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TOXIC
Hot Spots in Java II

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Toxic Hot Spots in Java II

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Abbreviations

AAS-AMA – Atomic Absorption Spectrometry with Advanced Mercury Analyser
ABS – Acrylonitrile Butadiene Styrene
BFRs – Brominated Flame Retardants
BTBPE – 1,2-Bis(2,4,6-tribromophenoxy) Ethane
C – Carbon
CPs – Chlorinated Paraffins
CRT – Cathode Ray Tube
DBDPE – Decabromodiphenyl Ethane
DDT – Dichlorodiphenyltrichloroethane
dl PCBs – Dioxin-like Polychlorinated Biphenyls
DP – Dechlorane Plus
e.g. – Exempli Gratia (for example)
ECF – Electrochemical Fluorination
EFSA – European Food Safety Authority
EU – European Union
GC/HRMS – Gas Chromatography/High-Resolution Mass Spectrometry
GC/TOF-HRMS – Gas Chromatography/Time-of-Flight High-Resolution Mass Spectrometry
GC-MS-NICI – Gas Chromatography-Mass Spectrometry-Negative Ion Chemical Ionization
GPC – Gel Permeation Chromatography
HBBz – Hexabromobenzene
HBCD – Hexabromocyclododecane
HCB – Hexachlorobenzene
HCBD – Hexachlorobutadiene
HCH – Hexachlorocyclohexane
HIPS – High-Impact Polystyrene
HpBDF – Heptabromodibenzofuran
IARC – International Agency for Research on Cancer
ICP-MS – Inductively Coupled Plasma Mass Spectrometry
IMIP – Indonesia Morowali Industrial Park
INC – Intergovernmental Negotiating Committee
ISO – International Organization for Standardization
LCCPs – Long Chain Chlorinated Paraffins
LOQ – Limit of Quantification
MCCPs – Medium Chain Chlorinated Paraffins
nBFRs – Novel Brominated Flame Retardants
NCI – Negative Chemical Ionization
ndl PCBs – Non-dioxin-like Polychlorinated Biphenyls
NIEHS – National Institute of Environmental Health Sciences
OBDF – Octabromodibenzofuran
OBIND – Octabromo-1,3,3-trimethylpheny-1-indane
OCDD – Octachlorodibenzo-p-dioxin
OCPs – Organochlorine Pesticides
OSPAR – The Convention for the Protection of the Marine Environment of the North-East Atlantic
PAHs – Polycyclic Aromatic Hydrocarbons
PBDD/Fs – Polybrominated Dibenzo-p-dioxins and Dibenzofurans
PBDEs – Polybrominated Diphenyl Ethers
PBEB – 2,3,4,5,6-Pentabromoethylbenzene
PBMT – Pentabromomonoterpene
PBT – Pentabromotoluene
PCBs – Polychlorinated Biphenyls
PCDD/Fs – Polychlorinated Dibenzo-p-dioxins and Dibenzofurans
PCNs – Polychlorinated Naphthalenes
PE – Polyethylene
PeCB – Pentachlorobenzene
PFASs – Per- and Polyfluoroalkyl Substances
PFHxS – Perfluorohexanesulfonic Acid
PFNA – Perfluorononanoic Acid
PFOA – Perfluorooctanoic Acid
PFOS – Perfluorooctanesulfonic Acid
POPs – Persistent Organic Pollutants
PP – Polypropylene
PRTR – Pollutant Release and Transfer Register
PVC – Polyvinyl Chloride
RDF – Refuse-Derived Fuel
SC – Stockholm Convention
SCCPs – Short Chain Chlorinated Paraffins
SMEs – Small and Medium-sized Enterprises
TBBPA – Tetrabromobisphenol A
TCDD – 2,3,7,8-Tetrachlorodibenzo-p-dioxin
TDI – Tolerable Daily Intake
TEFs – Toxic Equivalency Factors
TEQ – Toxic Equivalent
TTHQ – Total Target Hazard Quotient
U.S. EPA – United States Environmental Protection Agency
UHPLC-MS/MS-ESI – Ultra-high performance liquid chromatography-mass spectrometry
UN – United Nations
UNEA - United Nations Environment Assembly
U-POPs – Unintentional Persistent Organic Pollutants
US – United States
WHO – World Health Organization

Toxic Hot Spots in Java II - Summary

Introduction

Waste management has become one of the major challenges in countries of Southeast Asia, including Indonesia. Therefore, we selected sites specifically affected by plastic waste as the localities studied for their toxic pollution in our research conducted under the joint Arnika/Nexus3 project "Transparent Pollution Control in Indonesia". Results of our research are intended, among other things, to demonstrate the connections between national or global legislative instruments and local problems, and to explore what solutions they can offer. National instruments include Pollutant Release and Transfer Registers, which allow for a more comprehensive view of pollution sources in the country. Global conventions addressing waste and chemicals are also linked to toxic pollution, including the newly prepared global convention on plastics.

As previous research has shown, significant sources of pollution with toxic substances in Indonesia include small and medium-sized enterprises (SMEs), such as small aluminum smelters in Kendalsari, tofu factories in Tropodo, and lime kilns in Karawang. The latter two facilities are also related to the global problem of plastic pollution, as they use plastic waste as fuel, leading to emissions of toxic substances. All three are also related to the implementation of the Stockholm Convention on Persistent Organic Pollutants (POPs).

Aims and Background of the Study

Pollution from Small and Medium-sized Enterprises and Pollutant Release and Transfer Register

When introducing Pollutant Release and Transfer Register (PRTR) systems to countries where there are often many small and medium-sized enterprises (SMEs), governments should adopt a system for estimating releases from such smaller sites, similar to the approach taken by the Japanese government. Governments may need on-site inspections to calculate the quantities in use and releases from those sites. The results can then serve as a basis for estimating releases from small and medium-sized enterprises nationwide.

Additionally, independent research conducted by the Toxic Watch Network in Japan has affirmed the necessity of including small-scale business operators employing fewer than 21 individuals, which are currently not obligated to report the quantity of any chemicals they release (Mizutani et al., 2021; Nakachi, 2010). The study also "estimated the distribution of emissions from small-scale businesses. Depending on the chemical substance and industry, the estimated distribution of the released chemicals differed from that in the PRTR. This finding suggested that the reported release in PRTR was insufficient in assessing the risk of chemical leakage during a natural disaster" (Mizutani et al., 2021).

The issue of introducing SME data into PRTR systems (databases) was discussed in the report "Pollutant Release and Transfer Register and Civil Society" (Petrlik, Septiono, et al., 2023). However, data gathered in this study as well as in the previous Toxic Hot Spots in Indonesia (Petrlik, Ismawati, et al., 2020) study can help in gathering information about levels of pollution as well as pollutants related to specific SMEs in Indonesia.

Relation to the Global Plastic Treaty Negotiations

During the last two decades, a substantial body of research has consistently demonstrated that plastics have a detrimental impact on the environment (Beaumont et al., 2019; Kuhn & van Franeker, 2020; Marine Litter Topic Group, 2019). This impact includes the leakage of toxic chemicals affecting not only human health but also ecosystems, including global environmental balance (Persson et al., 2022; Steffen et al., 2015). This worldwide problem needs to be addressed at a global level (Aanesen et al., 2024).

In March 2022, at the fifth UN Environment Assembly (UNEA-5.2) in Nairobi, 175 UN Member States voted to establish an Intergovernmental Negotiating Committee (INC) with the mandate of agreeing on a legally binding instrument on plastic pollution by 2024 (Aanesen et al., 2024). Resolution 5/14 was adopted and titled "End Plastic Pollution: Towards an international legally binding instrument". Ambitiously supporting this initiative, in August 2022, the High Ambition Coalition to End Plastic Pollution by 2040 was launched, co-chaired by Norway and Rwanda and, as of May 2024, includes 66 member states.

Plastics contain various chemical additives that make these wastes hard to destroy or recycle (Marine Litter Topic Group, 2019). A study from 2021 identified *"more than 10,000 relevant substances"* in plastics (Wiesinger et al., 2021), and a more recent study published in 2024 found more than 16,000 such substances (Wagner et al., 2024). Over 4200 plastic chemicals are of concern because they are persistent, bioaccumulative, mobile, and/or toxic (PBMT). Over 1300 chemicals of concern are known to be marketed for use in plastics, and 29–66% of the chemicals used or found in well-studied plastic types are of concern (Wagner et al., 2024). Looking at pictures from plastic waste yards in Indonesia, Malaysia, or Turkey, we can identify plastic packaging in which a large number of these unregulated chemicals can be found (Petrlik et al., 2024). Studies included in Toxic Hot Spots in Java II reveal some PBMT substances that contaminate food chains in localities in Indonesia that are affected by inadequate management of plastic waste.

Photo 1: *Rice field and water channel in Bantar Gebang, close to a large municipal waste landfill. Photo: Ondrej Petrlik, Arnika, December 2022.*

The new global plastic convention undoubtedly cannot avoid addressing the chemical pollution associated with the production, use, and management of plastic waste. Analyses of this issue at the local level in places affected by poor plastic waste management, including Karawang, Bantar Gebang, and Tropodo in Indonesia, help identify critical chemical substances related to plastic pollution.

Methodology

We focused on mapping pollution by POPs and heavy metals in two locations mainly, in the villages of Karawang Regency, and in Bantar Gebang, part of the Bekasi city, both in West Java. Villages of the Karawang Regency include sites affected by using plastic and rubber waste (including used tires) as a fuel in lime kilns, similarly to Tropodo, where plastic waste is used in tofu factories. We also compared levels of POPs contamination of free-range chicken eggs from these two sites to those from a previous larger study of Toxic Hot Spots in Java: Bangun, Kendalsari, Sumberwuluh, Tangerang and Tropodo (Petrlik, Ismawati, et al., 2020). We added new analyses of POPs in free-range chicken eggs from Morowali, a site on Sulawesi island affected by nickel production as well. Finally, we also evaluated dietary exposure to selected POPs through the consumption of eggs from the studied sites on the island of Java and in Morowali.

For obtaining reference levels, we have included analyses from sites (Cisarua and Mbeji forests) that were chosen as potentially clean, showing background levels of pollution in Java. Egg samples from a supermarket in Java and convenience stores in Karawang were used as reference samples, because the eggs sold in these stores come from larger chicken farms, where hens do not have access to open areas and should not be affected by local pollution sources (DiGangi & Petrlik, 2005; Dvorska et al., 2009).

Samples of plastic waste, ash from incinerated waste (in Karawang), soil, sediments, rice and other plants, and free-range chicken eggs were analysed for their content of individual POPs and their groups[1] and heavy metals[2] in certified laboratories in Czech Republic, Netherlands and Germany.

Heavy metals in the environment of Bantar Gebang and Karawang

This study around the Bantar Gebang landfill in Indonesia revealed significant heavy metal contamination in soil and sediment samples. Most heavy metals, including zinc, lead and copper, were found at concentrations above reference levels, indicating localized contamination from the landfill. Fly ash from incinerators showed high concentrations of zinc and copper, which mirrored the heavy metal profile found in the soil, suggesting that waste incineration was a significant contributor to the pollution. The free-range chicken eggs collected near the landfill showed detectable levels of copper, mercury and zinc, but these levels were below potential health risk thresholds. However, comparisons with other contaminated areas showed that eggs from Bantar Gebang contained relatively higher levels of contamination.

The Karawang area showed a different but worrying pattern of heavy metal contamination, with soil samples showing extremely high levels of lead, well above global averages and reference sites. This indicates severe contamination that poses significant environmental and health risks. Other heavy metals, including cadmium, copper and nickel, were also found at elevated levels, highlighting the impact of industrial activities in the region. The geographic distribution of the contaminants suggests potential pollution hotspots in the area that warrant further investigation. The study highlights the need for urgent remediation and monitoring to address this pollution and prevent its spread to the wider environment.

POPs in Free-range Chicken Eggs

Severe environmental and food chain contamination with POPs resulting from the use of plastic and rubber waste as fuel in both tofu factories in Tropodo and lime kilns in Karawang Regency has been confirmed through the analysis of free-range chicken egg samples in this study.

Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) and polychlorinated biphenyls were analysed in all 20 free-range and two reference chicken egg samples in this study. Summarized levels of PCDD/Fs and dl PCBs are presented in Figure 1.

