	2005	10.7	Municipal waste incinerator	(DiGangi and Petrlik 2005, Petrlik, Hegyi et al. 2005)
Czech Rep.	Lhenice	2016	11.3	Stockpile of obsolete pesticides	(Mach, Petrlík et al. 2016)

Country	Locality	Year	HCB in ng/g fat	Potential source of contamination	Reference
Russia	Igumnovo	2005	11.7	Chemical industry	(DiGangi and Petrlik 2005, Petrlik, Speranskaya et al. 2005)
Egypt	Helwan	2005	15	Metallurgical industry	(DiGangi and Petrlik 2005, Petrlik, DiGangi et al. 2005)
Slovakia	Stropkov	1999	17	Production of PCBs	(Kočan 1999)
Uzbekistan	Chimbay	2003	19	Use of pesticides use	(Muntean, Jermini et al. 2003)
Tanzania	Vikuge	2005	19	Storage of obsolete pesticides	(DiGangi and Petrlik 2005, Petrlik, Mng'anya et al. 2005)
Ghana	Agbogbloshie	2018	25	E-waste site	(Petrlik, Adu-Kumi et al. 2019).
Bulgaria	Kovachevo	2005	26	Storage of obsolete pesticides	(DiGangi and Petrlik 2005, Petrlik, Hlebarov et al. 2005)
China	Wuhan 2	2014	29	Municipal waste incinerator	(Petrlik 2016)
Mexico	Coatzacoalcos	2005	35	Chemical industry	(DiGangi and Petrlik 2005, Petrlik, Bejarano et al. 2005)
Czech Rep.	Usti nad Labem	2005	36	Chemical industry	(DiGangi and Petrlik 2005, Petrlik, Skalsky et al. 2005)
Slovakia	Michalovce	1999	41	Production of PCBs	(Kočan 1999)
Russia	Gorbatovka	2005	69	Chemical industry	(DiGangi and Petrlik 2005, Petrlik, Speranskaya et al. 2005)
Russia	Chapaevsk	2006	114	Chemical industry	(Shelepchikov, Revich et al. 2006)
Czech Rep.	Liberec	2005	250	Municipal waste incinerator	(DiGangi and Petrlik 2005)
China	Wuhan 1	2014	481	Municipal waste incinerator	(Petrlik 2016)

The levels of HCBD were below LOQ in all samples in this study.

6. CONCLUSIONS

Contamination with POPs was revealed at all three locations researched in this study, Khao Hin Son Moo 9 - Nong Khok, Khao Hin Son Moo 1, and Hat Nang Kaeo. The highest levels were observed in the surroundings of the Supcharoen Recycle Co. Ltd. factory, in the village of Nong Khok, where contamination of the food chain was confirmed by high levels of some POPs in free-range duck eggs. The dismantling and incineration of e-waste is most likely to be the source of this serious contamination. The dumping of industrial sludge from a drum "donated" by a factory to villagers caused serious contamination with SCCPs.

Very high levels of unintentionally produced POPs were confirmed in the free-range duck eggs from Nong Khok. The level of PCDD/Fs is the tenth-highest ever measured level in poultry eggs in Asia, and the second-highest level measured in eggs from Thailand. The level of PBDD/Fs in eggs from Nong Khok is the sixth-highest measured in free-range poultry eggs from polluted sites globally. Also, the levels of PCDD/Fs and PBDD/Fs in soil samples from this locality are many times higher compared to the reference site. The PeCB and HCB levels in these eggs belong among the highest measured in free-range egg samples in Thailand.

The level of PCDD/Fs and total TEQ level of PCDD/Fs and dl PCBs in the sample of duck eggs from Nong Khok exceed the maximum levels set in EU by more than 24 and 14 times, respectively.

Serious contamination with SCCPs was discovered at Nong Khok, as well as Hat Nang Kaeo, most probably as a result of the dumping of industrial sludge at these sites. It also resulted in a high concentration of SCCPs measured in the free-range duck eggs at Nong Khok. A relatively high level of ndl PCBs was measured in the soil at Hat Nang Kaeo, in addition to contamination with SCCPs.

The levels of PBDD/Fs were most significant among the chemicals analysed in the samples from the Khao Hin Son Moo 1 locality, followed by PCDD/Fs, which shows that the burning of e-waste residues is the most important pathway of contamination at this locality.

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