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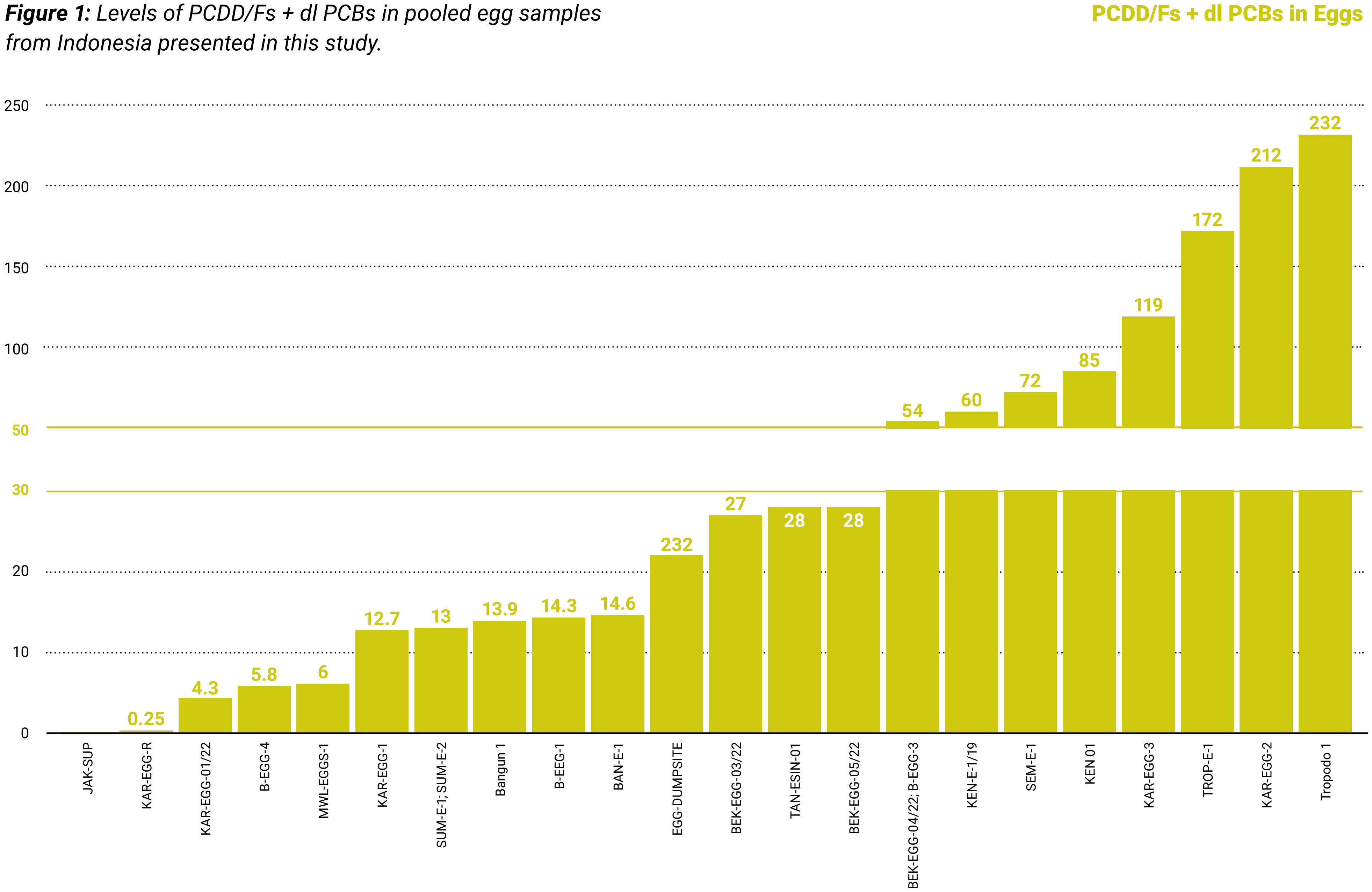
[1] Analysed POPs included: dioxins (PCDD/Fs), polychlorinated biphenyls (PCBs), brominated flame retardants (PBDEs, HBCD, TBBPA, and novel brominated flame retardants - nBFRs), 17 per- and polyfluoroalkylated substances (PFASs), including those listed under the Stockholm Convention (PFOA, PFOS and PFHxS), short and medium chain paraffins (SCCPs, MCCPs), polychlorinated naphthalenes (PCNs), dechlorane plus (DP), DDT and its metabolites, 3 setereoisomers of hexychlorocyclohexane (HCH), pentachlorobenzene (PeCB), hexachlorobenzene (HCB), and hexachlorobutadiene (HCBD).

[2] Analysed heavy metals included: antimony, arsenic, cadmium, copper, mercury, nickel, lead, and zinc.

Figure 1: *Levels of PCDD/Fs + dl PCBs in pooled egg samples from Indonesia presented in this study.*



The contamination of eggs with dioxins and dioxin-like compounds (dl PCBs and PBDD/Fs) represents some of the highest levels ever recorded in Asia and globally. Furthermore, the contamination of eggs with Per- and Polyfluoroalkyl Substances (PFASs) is particularly concerning, notably in Bangun, Bantar Gebang, and Tangerang, where the highest rates of exceedance of the Tolerable Daily Intake (TDI) by consuming just half an egg per day were estimated based on measured levels of four PFASs evaluated by EFSA in 2020.

By consuming a normal average portion of eggs, which is half an egg from free-range hens at any of the sampled localities in this study, an adult Indonesian can reach or exceed the TDI of dioxins and/or dioxin-like compounds by up to 48 times.

In the free-range chicken egg samples presented in this study, four (Tropodo-1, KAR-EGG-2, TROP-E-1, and KAR-EGG-3) were measured as the fourth, fifth, sixth, and seventh highest levels of PCDD/Fs in eggs from Asia and seventh, eighth, ninth, and eleventh highest levels globally, respectively, in comparison with other samples included in the global review and scientific literature (Petrlik, Bell, et al., 2022). They exhibit the same level of contamination from both localities contaminated by incineration of plastic waste used as fuel in tofu (Tropodo) and lime (Karawang) production facilities, respectively. Dioxin concentrations in these eggs exceeded the EU standard of 2.5 pg TEQ/g fat by approximately 80, 71, 56, and 44-fold, respectively. Higher levels of dioxins in free-range chicken eggs from Asia were observed only in Bien Hoa, a former US Army base in Vietnam contaminated by Agent Orange (Kudryavtseva et al., 2020).

Brominated dioxins were found for the first time to contribute significantly to the overall dioxin-like toxicity. They accounted for three-quarters when compared to chlorinated dioxins and dioxin-like PCBs in a pooled egg sample from hens foraging at a site with ash from incinerated plastic waste in Karawang.

The EU standard of 40 ng/g for six non-dioxin-like (ndl) PCB congeners was exceeded in KAR-EGG-2 by more than twice the limit, but was not as high in other samples presented in this study. The second and fifth highest ever measured level of HCB (41 and 15.5 ng/g fat) from Asian countries were confirmed in the pooled free-range egg samples from Bantar Gebang and Karawang (see graph in Figure 2). MCCPs, measured for the first time in Indonesian food, reached much higher levels than SCCPs in eggs from Bantar Gebang, ranging from below the Limit of Quantification (LOQ) to 2,345 ng/g fat, comparable to levels observed in eggs from neighbourhoods near waste disposal sites in Tanzania.

The EU standard of 40 ng/g for six ndl PCB congeners (European Commission, 2022a) was exceeded in KAR-EGG-2 by more than twice.

The highest levels of PBDEs in this study were measured in the eggs from Tropodo and Bangun sampled in October/November 2019. The level exceeding 27,000 ng g-1 fat of PBDEs measured in eggs from Tropodo is the second-highest ever measured level in eggs globally. The PBDEs in eggs from Tropodo and Bangun were in the same range as in egg samples from e-waste sites in China. Levels of PBDEs in eggs from Karawang and Bantar Gebang were much lower compared to those from Tropodo and Bangun,

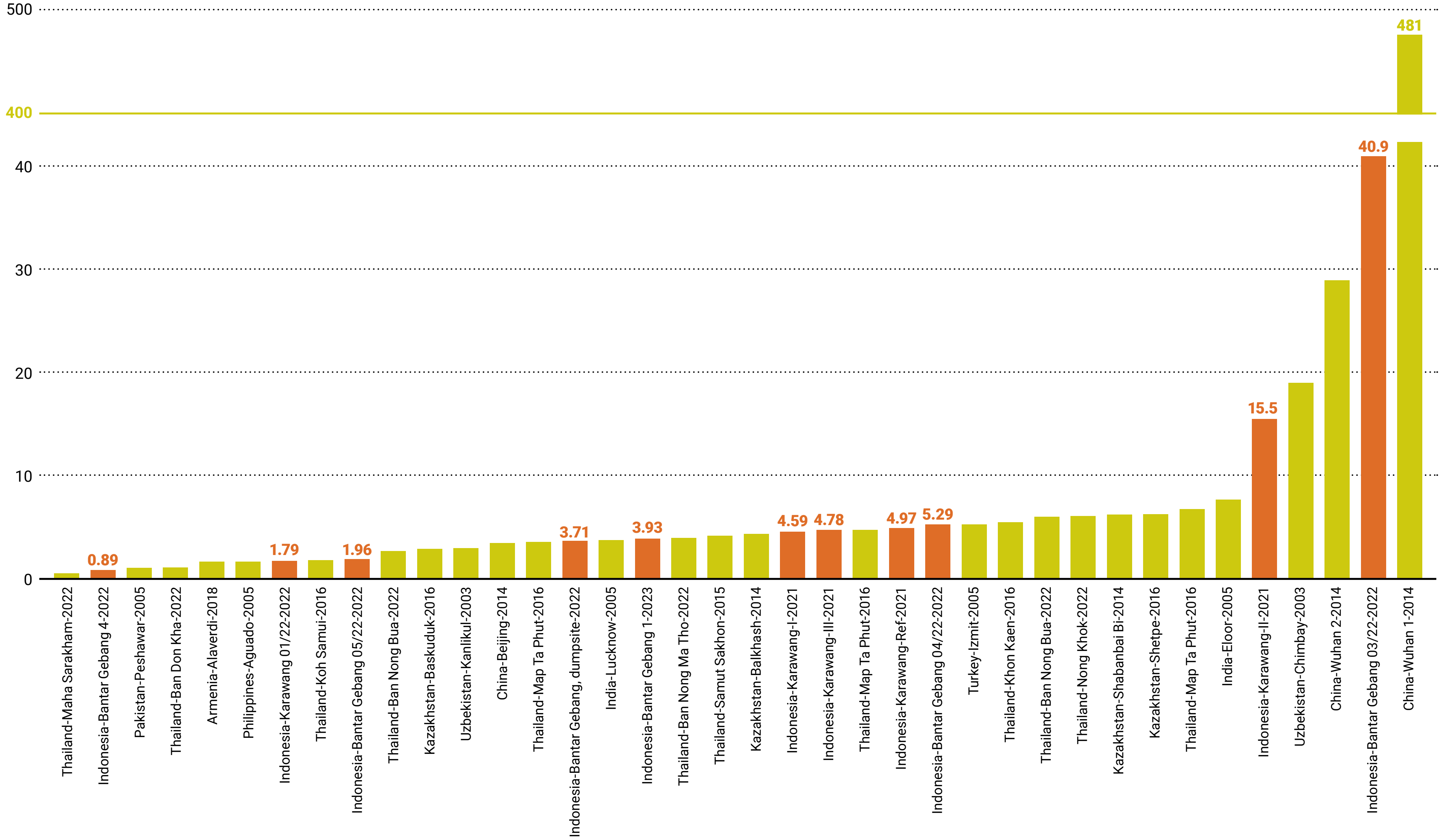
Levels of other POPs (PCNs, HCBD, or OCPs) measured in eggs from the studied localities were relatively low.

Risks of dietary intake of selected POPs through free-range eggs consumption at presented localities

We tried to estimate dietary intake of PFASs evaluated by EFSA in 2020 (EFSA CONTAM Panel et al., 2020), and for dioxin-like compounds for each pooled egg sample presented in this study. For the calculation we used the same approach as in the previous study on Toxic Hot Spots in Java (Petrlik, Ismawati, et al., 2020).

We calculated the dietary intake for the following groups of contaminants per day: 1) dioxin-like compounds that include PCDD/Fs, dl PCBs, and PBDD/Fs, and 2) PFASs evaluated by EFSA in 2020, which included PFOA, PFNA, PFOS and PFH_{xS} (EFSA CONTAM Panel et al., 2020). The calculation was made by using measured levels of certain chemicals per gram of fresh weight egg and a

***Figure 2:** Comparison of HCB levels in eggs from Asian countries.*
For data outside of Indonesia, look at a report by Petrlik, Boontongmai, et al. (2022).



calculation of the daily intake through consumption of half of a bigger egg per day (20 grams of egg weight). An average body weight was taken from information about average human body weight in different parts of the world, available from Wikipedia (Walpole et al., 2012; Wikipedia, 2020c). The average body weight of 58 kg for an adult person in Asia was applied.

The results were then compared with available information about suggested daily intake of the evaluated chemicals. They are discussed in a text below.

Dietary intake of PFASs by consumption of eggs from sampled sites in Indonesia: EFSA has recently established tolerable levels of intake for four PFASs at a level of 0.63 ng/kg body weight/day (EFSA CONTAM Panel et al., 2020). This sets the limit of 36.5 ng of these four PFASs – namely, PFOA, PFNA, PFOS, and PFHxS – for the average Indonesian adult per day. Only eight pooled free-range egg samples presented in this study do not exceed this limit in a single egg.

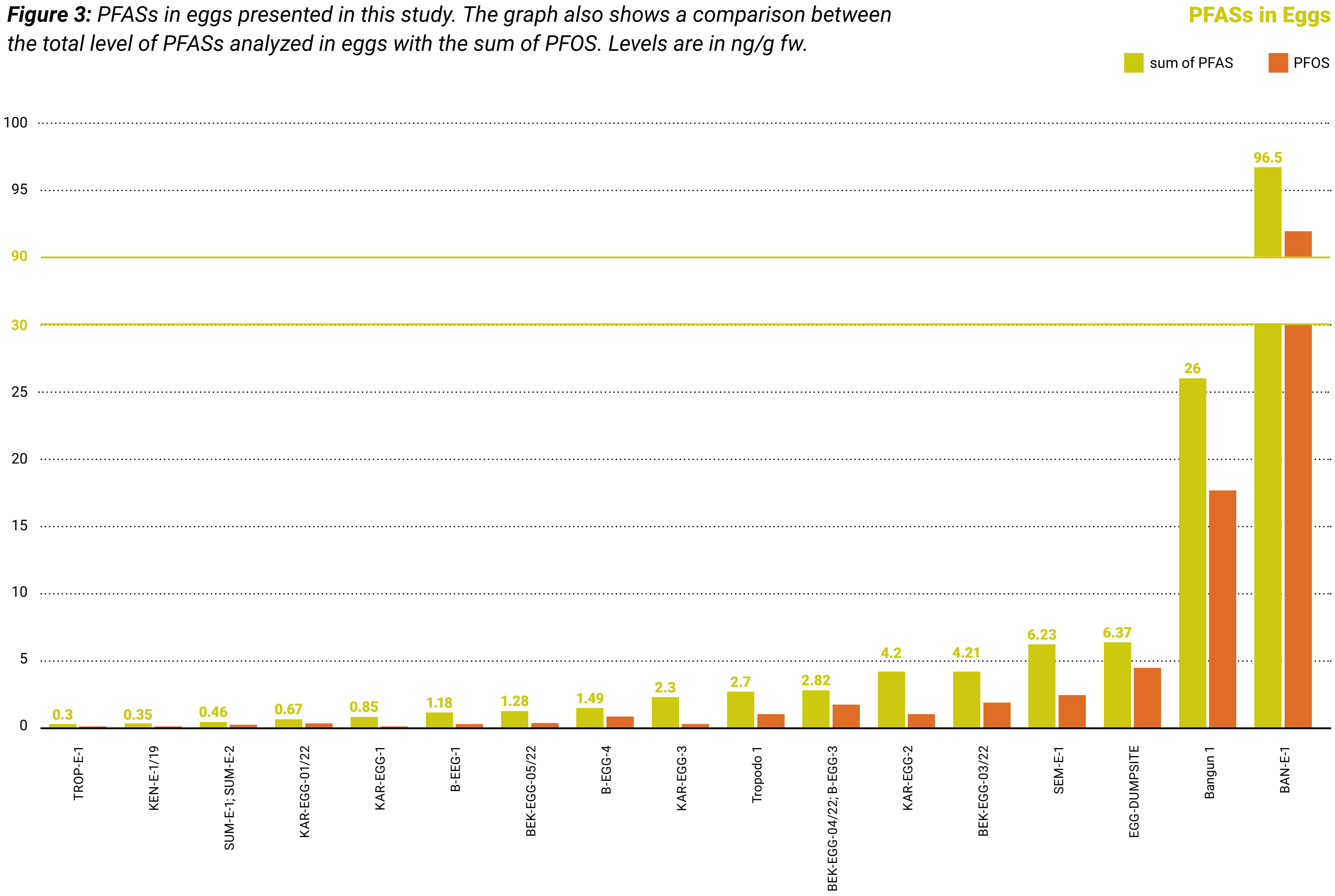
The dietary intake of four PFASs evaluated by the European Food Safety Authority (EFSA), namely PFOA, PFNA, PFOS, and PFHxS, shows that the highest risk related to these compounds was found in Bangun, Bantar Gebang, and Tangerang, where eggs contained the highest levels of these four PFASs. Levels in reference egg samples from supermarkets in Jakarta and convenience stores in Karawang were well below the risk threshold. The graph in Figure 3 shows the sums of the 17 PFASs analysed in eggs presented in this study and compares them with PFOS levels in each pooled egg sample. We must also consider that eggs are not the only source of food contaminated with PFASs (EFSA CONTAM Panel et al., 2020; Mikolajczyk et al., 2023; Sznajder-Katarzyńska et al., 2019).

Dietary intake of PCDD/Fs and dioxin-like compounds by consumption of eggs from sampled sites in Indonesia: As for PFASs, EFSA has established a tolerable level of intake for PCDD/Fs and dioxin-like PCBs as well, which is set at a level of 0.25 pg WHO-TEQ/kg body weight/day (EFSA CONTAM, 2018a). This sets the limit of 14.5 pg WHO-TEQ for these compounds for the average Indonesian adult per day. We have also incorporated PBDD/Fs in our calculations, as they are considered to have almost the same health effects and toxicity as chlorinated analogues (PCDD/Fs) (Behnisch et al., 2003; Birnbaum et al., 2003; Kannan et al., 2012; Mason et al., 1987; Piskorska-Pliszczyńska & Maszewski, 2014). None of the 20 pooled free-range egg samples presented in this study were below this limit in a single egg. Our estimates show that the contamination of food chains at the studied localities is even more serious than with the four PFASs. Also, in the case of dioxins and dioxin-like compounds, we have to take into account that eggs are not the only source of food contaminated with them (EFSA CONTAM, 2018a; Fiolet et al., 2024; Grechko, Amutova, et al., 2021).

Photo 2: *Free-range chicken eggs were used to monitor food chain contamination at several Indonesian localities in this study.*
This photo is from Karawang. Photo: Ondrej Petrlik, Arnika, December 2022.

From the point of view of dioxin and dioxin-like contamination of eggs as a representative example of the food chain, the most serious situations were

Figure 3: *PFASs in eggs presented in this study. The graph also shows a comparison between the total level of PFASs analyzed in eggs with the sum of PFOS. Levels are in ng/g fw.*



found in Tropodo, Karawang, and Kendalsari, followed by Tangerang and Bantar Gebang. Levels in reference egg samples were well below the risk threshold. Additional contamination of eggs presented in previous subchapters adds an overall burden of POPs to the health of consumers of locally grown food.

Recommendations

Very serious contamination of the environment and the food chain with POPs resulting from the use of plastic and rubber waste as fuel in lime kilns in Karawang Regency was confirmed in this study through measurements of ash, soil, and free-range chicken egg samples. Bantar Gebang and Karawang are additional examples, alongside Bangun, Tangerang, and Tropodo, of many similar sites in Southeast Asia. The study has several recommendations aimed at improving the situation.

On plastics:

- In agreement with a recent study from Kenya (Petrlik, Strakova, et al., 2023), the results of this study also suggest that the new global Plastics Treaty should focus on the chemical content of plastic materials and prohibit materials such as PVC or plastics containing brominated compounds.
- The use of plastic waste as fuel in all small and medium-sized enterprises (SMEs) should be prohibited. These facilities openly burn plastics and lack air pollution control equipment or practices to manage dioxin and other U-POPs emissions.
- Strict enforcement of the new provisions of the Basel Convention to block imports of hazardous waste and regulate transboundary movements of plastic waste is necessary, and/or enactment of a ban on the import of plastic waste.

On the use of ash:

- All ashes from waste incineration or metallurgical processes should be primarily classified as hazardous waste and monitored for their POPs content. Strict limits for POPs content in wastes should be introduced into national legislation to prevent further contamination of the environment and food chains.

***Photo 3:** Important decisions about limits for toxic chemicals are often taken far away from the sites that are affected by them, like e.g. at this meeting of Basel, Rotterdam and Stockholm Convention Conferences of the Parties, held in Geneva in 2023. Photo: Nikola Jelinek, Arnika, June 2023.*

- More strict limits for the definition of POPs waste are needed to regulate disposal options for waste produced by waste incineration globally.

On information available to the public on environmental pollution:

- Based on experiences from other countries, establishing a PRTR system helps monitor the flow of toxic substances and reduce environmental pollution. It will be necessary to include small and medium-sized enterprises (SMEs) – such as lime kilns in Karawang, tofu factories in Tropodo, or aluminum smelters in Kendalsari – in the PRTR design for Indonesia.
- PRTR should cover heavy metals and POPs, particularly lead, mercury, zinc, copper, dioxins (PCDD/Fs), polychlorinated biphenyls (PCBs), selected brominated flame retardants, hexachlorobenzene (HCB), chlorinated paraffins, and PFASs.

1. Introduction

Waste management has become one of the major challenges in countries of Southeast Asia, including Indonesia. Therefore, we selected sites specifically affected by plastic waste as the localities studied for their toxic pollution in our research conducted under the project "Transparent Pollution Control in Indonesia", funded by the European Commission.

Many toxic additives in plastic waste can leak into the environment when disposed of or burned, including persistent organic pollutants (POPs) listed in the Stockholm Convention (SC) (Stockholm Convention, 2010) such as polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD), short-chained chlorinated paraffins (SCCPs), and perfluorooctane sulfonate (PFOS) (POP RC, 2006c, 2009; Stockholm Convention, 2023a). Plastic waste also contains a lot of heavy metals containing chemicals used as stabilizers, for instance. Other toxic chemicals are generated when plastic waste is incinerated as fuel, including those listed as unintentionally produced POPs in Annex C of the SC; for example, polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs)[3], dioxin-like PCBs (dl PCBs), hexachlorobenzene (HCB), or pentachlorobenzene (PeCB) (Stockholm Convention, 2023a). Contamination by all these chemicals was documented recently at sites where various plastic wastes are burned or incinerated in developing countries (Bystriansky et al., 2018; Kanmani & Gandhimathi, 2012; Pathak et al., 2023; Petrlik, Adu-Kumi, et al., 2019; Jindřich Petrlik et al., 2016; Petrlik et al., 2018; Velis & Cook, 2021). In Indonesia, plastic waste of both domestic origin as well as imported from developed countries is often used as fuel in the production of tofu or lime (Petrlik, Ismawati, et al., 2020; Petrlik, Ismawati, et al., 2022).

The results of chemical analyses and their interpretations are presented in four comprehensive chapters focusing on: 1) the interpretation of heavy metal pollution both in Bantar Gebang and in Karawang (Chapter 4); 2) the contamination of POPs in Karawangu (Chapter 5) and 3) in Bantar Gebang (Chapter 6); and 4) the contamination of free-range chicken eggs from various locations (Chapter 7). The latter section also utilized data published in a similar publication, "Toxic Hot Spots in Java", published in 2020 (Petrlik, Ismawati, et al., 2020). Additionally, the section dedicated"to Karawangu builds upo" a previous mini-study presented at the Dioxin 2022 Conference in New Orleans (Petrlik, Ismawati, et al., 2022). Some of the analyses used here were also part of a global study by the International Pollutants Elimination Network (IPEN) focusing on sites affected by plastic waste disposal (Petrlik et al., 2021).

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[3] 'Dioxins' is used for PCDD/Fs.

1.1 Pollution from Small and Medium-sized Enterprises and and the Use of Pollutant Release and Transfer Registers

Jindrich Petrlik, Yuyun Ismawati

Mapping of basic information about pollution at sites with concentrations of SMEs such as in Kendalsari (aluminum smelters), Tropodo (tofu factories) and/or Karawang (lime foundries) is essential, relates to potential introduction of a Pollutant Release and Transfer Register (PRTR) in Indonesia, and acts as a significant activity in the project "Transparent Pollution Control in Indonesia"; jointly run by Nexus3 Foundation (Indonesia) and Arnika – Toxics and Waste Programme (Czech Republic), which is funded by the European Commission.

When introducing PRTR systems to countries with many small and medium-sized enterprises (SMEs), such as Indonesia, it is crucial to adopt a system for estimating releases from smaller sites. This noteworthy approach is taken by the Japanese government, and may require the government to conduct on-site inspections to calculate the quantities in use and releases from those sites. The results of these inspections can then serve as a basis for estimating releases from small and medium-sized enterprises nationwide.

Additionally, independent research conducted by the Toxic Watch Network in Japan has affirmed the necessity of including small-scale business operators employing fewer than 21 individuals, which are currently not obligated to report the quantity of any chemicals they release (Mizutani et al., 2021; Nakachi, 2010). The study also "estimated the distribution of emissions from small-scale businesses. Depending on the chemical substance and industry, the estimated distribution of the released chemicals differed from that in the PRTR. This finding suggested that the reported release in PRTR was insufficient in assessing the risk of chemical leakage during a natural disaster" (Mizutani et al., 2021). Indonesia is a volcanic and natural disaster-prone country (Reid & Mooney, 2023; Supriyadi et al., 2018) that will benefit from taking a similar approach to Japan.

This study does not focus on the issue of introducing SME data into the PRTR system (database). We discussed this in the report "Pollutant Release and Transfer Register and Civil Society" (Petrlik, Septiono, et al., 2023). However, data gathered in this study and previous Toxic Hot Spots in Indonesia (Petrlik, Ismawati, et al., 2020) can help inform levels of pollution and pollutants related to specific SMEs in Indonesia.

1.2 Relation to the Global Plastic Treaty Negotiations

Jindrich Petrlik, Yuyun Ismawati

A substantial body of research over the last two decades has consistently demonstrated that plastics have a detrimental environmental impact (Beaumont et al., 2019; Kuhn & van Franeker, 2020; Marine Litter Topic Group, 2019). This impact includes the leakage of toxic chemicals, which affects human health, ecosystems, and global balance (Persson et al., 2022; Steffen et al., 2015). This global problem needs to be addressed at a global level (Aanesen et al., 2024).

In March 2022, at the fifth UN Environment Assembly (UNEA-5.2) in Nairobi, 175 UN Member States voted to establish an Intergovernmental Negotiating Committee (INC) to agree on a legally binding instrument on plastic pollution by 2024 (UNEA, 2022). This significant step was taken by adopting Resolution 5/14, "End Plastic Pollution: Towards an International Legally Binding Instrument". In a further show of commitment, the High Ambition Coalition to End Plastic Pollution by 2040 was launched in August 2022, co-chaired by Norway and Rwanda. At the time of writing, the Coalition includes 58 member states (Aanesen et al., 2024). These initiatives give hope for a future free from plastic pollution.

Plastics contain various chemical additives that make these wastes hard to destroy or recycle (Marine Litter Topic Group, 2019). A study from 2021 identified *"more than 10,000 relevant substances"* in plastics (Wiesinger et al., 2021), and a more recent study published in 2024 found more than 16,000 such substances

Photo 1.1: *Imported plastic waste is a big challenge for Indonesia and other southeast Asian countries. Photo: Ecoton, January 2019.*

Photo 1.2: *Open burning of useless plastic waste creates space for new imports but also pollutes air and locally grown food. Photo: Ecoton, January 2019.*

(Wagner et al., 2024). Over 4200 plastic chemicals are of concern because they are persistent, bioaccumulative, mobile, and/or toxic (PBMT). Over 1300 chemicals of concern are known to be marketed for use in plastics, and 29–66% of the chemicals used or found in well-studied plastic types are of concern (Wagner et al., 2024). Looking at pictures from plastic waste yards in Indonesia, Malaysia, or Turkey, we can identify plastic packaging in which many unregulated chemicals can be found (Petrlik et al., 2024). Studies in this report reveal some of the PBMT substances that contaminate food chains in localities in Indonesia that are affected by inadequate plastic waste management.

It is well established that toxic chemicals are released into the environment during the production and use of plastics (Karlsson et al., 2021; Møller et al., 2020) and their disposal (BC & SC Secretariat, 2019; Hahladakis et al., 2018), mainly when burning or incineration is involved (Blankenship et al., 1994; Stockholm Convention, 2008). Not only does the dumping and open burning of imported plastic waste specifically affect communities in the Global South, including Indonesia, the lack of adequate waste management infrastructures is attributed to environmental pollution (Velis & Cook, 2021). In several places, local people found plastic waste to be a functional fuel to replace the use of wood, but it produces a much more comprehensive range of toxic pollutants such as polychlorinated or polybrominated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs and PBDD/Fs), as well as dioxin-like polychlorinated biphenyls (dl PCBs) or polycyclic aromatic hydrocarbons (PAHs). For example, in Tropodo, Indonesia, unwanted plastic waste imported by paper and mill factories is used as fuel in tofu-mak-

Photo 1.3: *In Tropodo, plastic waste used as fuel in tofu factories was documented in a report about Toxic Hot Spots in Java (Petrlik, Ismawati, et al., 2020). This use of waste as fuel also significantly contaminated free-range chicken eggs with dioxins (PCDD/Fs). Photo: Jindrich Petrlik, Arnika, October 2019.*

ing facilities (Ismawati Drwiega et al., 2019). In Karawang, Indonesia, it is used as fuel in kilns for chalk production. At both places, high levels of dioxins were measured in free-range chicken eggs (Petrlik, Bell, et al., 2022; Petrlik, Ismawati, et al., 2022).

The new global plastic convention undoubtedly must address the chemical pollution associated with producing, using, and managing plastic waste. Analyses of this issue at the local level in places affected by poor plastic waste management, including Karawang, Bantar Gebang, and Tropodo in Indonesia, help identify critical chemical substances related to plastic pollution. However, challenges such as limited laboratory capacity to test POPs in developing countries needs to be considered.

2. Sampling and chemical analysis

Jindrich Petrlik, Nikola Jelinek, Valeriya Grechko, Annisa Maharani

We focused on mapping pollution by POPs and heavy metals mainly in two locations; in villages of Karawang Regency, and in Bantar Gebang, part of the Bekasi city, both in West Java. Sites in the villages of Karawang Regency are affected by burning plastic and rubber waste (including used tires) as fuel in lime kilns; similar to Tropodo, where plastic waste is used to produce steam in tofu factories. We also compared levels of POPs contamination of free-range chicken eggs from these two sites in to those from a previous larger study of Toxic Hot Spots in Java: Bangun, Kendalsari, Sumberwuluh, Tangerang and Tropodo (Petrlik, Ismawati, et al., 2020). We added new analyses of POPs in free-range chicken eggs from Morowali, a site on Sulawesi Island affected by nickel production.

For reference levels, we also included analyses from sites (Cisarua and Mbeji forest) that were chosen as potentially clean, showing background levels of pollution in Java. For the egg samples, eggs bought from a supermarket in Java and convenience stores in Karawang were used as reference samples, because the eggs sold in these stores come from larger chicken farms, where hens cannot access open areas and should not be affected by local pollution sources. This approach is based on experiences from previous studies (DiGangi & Petrlik, 2005; Dvorska et al., 2009; Jindrich Petrlik et al., 2016).

2.1 Sampling

In this series of studies, we evaluated the analysis of toxic substances in pooled samples of plastic waste, ash, soil, sediments, plants (primarily rice), and eggs. Their locations are indicated on the maps in Figures 2.1, 2.2, 2.3, 2.4, and 5.1. We chose pooled samples to obtain more representative data. Information about the number of pooled samples at evaluated locations is specified in text about specific localities or samples (see Chapters 4, 5, 6 and 7).

Pooled egg samples consistently comprised two to nine individual egg samples from free-range hens from the same location, often from the same family and/or flock of hens. The eggs were collected in typical plastic egg packaging and boiled for approximately 7 minutes. The homogenates from the edible parts of the eggs were used for laboratory analysis.

Soil, sediment, and ash were also pooled samples. The soil was collected by a stainless-steel shovel, removing the vegetation cover and sampling at a depth of about 10 cm across multiple points (usually five point samples) within a defined area (typically 3 x 3 meters). Ash samples were collected similarly to soil samples taken from multiple random points. Sediment samples consist of 4 – 7-point samples taken with a grab (0-10 cm depth). Samples were homogenized

Figure 2.1 *Overview of samples in this study (yellow – eggs, red – hotspots, blue – sediment, black – waste or ash, brown – soil).*

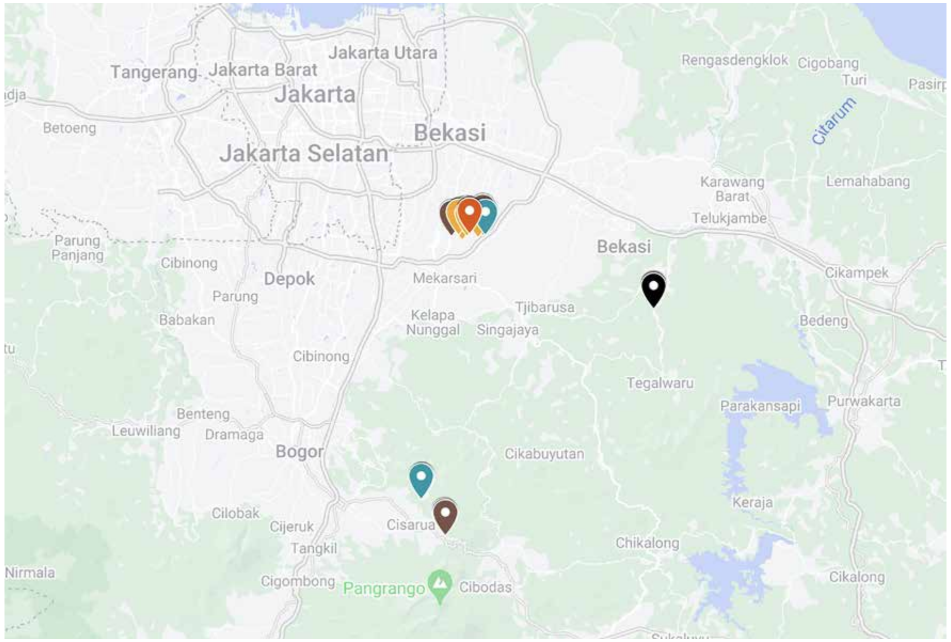

Figure 2.2 *Cisarua – reference sampling site.*

Figure 2.3 *Sampling site Bantar Gebang, Bekasi, West Java.*

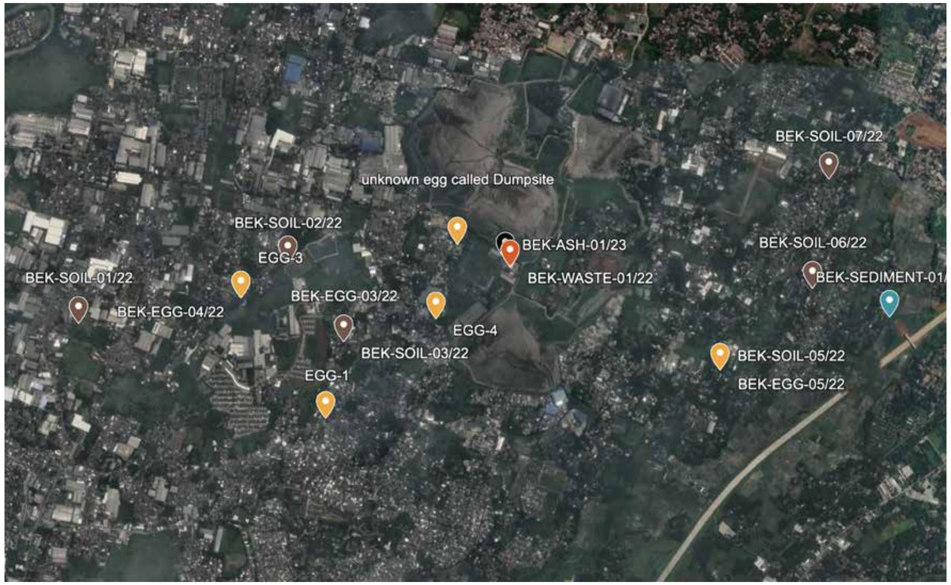

Figure 2.4 *Sampling site at Karawang, West Java.*

Photo 2.1: *Sampling of sediment at reference site. Photo: Ondrej Petrlik, Arnika, December 2022.*

Photo 2.2: *Sampling of ash in one of the lime kilns in Karawang. Photo: Nexus3, March 2021.*

in a stainless-steel bowl, transported in PE zip-lock bags or 250 ml PE plastic containers to the laboratory, and kept during storage and transportation under cool conditions.

Plant samples, including rice, always consisted of multiple whole plants, which were dried and ground in the laboratory. The samples were not rinsed, allowing them to potentially contain any dust captured on the plants, simulating real consumption situations by animals.

In the case of plastic waste, samples consisted of several (3 to 5) different pieces of the same type of plastic.

These methodologies were complemented by detailed site descriptions and environmental context, such as proximity to pollution sources and land use, which are critical for interpreting the results. The collected data from these diverse sampling methods, encompassing a total of 19 samples across all types, provide crucial insights into the pollution levels and help guide environmental protection and remediation efforts. The respective chapters interpreting the results of their analyses provide more details about the quantity and characteristics of individual samples.

2.2 Analytical methods

Samples were analysed for their content of individual PCDD/Fs and dl PCBs using GC/HRMS[4] in an ISO 17025 accredited laboratory, with a resolution >10,000 using ^{13C} isotope labeled standards. The analysis of PCDD/Fs and dl PCBs in

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[4] GC/HRMS - Gas chromatography/high-resolution mass spectrometry is an analytical technique used to separate and identify compounds in a sample based on their mass-to-charge ratio.

Photo 2.3: *Rice sampling near Karawang. Photo: Nexus3.*

eggs followed the methods prescribed for controlling levels of these substances in foodstuffs according to European Union (EU) regulations (European Commission, 2012). The results are presented in pg WHO-TEQ[5] per gram (of fat for eggs, wet weight for other samples). Toxic equivalency factors (TEFs) defined in 2005 (van den Berg et al., 2006) were used to evaluate dioxin toxicity in all samples.

Analyses of PBDEs, HBCD, TBBPA, novel brominated flame retardants (nBFRs), 17 PFASs (including PFOA, PFOS and PFHxS), short and medium chain chlorinated paraffins (SCCPs, MCCPs), 13 PCN congeners, two stereoisomers of dechlorane plus (DP), DDT and its metabolites, 3 HCH setereoisomers, PeCB, HCB, hexachlorobutadiene (HCBD), and seven non dioxin-like PCB (ndl PCBs) congeners were conducted in a Czech certified laboratory at the Department of Food Chemistry and Analysis of the University of Chemistry and Technology in Prague. 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 was conducted by gas chromatography coupled with tandem mass spectrometry detection in electron ionisation mode for HCB, PeCB, HCBD, and indicator PCBs. Novel BFRs analysis was described in one of the previous reports from Indonesia10. The extract 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 negative chemical ionisation (NCI) mode.

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

The results of POPs analyses in eggs were also compared with EU and Indonesian standards for foodstuff (European Commission, 2022a; Republik Indonesia, 2018). The carry-over rates, determined by the Dutch National Laboratory (Hoogenboom et al., 2006), were used to re-calculate PCDD/F and PCB congener profiles in eggs for better comparison with profiles in ash and soil samples. The carry-over rates for PCDD/Fs range from 44% (TCDD[6]) to 10% (OCDD[7]). On average, the transfer factors for dl PCBs are high and range from 80% (PCB-167) to 41% (PCB-81). For some comparison with source patterns, these carry-over rates

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[5] WHO TEQ - World Health Organization Toxic Equivalent, a measure used to quantify the toxicity of mixtures of dioxin-like compounds relative to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), which is considered the most toxic dioxin congener.

[6] TCDD - 2,3,7,8-Tetrachlorodibenzo-p-dioxin is a highly toxic dioxin congener that is often used as a reference standard for assessing the toxicity of other dioxin-like compounds.

[7] OCDD - Octachlorodibenzo-p-dioxin is another dioxin congener with eight chlorine atoms.

are used to roughly recalculate the measured PCDD/F and PCB data in eggs (Petrlik, Bell, et al., 2022).

All heavy metals analysis were conducted in the laboratory of the State Veterinary Institute in Prague (Czech Republic). The analytical part included mineralization with HNO3 and H2O2 and the two main analytical techniques used inductively coupled plasma mass spectrometry (ICP-MS) and atomic absorption spectrometry with an advanced mercury analyzer (AAS-AMA).

A brief description and properties of the analysed substances can be found for the group of heavy metals in Annex I and for POPs in Annex II.

Results for individual samples are presented in tables for each locality. There is also information about which compounds were analysed in these samples; see Tables 4.2, 4.3, 4.4, 4.5, 4.7, 5.1, 5.2, 6.1, 6.2, 7.1, and 7.2 in Chapters 4, 5, 6 and 7.

3. Localities

Nikola Jelinek, Annisa Maharani

3.1 Bantar Gebang, Bekasi, West Java Province, Indonesia

Bekasi is a city in West Java, located on the eastern border of Jakarta. The city stands separately (as Bekasi) next to the Regency of Bekasi, Jakarta, Depok, and the Regency of Bogor.

The district of Bantar Gebang is part of Bekasi, and a huge landfill is located within its territory, TPA Bantar Gebang (English: Bantar Gebang Landfill). Even though the landfill is in Bekasi, the landfill is an asset of Jakarta, hence becoming the main dumping point of Jakarta's household waste, with several spots in Tangerang (Banten Province) and Bekasi (West Java Province). It is also the site of Indonesia's only proper pilot-scale waste incinerator. The incinerator in the area has been operating since 2019 with a maximum capacity of 100 tons of waste from the landfill per day. Due to the maintenance process and pollution prevention, some types of waste cannot be incinerated - recyclables, metals, electronic waste, aerosol cans, construction debris, and hazardous waste.

However, other sources of contamination at the site may also exist, such as the rubber manufacturing and galvanizing industries.

Photo 3.1: *Waste picker, a typical picture from large landfill in Bantar Gebang. Photo: Ondrej Petrlik, Arnika, December 2022.*

Photo 3.2: *Burning of plastic waste in lime kilns in Karawang generates toxic fumes. Photo: Nexus3, March 2021.*

3.2 Morowali, Central Sulawesi Province, Indonesia

Morowali Regency is home to rich deposits of high-quality nickel, a vital material that is required for lithium battery production. The main location of interest is Indonesia Morowali Industrial Park (IMIP), which comprises nickel processing industries along with its relevant industries along its supply chain, including the battery industry. Indonesia Morowali Industrial Park (IMIP) has the world's longest industrial chain that produces nickel, stainless steel, and carbon steel. It is no surprise that IMIP's activities have seriously polluted the local environment and disrupted the lives of surrounding communities. IMIP is mainly filled with stainless steel smelters of Chinese companies, such as Tsingshan Holding Group and its subsidiaries, along with captive coal-fired power plants to power them up.

Photos 3.3 and 3.4: *Reference site in Cisarua was rich in fauna and flora but not a totally virgin site. Influence of human activity was visible. Photo: Jindrich Petrlik, Arnika, December 2022.*

Photos 3.5 and 3.6: *Two sites where soil samples were taken in Cisarua. These photos demonstrate potential influence of human activities (tourism and recreation), as well as agricultural use of land, specifically for tea plantation. Photos: Jindrich Petrlik and Ondrej Petrlik, Arnika, December 2022.*

3.3 Karawang, West Java Province, Indonesia

Karawang is the capital city of Karawang Regency, West Java and is known as a major rice production source in West Java, as well as for automobile manufacturing facilities. In many villages of Karawang Regency, West Java, plastic and rubber waste (including used tires) is used as fuel in lime kilns (see Photo 3.2).

3.4 Cisarua, West Java Province, Indonesia (reference site)

Cisarua is located in the Regency of Bogor, West Java. It is known for its mild climate and tea plantations, which grow in significant quantities due to their altitude. This site was chosen because it is not expected to have significant anthropogenic pollution, and we can also obtain information on the normal levels of the monitored substances in the environment. There are no major industrial sources in the vicinity.

3.5 Mbeji Forest, East Java Province, Indonesia (reference site)

Sumber Beji, known as "Mbeji Forest", is the second reference site used in this study. It is located in Sranten, Panglungan village. The village, nestled between Anjasmoro Mountain and Bromo Tengger Semeru National Park, boasts scenic landscapes and potential for tourism. Sumber Beji is a natural forest with sacred springs that feed the Gunting River. Despite threats from development and poultry farms, local conservation efforts aim to protect the forest and its cultural significance.

3.6 Other locations from Java

This report mentions more locations related to free-range chicken egg sampling, such as Tangerang, Tropodo, or Bangun (see Chapter 7). These locations were described in the previous report Toxic Hot Spots in Java (Petrlik, Ismawati, et al., 2020).

4. Environmental contamination by heavy metals at Bantar Gebang, Karawang and Morowali sites

Valeriya Grechko

4.1 Introduction

Landfills , including the large landfill in Bantar Gebang, are a considerable source of heavy metal pollution. Waste materials containing heavy metals, such as batteries, electronics, and some industrial waste, risk leaching these contaminants into the surrounding soil and groundwater when disposed of in landfills. This process is enhanced by factors such as rainfall and the decomposition of organic materials in the landfill, which can facilitate the mobilization of heavy metals.

4.2 Sampling

4.2.1 Soil, ash, sediment and egg sampling

In 2022, 15 soil, sediment, and ash samples were collected near potential pollution hotspots in the village of Bantar Gebang, where a landfill and municipal waste incinerator are located, and in the villages of Karawang Regency, where several lime kilns are located. Three samples were collected from a reference site in Cisarua, where no industrial activity was taking place and where no industrial pollution was expected.

A total of 10 soil samples were collected using a grab sampler technique, described in Chapter 2. This method has been consistently applied at various locations including open fields, grassy areas and industrial areas within 1000-2300 m of the Bantar Gebang landfill and incinerator.

Photo 4.1: *Sampling of the sediment at reference site in Cisarua. Photo: Ondrej Petrlik, Arnika, December 2022.*

One sediment sample in Bantar Gebang and one sediment from the reference location were collected to understand the influence of anthropogenic factors on aquatic systems.

Two ash samples were collected from industrial sites like incinerator and lime kilns. One sample of bricks containing fly ash from the incinerator was also included in this report.

The pooled free-range chicken eggs were collected from the local farmers.

The analytical method for heavy metals analysis is described in Chapter 2.2, and characteristics of major heavy metals that we focused our analyses on can be found in Annex I.

4.3 Results and Discussion

The results of the heavy metals analyses are presented in mg/kg dry matter.

4.3.1 Bantar Gebang

Landfills serve as an element of modern waste management systems, designed to contain the vast amounts of waste generated by human activity. Household waste, which accounts for more than two-thirds of municipal solid waste, contributes significantly to environmental pollution, and almost 70% of municipal solid waste worldwide ends up in landfills (OECD, 2002). Despite their role in mitigating surface litter and uncontrolled dumping, landfills often pose significant environmental risks, primarily due to the leakage of pollutants. Among these pollutants, heavy metals and persistent organic pollutants stand out for their potential to inflict long-term environmental and health damage.

Photo 4.2: *Many small enterprises/workshops that sort mainly plastic waste and burn it in the open afterwards may contribute to overall contamination in Bantar Gebang. Photo: Ondrej Petrlik, Arnika, December 2022.*

Heavy metals such as lead, mercury, cadmium, and arsenic leach from waste materials into the environment, contaminating soil, groundwater, and surface water (Kanmani & Gandhimathi, 2012; Slack et al., 2005). Their toxic effects can lead to bioaccumulation in plants and animals, posing severe health risks to humans throughout the food chain. The persistence and non-biodegradability of heavy metals exacerbate their potential to contaminate ecosystems for extended periods (Ruchuwararak et al., 2018).

4.3.1.1 Soil samples

All heavy metals analysed in soil samples from the vicinity of the Bantar Gebang landfill were identified at concentrations exceeding the limit of quantification (LOQ), except for antimony, which was not detected at levels above the LOQ (<0.10 mg/kg).

Arsenic levels across the samples varied from 1.6 mg/kg to 3.1 mg/kg, with a mean of 2.3 mg/kg and a median of 2.3 mg/kg. This range is slightly below the

Table 4.1 *Heavy metal concentrations in the soil samples from Bantar Gebang (mg/kg DW). The total number of samples (n) is 7; LOQ – limit of quantification*

Soil	**As**	**Cd**	**Cu**	**Hg**	**Ni**	**Pb**	**Sb**	**Zn**
	mg/kg	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**
n >LOQ (% of all samples)	7 (100%)	7 (100%)	7 (100%)	7 (100%)	7 (100%)	7 (100%)	0 (0%)	7 (100%)
Range of samples >LOQ	1.7-3.1	0.05-10.2	28.0-52.4	0.03-0.06	5.3-8.5	11.8-32.7	<0.10	50.2-106
Mean of samples >LOQ	2.3	0.13	37.9	0.04	7.1	21.9	<0.10	70.8
Median	2.3	0.11	37.0	0.04	7.0	20.7	<0.10	68.4
Reference locations	4.6	0.09	22.5	0.12	3.5	11.8	<0.10	31.9

concentration found in soil samples from the reference site, which had an As level of 4.6 mg/kg.

Cadmium showed more variation, with concentrations ranging from 0.05 mg/kg to 0.24 mg/kg. The mean Cd concentration was 0.13 mg/kg, and the median was 0.11 mg/kg. These values are generally higher than the reference location, which had a Cd level of 0.09 mg/kg.

Copper concentrations in soil samples from Bantar Gebang ranged significantly from 28.0 mg/kg to 52.4 mg/kg, with a mean of 37.9 mg/kg and a median of 37.0 mg/kg. The reference samples had a lower Cu concentration of 22.5 mg/kg, indicating higher exposure or accumulation in the sampled soils.

Mercury levels varied from 0.03 mg/kg to 0.06 mg/kg, with the mean and median at 0.04 mg/kg. This is notably lower than the Hg concentration in the reference samples, 0.12 mg/kg.

Nickel was found in concentrations ranging from 5.3 mg/kg to 8.5 mg/kg, with a mean of 7.1 mg/kg and a median of 7.0 mg/kg. These levels are significantly higher than those in the reference samples, which contained 3.5 mg/kg.

Lead varied from 11.8 mg/kg to 32.7 mg/kg, with a mean of 21.9 mg/kg and a median of 20.7 mg/kg. Pb concentration in the reference samples was significantly lower at 11.8 mg/kg, suggesting potential localized contamination in the soils collected in Bantar Gebang.

Zinc showed the greatest variation, ranging from 50.2 mg/kg to 106.0 mg/kg, with a mean of 70.8 mg/kg and a median of 68.4 mg/kg. The Zn level at the reference location was much lower, at 31.9 mg/kg, indicating a higher accumulation in the studied sites.

The set of seven soil samples collected in Bantar Gebang can be divided into two location groups (east and west group), see map below.

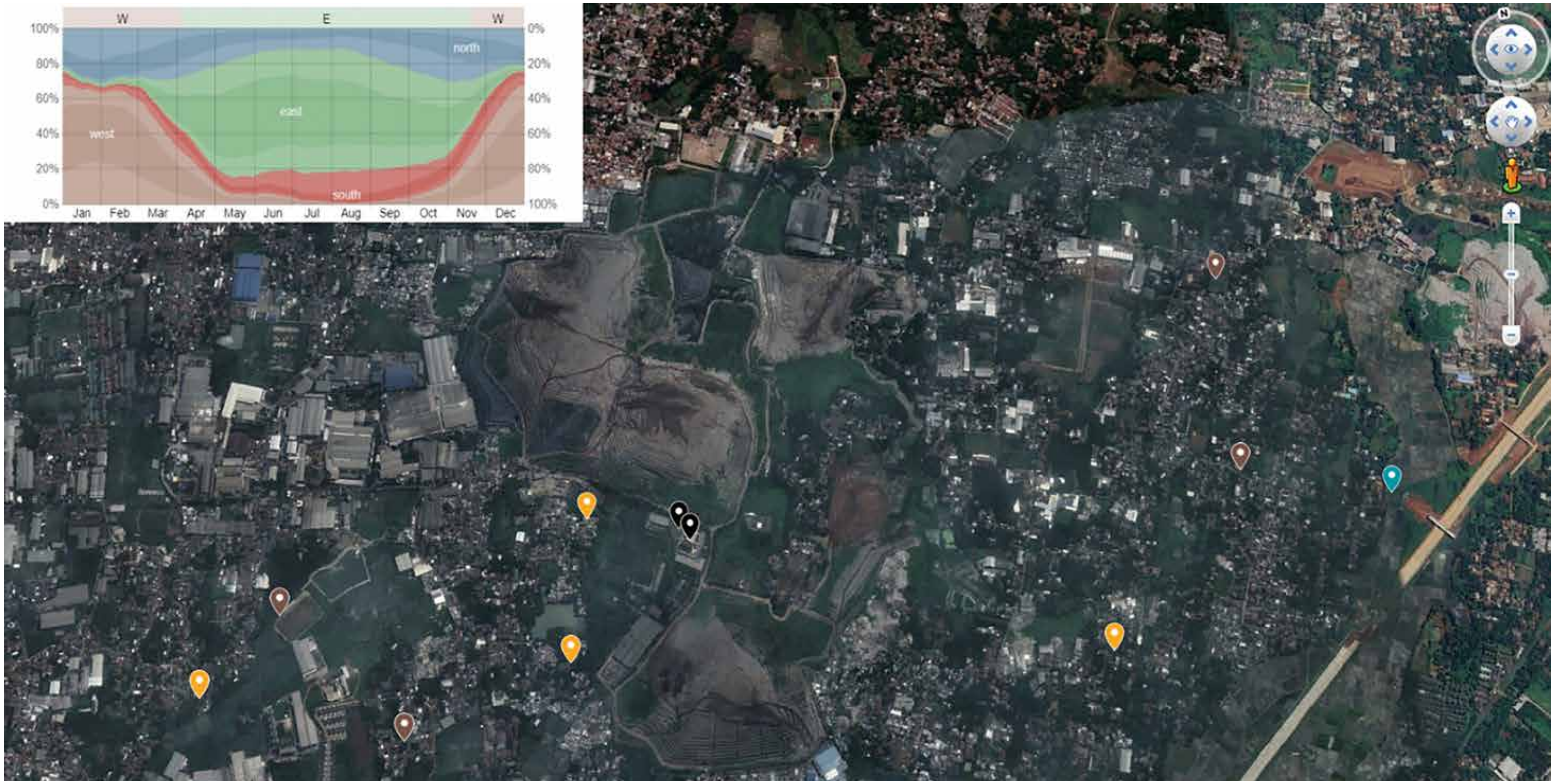

Figure 4.1: *Map of Bantar Gebang with marked locations of samples, and graph showing prevailing wind directions throughout the year.*

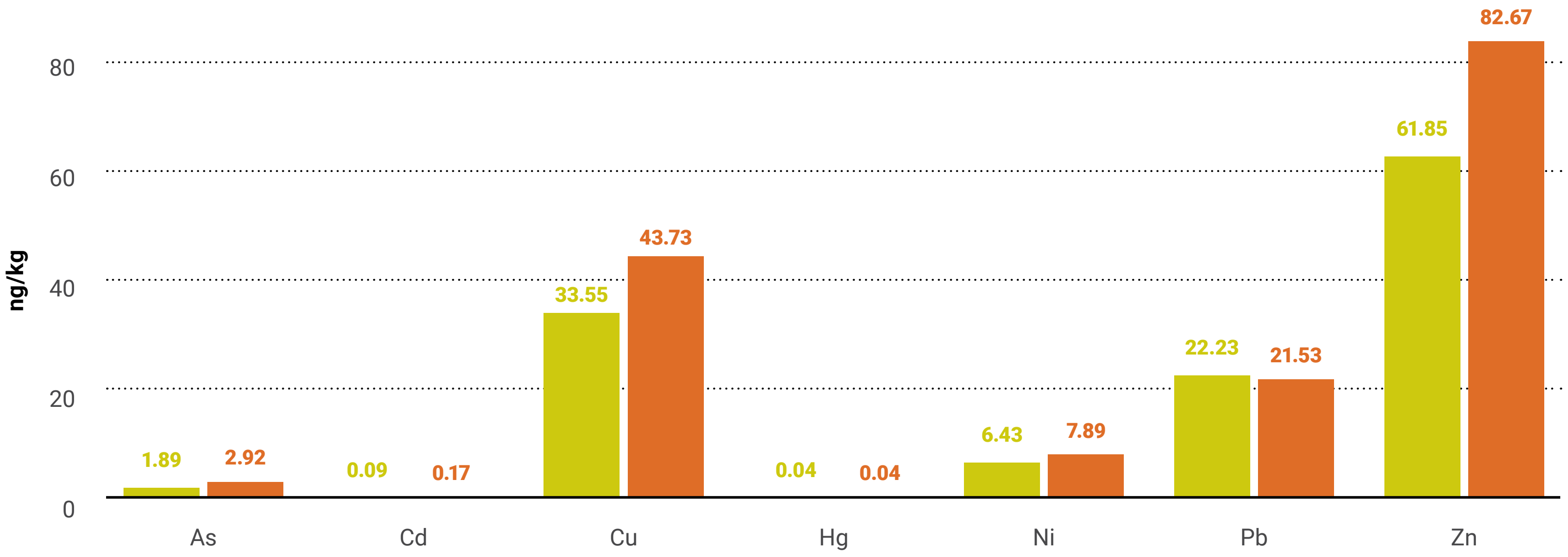

Figure 4.2: *Comparison of heavy metal levels in eastern and western group of samples.*

🟨 Soil samples from the eastern group (sample ID 1-4)

🟧 Soil samples from the western group (sample ID 5-7)

Table 4.2 *Heavy metal concentrations in the sediment samples from Bantar Gebang (mg/kg DW).*

Sample ID	**Matrix**	**As**	**Cd**	**Cu**	**Hg**	**Ni**	**Pb**	**Sb**	**Zn**
		mg/kg	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**
BEK-SEDIMENT-01/22	sediment	2.1	0.15	30.4	0.04	4.9	13.8	<0.10	54.6
CIS-REF-SED-02/22	sediment	3.6	0.05	25.6	0.04	3.7	6.1	<0.10	42.8

For most metals, the results from the sites east of the potential operations had higher values on average than the western sites, see graph below. This trend may be due to the prevailing westerly winds in the Bekasi Regency; however, a more detailed investigation is needed to examine the distribution of heavy metals around potential polluting hot spots further.

The levels of the monitored heavy metals in soil samples from Bantar Gebang are within the world average background heavy metals concentrations (Kabata-Pendias, 2011).

The results of the heavy metal analyses of soil samples from the Bantar Gebang site are lower or comparable to those reported in other studies conducted at industrial sites. For Ni, the values in the Bantar Gebang soil samples (5.3-8.5 mg/kg) are lower than those observed in soil samples collected around the Antang landfill site in Indonesia (27-32 mg/kg) (Artiningsih et al., 2019). The average Pb concentration in soil samples from Bantar Gebang (20.7 mg/kg) is twice the concentration reported in soil samples from Putri Cempo landfill in Indonesia (11.1 mg/kg), where samples were collected even from the closest distance to the landfill (Nyiramigisha, 2021). This means heavy metals pollution from waste treatment infrastructure in Bantar Gebang may be even more significant.

The heavy metal profile of the Bantar Gebang samples is lower than that observed in soil samples collected around mining deposits and processing industries in Armenia (Grechko, Petrlík, et al., 2021; Matoušková et al., 2023).

The results for arsenic and mercury at the reference sites had higher values than the samples from Bantar Gebang. These locations need further investigation by monitoring possible sources of heavy metal exposure. This may be due to the deposition of the chemical profile of the puddle substrate at the referencing sites or external factors such as exposure to chemical latices like pesticide application containing heavy metals (El-Bahnasawy et al., 2013; Li et al., 2016).

4.3.1.2 Sediment samples

The one sample of sediment collected from the rice field in Bantar Gebang (approx. 2 km away from the waste landfill and incinerator) yielded higher concentrations for all studied elements compared to the reference sediment from Cisarua, see Table 4.2. The values of heavy metals in sediment sample from Bantar Gebang did not identify higher risks of heavy metal presence in the aquatic system. The previous results from the different industrial areas in Armenia, Kazakhstan, the Balkans and Thailand showed (Mach V et al., n.d.) higher metal presence in the sediment (Grechko, Petrlík, et al., 2021; Mach et al., 2018; Matoušková et al., 2023; Petrlik et al., 2015). The sediment results also fulfilled the Canadian sediment quality guidelines (Canadian Council of Ministers of the Environment) and Czech legislation (MŽP, 2016). The studied sediment shows a lower presence of Pb and Cd compared to the results in the Cisadane River in the northwestern part of Java (Sulistyowati et al., 2023).

4.3.1.3 Ash and waste samples from Merah Putih Incinerator

In addition to the environmental samples, a sample of fly ash was collected from the Merah Putih incinerator (BEK-ASH-01/23) and a brick that had been contaminated by the fly ash generated from waste incineration.

The trend of heavy metal abundance in the fly ash sample is similar to the finding of heavy metal abundance in Bantar Gebang soil: Zn>Cu>Pb>Ni>Cd(As)>Sb(Hg).

4.3.1.4 Free-range chicken eggs

Three heavy metals out of eight were detected in the egg samples: copper, mercury and zinc. However, the concentration of these metals is below the level of concern, and the cumulative potential health risk caused by exposure to the mixture of these three metals is not significant, even for sensitive populations; the Total Target Hazard Quotient (TTHQ) is <1. Copper and zinc are essential elements for human health and their supply is essential for health. Cu and Zn concentrations in eggs from free-range Bantar Gebang hens were higher than in home-reared eggs from Australia (mean 0.75 and 11.3 mg/kg for Cu and Zn, respectively) (Grace & MacFarlane, 2016). However, when the results were compared with other eggs from industrially burdened areas, eggs from mining areas in India were found to have higher levels of Cu and Zn (Giri and Singh, 2019). The mercury level is significantly lower than those previously analysed in the mining region of Colombia (González-Álvarez et al., 2023).

4.3.2 Karawang industrial area

All heavy metals analysed in soil and ash samples from Karawang were identified at concentrations exceeding the limit of quantification.

Table 4.3 *Heavy metal concentrations in the samples collected at the Merah Putih Incinerator (mg/kg DW).*

Sample ID	Matrix	As	Cd	Cu	Hg	Ni	Pb	Sb	Zn
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
BEK-WASTE-01/22	brick from ash	0.6	10.9	343	0.002	31.8	65.5	0.42	989
BEK-ASH-01/23	ash	1.2	21.5	407	0.002	63.7	85.7	0.69	1,465

Table 4.4 *Heavy metal concentrations in the egg samples collected in Bantar Gebang (mg/kg DW).*

Sample ID	As	Cd	Cu	Hg	Ni	Pb	Sb	Zn
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
B-EGG-1	<0.01	<0.005	1.2	0.006	<0.05	<0.05	<0.05	24.3
B-EGG-4	<0.01	<0.005	1.2	0.008	<0.05	<0.05	<0.05	25.2
BEK EGG-04/22 + B-EGG-3	<0.01	<0.005	1.0	0.008	<0.05	<0.05	<0.05	19.3

Photo 4.3: *The whole area in Karawang is affected by pollution caused by burning plastic waste in lime kilns. Photo: Ondrej Petrlik, Arnika, December 2022.*

Arsenic was found at the level of 13.2 mg/kg in the soil sample, which was almost three times higher than the reference soil samples collected in Cisarua.

Cadmium was detected at 1.5 mg/kg in the soil sample form Karawang. This is 16 times higher than the Cd level in the reference soil samples, which had a concentration of 0.09 mg/kg.

Copper levels in the soil sample from Karawang were found to be 16 times higher than the reference soil sample's Cu concentration of 22.5 mg/kg.

Mercury concentration in the soil sample was measured at 0.55 mg/kg, which was 4.5 times higher than the reference soil sample's concentration of 0.12 mg/kg.

Nickel levels in soil samples from Karawang were 34 times higher than the Cisarua reference soil sample's concentration of 3.5 mg/kg.

Lead concentration was found to be highest in the soil sample at 421.0 mg/kg, which was 35 times higher than the reference soil samples' Pb concentration of 11.8 mg/kg.

Zinc concentration in the soil sample in Karawang had a concentration of 3407 mg/kg, which was significantly higher than zinc levels in the soil from the reference location.

With the exception of Sb and Cu, the heavy metal values in the Karawang soil sample were found to be higher than those in the sample of ash from waste incineration in the lime kiln, see Table 4.5. This difference is significant and ranges from twice the value for Ni to 25 times the value for Hg.

A soil sample was collected at a distance of approximately 60 metres from the nearest lime kiln. This is the soil where residual ash from waste incineration is deposited. Therefore, the soil is contaminated by both ash and combustion gases deposited on the surface over a long period of time. This site also poses a high risk to the neighbouring pond, where this soil can leach into and thus pollute the aquatic ecosystem.

The soil sample exceeds the U.S. EPA published residential soil contamination limits for As, Cd, Cu, Ni, Pb and Zn and the Czech soil contamination indicator values for Pb, see Table 4.6.

The soil sample from Karawang exhibited elevated concentrations of heavy metals in comparison to the global ranges for Cu, Ni, Pb and Zn. The concentration of Cu was almost 5 times higher than the level of the global range of 109 mg/kg, while the concentration of Ni was more than 3 times higher than the higher level

***Table 4.5** Heavy metal concentrations in the ash and soil samples collected in Karawang Regency (mg/kg DW).*

Sample ID	Matrix	As	Cd	Cu	Hg	Ni	Pb	Sb	Zn
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
KAR-ASH-02/22	ash	2.9	0.34	725	0.02	58.4	47.3	5.7	3,102
KAR-SOIL-01/22	**soil**	13.2	1.49	501	0.55	120	421	0.68	3,407
Reference locations	**soil**	4.6	0.09	22.5	0.12	3.5	11.8	<0.10	31.9

***Table 4.6** Table of soil sample from Karawang compared to relevant legislation*

	As	Cd	Cr	Cu	Fe	Hg	Mo	Ni	Pb	V	Zn
KAR-SOIL-01/22	13.2	1.5	-	501	-	0.55	-	120	421	-	3,407
Levels of pollution limits – resident soil (US EPA)[8]	0.68	0.71	-	310	5,500	1.1	39	84	400	39	2,300
Czech pollution indication[9]	40	20	-	-	-	20	-	-	400	-	-

of the global range of 37 mg/kg. The concentration of Pb was 15 times higher than the global average of 27 mg/kg, and the concentration of Zn was 3407 mg/kg, far exceeding the global range of 60 to 89 mg/kg (Kabata-Pendias, 2011).

The alarming Pb pollution levels from the non-industrial soil are twice as high as samples even from the copper and molybdenum mining and processing region in Alaverdi in the northern region of Armenia (Pb maximum 206 mg/kg) (Bystrianský et al., 2018), and gold mining in Melikgyugh, where a Pb maximum of 212 mg/kg was found (Matoušková et al., 2023).The Hg level in soil exceeded the level of soil samples taken in the vicinity of the recycling company focused on metal smelting, including burning of waste, where Hg levels were measured at 0.046 and 0.245 mg/kg (Bystrianský et al., 2018).

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[8] Czech Decree No. 153/2016 issued by the Ministry of Agriculture. Available at: https://www.zakonyprolidi.cz/cs/2016-153

[9] US EPA. Regional Screening Levels of November 2023. https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables

Photo 4.4: *Contamination with heavy metals in Bantar Gebang was compared with an area affected by the mining industry in Armenia. This photo is from Metz Ayrum, Armenia. Photo: Ecolur, July 2018.*

4.3.3 Morowali

Four out of eight heavy metals - arsenic, copper, mercury and zinc - were detected in a sample of eggs from a residential area 7 km from the Morowali Industrial Park in Indonesia. Zinc concentration in eggs from the Morowali location was higher than in home-reared eggs from Australia (mean 11.3 mg/kg Zn) (Grace & MacFarlane, 2016). A comparative analysis was conducted on a sample from Morowali and eggs from areas of high industrial load. The results demonstrated that eggs from mining areas in India exhibited elevated levels of Cu and Zn (Giri & Singh, 2019). The mercury level is significantly lower than those previously analysed in the mining region of Colombia (González-Álvarez et al., 2023).

4.4 Conclusion

Our study around the Bantar Gebang landfill in Indonesia revealed significant heavy metal contamination in the soil and sediment samples. Most heavy metals, including zinc, lead, and copper, were found at concentrations exceeding reference levels, indicating localized pollution from the landfill. Fly ash from incinerators showed high concentrations of zinc and copper, mirroring the heavy metal profile found in the soil, thus suggesting that waste incineration significantly contributed to the pollution. The free-range chicken eggs collected near the landfill showed detectable levels of copper, mercury, and zinc, but these levels were below potential health risk thresholds. However, comparisons with other contaminated areas showed that eggs from Bantar Gebang contained relatively higher levels of contamination.

The Karawang area displayed a different yet concerning pattern of heavy metal pollution, with soil samples showing extremely high levels of lead, significantly exceeding global averages and reference sites. This indicates severe contamination that poses substantial environmental and health risks. Other heavy metals, including cadmium, copper, and nickel, were also found at elevated concentrations, reinforcing the impact of industrial activities in this region. The geographical distribution of contaminants suggests potential pollution hotspots within the area, warranting further investigation. The study highlights the need for urgent remediation and monitoring to address this pollution and prevent its spread to the broader environment.

Table 4.7 *Heavy metal concentrations in the egg samples collected in Morowali City (mg/kg DW).*

Sample ID	**Matrix**	**As**	**Cd**	**Cu**	**Hg**	**Ni**	**Pb**	**Sb**	**Zn**
		mg/kg	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**
MWL-EGG-1	eggs	0.01	<0.005	0.82	0.007	<0.05	<0.05	<0.05	18.8

5. POPs Contamination in Karawang

Jindrich Petrlik, Yuyun Ismawati, Lee Bell, Bjorn Beeler, Valeriya Grechko, Nikola Jelinek, Mochamad Adi Septiono

5.1 Introduction

Many toxic additives in plastic waste can leak into the environment when disposed of or burned, including chemicals listed in the SC (Stockholm Convention, 2010, 2023a). Other toxic chemicals are generated when plastic waste is incinerated as fuel, including those listed as unintentionally produced POPs in Annex C to the Stockholm Convention; for example, PCDD/Fs, dl PCBs, HCB or PeCB (Stockholm Convention, 2023a). Contamination by all these chemicals was documented recently at sites where various plastic wastes are burned or incinerated in developing countries; e.g., Ghana, Cameroon (Petrlik, Adu-Kumi, et al., 2019), Kenya, Tanzania (Petrlik, Ochieng Ochola, et al., 2020), Kazakhstan, China, Thailand (Bystriansky et al., 2018; Petrlik et al., 2018) or Indonesia (Petrlik, Ismawati, et al., 2019). In Indonesia, plastic waste imported from developed countries is often used as fuel in the production of tofu or lime (Petrlik, Ismawati, et al., 2020). We focused on mapping pollution by POPs in villages of Karawang Regency, West Java, at sites affected by using plastic and rubber waste (including used tires) as a fuel in lime kilns.

5.2 Sampling

Pooled samples of four individual egg samples from free-range hens were collected at three selected sampling sites in Tamansari, Pangkalan subdistrict of Karawang Regency in order to obtain more representative samples. We also used a sample of a pooled eggs sample from a convenience store located in the same subdistrict as a reference sample to exhibit background levels of POPs, following precedents from other studies (DiGangi & Petrlik, 2005; Dvorská, 2015).

Photo 5.1: *Plastic waste is used as fuel in lime kilns in Karawang.*
Photo: Ondrej Petrlik, Arnika, December 2022.

Photo 5.2: *Plastic waste is used as fuel in lime kilns in Karawang.*
Photo: Ondrej Petrlik, Arnika, December 2022.

Photo 5.3: *Free-range chicken eggs sampling in Karawang.*
These eggs contained quite high level of brominated dioxins (PBDD/Fs).
Photo: Ondrej Petrlik, Arnika, December 2022.

Figure 5.1: *Map with group of samples in the middle of lime kilns concentrated around the road, locality Karawang II.*

Three samples of the rice grown and consumed in the village and two plant samples were collected from five different locations around the village.

The residual ash from lime kilns and/or ash dumped nearby, and soil samples, all of which were accessible to chickens foraging, were taken. Two soil samples were taken at locations affected by both air emissions from lime kilns and ash deposits.

One of the pooled egg samples (KAR-EGG-1) was taken in a separate part of the village marked as 'locality Karawang I,' a little bit further north from samples of ash and eggs labelled sample KAR-EGG-2. The majority of samples (KAR-EGG-2, KAR-ASH-1-3 and KAR-SOIL-1) were taken near the part of the village with concentrated lime kilns, and it is marked on the map at Figure 5.1 as Karawang II. Most of the samples of plastic and rubber wastes were also taken at this location. Samples of ash, soil and a third egg sample (KAR-ASH-4, KAR-SOIL-2, KAR-

EGG-3) were taken further south from the major group of samples, approximately 1 km away, and is labelled Karawang III.

All samples but rice were analysed for their content of individual PCDD/Fs and dl PCBs.

Analyses of PBDEs, HBCD, nBFRs, 17 PFASs, PeCB, HCB, HCBD, and ndl PCBs were conducted in a Czech certified laboratory at the Department of Food Chemistry and Analysis of the University of Chemistry and Technology in Prague, and the analytical method is described in Chapter 2.2.

Six samples of tire, plastic and rubber waste used as fuel were also analysed for some of the analysed POPs.

5.3 Results and discussion

The results of chemical analyses for pooled samples of free-range chicken eggs, ash, and soil are summarized according to groups of samples from the same locations in Table 5.1, below. The results of chemical analyses for rice and other plants are in Table 5.2.

Table 5.1: *Results of the analyses for POPs in pooled samples of eggs, ash and soil from localities Karawang I, II and III, and reference sample of eggs. All results for egg samples are expressed per gram of fat, except PFASs (expressed per gram of fresh weight).*

Locality	**Units**	**Karawang II**			
Sample ID		**KAR-EGG-2**	**KAR-ASH-1**	**KAR-ASH-2**	**KAR-SOIL-1**
Matrix		4 Eggs	Ash	Ash	Soil
Fat content	%	13.5	/	/	/
PCDD/Fs	pg WHO-TEQ/g	178	5.6	536	/
dl PCBs		34	0.19	43	/
HCB	ng/g	16	0.03	991	10
PeCB		6.1	0.04	414	5.5
HCBD		<0.10	0.12	0.05	0.24
6 ndl PCB		98	0.04	0.34	19
13 PCN congeners		2.4	<LOQ	2.8	1.9
SCCPs		69	/	/	/
sum HBCD		39	<LOQ	<LOQ	1.71
sum of PBDEs		73	<LOQ	0.06	1,515
sum of nBFRs		18	1.9	1.3	1,456
sum of PFASs		4.2	/	/	/

Locality	Units	Karawang II				
Sample ID		**KAR-EGG-01/22**	**KAR-ASH-01/22**	**KAR-ASH-02/22**	**KAR-ASH-3**	**KAR-SOIL-01/22**
Matrix		3 eggs			Ash	Soil
Fat content	%	14.9			/	/
PCDD/Fs (pg TEQ/g)	pg WHO-TEQ/g	3.2	1,134	166	349	72.4
dl PCBs (pg TEQ/g)		1.1	57	6.7	5	11.6
HCB	ng/g	1.8	7.3	12.5	273	2.6
PeCB		0.85	6.8	9.0	225	3.1
HCBD		<0.1	<0.02	<0.02	0.16	1.08
6 ndl PCB		12.9	736	0.23	0.36	148
13 PCN congeners					0.14	
SCCPs		<50	1,560	<5	/	1,410
MCCPs		732	6,950	<10		14,400
sum HBCD		<4.2	4.8	<0.75	<LOQ	68
sum of PBDEs		10.22	4,963	<LOQ	<LOQ	189
sum of nBFRs		<LOQ	430	<LOQ	0.05	252
TBBPA		NA	75	<1.5		24
Sum of DP		2.0	211	<0.01	NA	11.9
sum of PFASs		0.67	8.7	<0.3	/	0.82

Locality		**Karawang I**		**Karawang III**		**Reference**
Sample ID		KAR-EGG-1	KAR-EGG-3	KAR-ASH-4	KAR-SOIL-2	KAR-EGG-R
Matrix		4 Eggs	4 Eggs	Ash	Soil	3 Eggs
Fat content	%	13.8	16.7	/	/	17.4
PCDD/Fs	pg WHO-TEQ/g	11	109	14	72	0.23
dl PCBs		1.7	9.8	0.2	1.7	0.02
HCB	ng/g	4.6	4.8	0.15	0.76	5.0
PeCB		0.70	3.5	0.27	1.6	1.9
HCBD		<0.10	0.13	0.03	<0.02	2.1
6 ndl PCB		4.5	5.7	0.17	0.29	4.8
13 PCN cong.		<LOQ	<LOQ	<LOQ	0.54	<LOQ
SCCPs		<50	237	/	/	151
sum HBCD		47.6	36.5	<LOQ	<LOQ	<LOQ
sum of PBDEs		<LOQ	<LOQ	<LOQ	2.1	<LOQ
sum of nBFRs		<LOQ	<LOQ	0.03	19	<LOQ
sum of PFASs (ng g^{-1})		0.85	2.3	/	/	0.05

Tires, plastic and rubber waste used as fuel, also partly analysed for some of the POPs measured in ash, soil and eggs, mainly exhibited POPs as follows: Tires contained significant levels of ndl PCBs (172 ng/g), and some other plastic wastes contained PBDEs (35 and 170 ng/g respectively) and nBFRs (0.9; 2.2 and 261 ng/g). These POPs were <LOQ in all other measured samples of plastic waste or rubber. A comparison of PCDD/Fs and dl PCBs patterns are in graphs at Figures 5.2 and 5.3 below.

Figure 5.2: *PCDD/F patterns.*

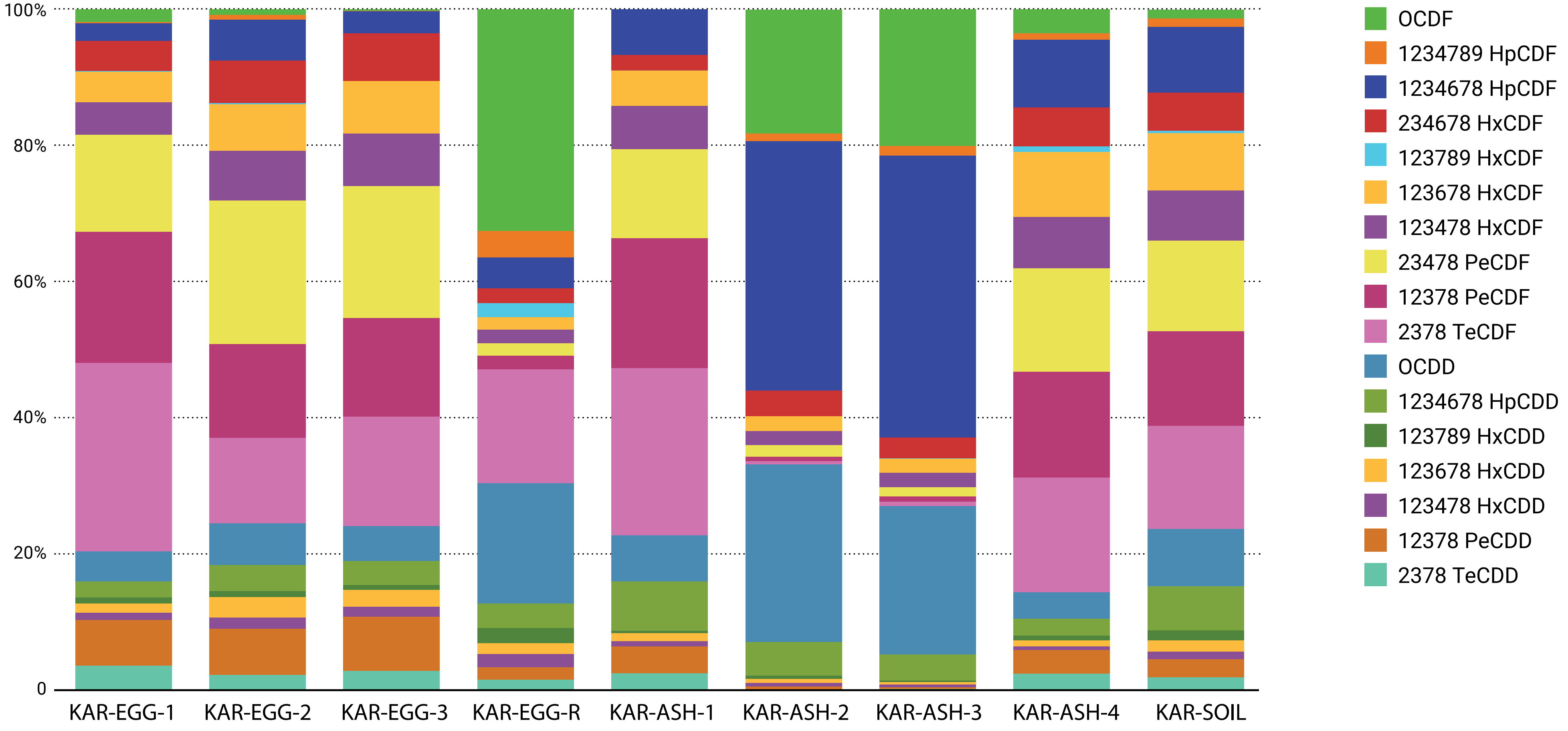


Figure 5.3: *DI PCB patterns in samples from Karawang.*

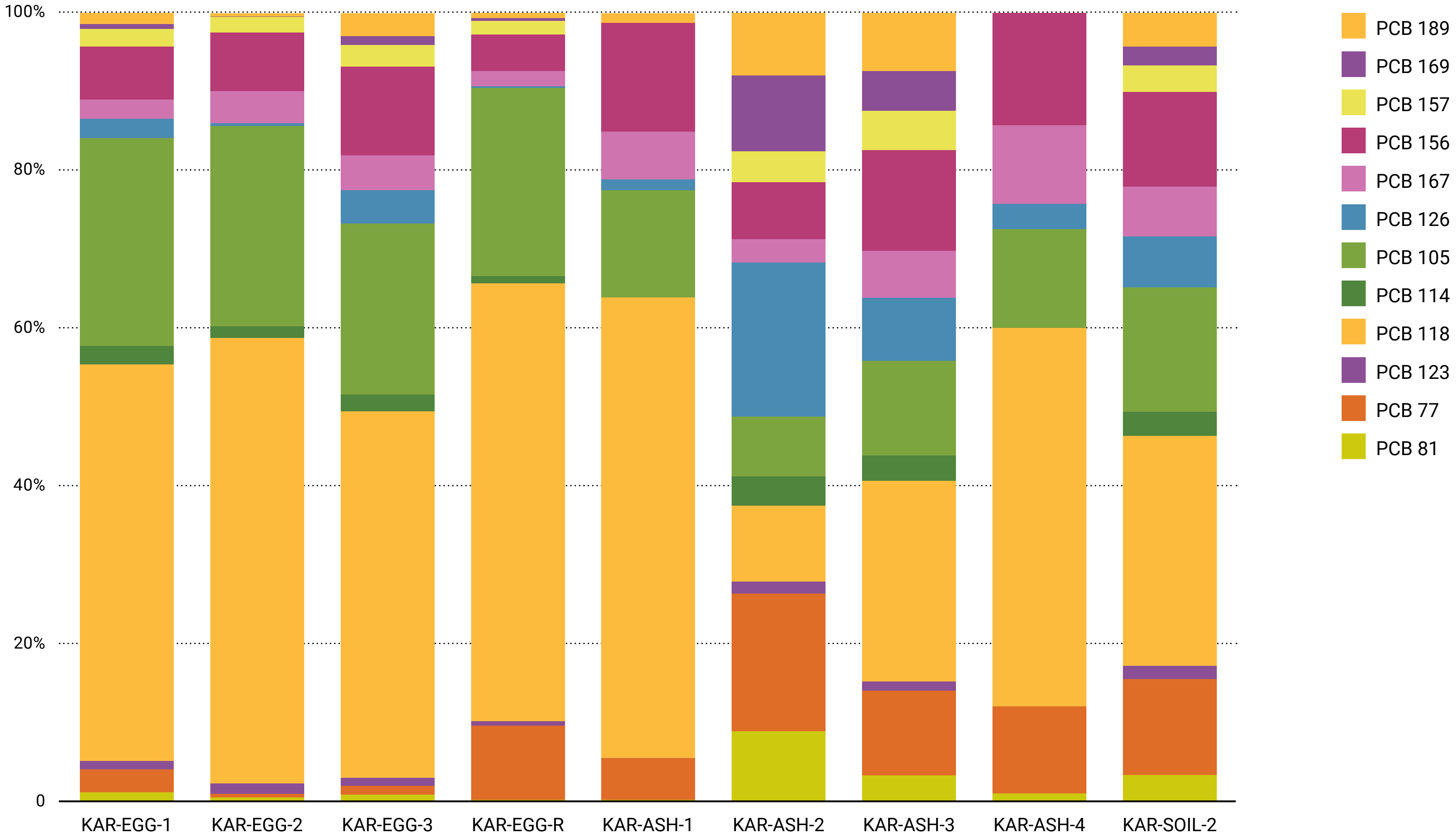


Table 5.2: *Results of analyses for some POPs in samples of rice and other plants from localities in Karawang. Results are expressed in ng/g dry matter unless otherwise noted.*

Sample ID	KAR-PLA-02	KAR-PLA-04	KAR-PLA-05	KAR-PLA-06	KAR-PLA-07
Matrix	plant	plant	rice	rice	rice
PeCB	0.07	0.52	<0.02	<0.02	<0.02
HCB	0.24	0.41	0.03	0.32	<0.02
HCBD	<0.02	0.03	<0.02	<0.02	<0.02
sum of HBCD	<0,1	<0,1	<0,1	<0,1	<0,1
sum of PBDEs	0.30	<LOQ	0.04	<LOQ	0.02
sum of nBFRs	0.18	62.7	<LOQ	<LOQ	<LOQ

Photo 5.4: *Sampling of ash near one of lime kilns in Karawang. Photo: Ondrej Petrlik, Arnika. December 2022.*

High levels of the unintentionally produced POPs PCDD/Fs, dl PCBs, HCB, and PeCB, were measured in two samples of ash and free-range chicken eggs from Karawang II. Chicken eggs samples and soil samples from Karawang III contained high levels of PCDD/Fs. Very high levels of PBDEs and nBFRs were measured in soil from Karawang II. PCDD/Fs levels were much higher in "fresh" ash samples taken in close vicinity (5 to 10 m) to the lime kilns (KAR-ASH-2 and 3), while they were lower in older, weathered ash samples (KAR-ASH 1 and 4). These groups of ash samples also had very different congener patterns. Weathered ash samples had similar patterns to soil, which can be caused due to the fact that weathered ash samples were already partly mixed with surrounding soils. PCNs were measured at low levels or they were not detected above LOQ in half of all samples. High levels of ndl PCBs were measured in eggs and soil from Karawang II, which is interesting when compared to the significant ndl PCBs level also found in used tire samples.

All three free-range chicken egg samples exhibit a waste incineration pattern of dl PCB congeners (see Figure 5.3) according to the dl PCB congener profile already established in a previous study (Petrlik, Bell, et al., 2022). However, egg samples from Karawang II have dl PCB patterns very close to Aroclor 1254 (Petrlik, Bell, et al., 2022).

In two free-range chicken egg samples presented in this study, KAR-EGG-2 and 3 were measured as the eighth and eleventh highest level of PCDD/Fs in eggs respectively, compared to other samples included in the global review and from scientific literature (Petrlik, Bell, et al., 2022). They exhibit the same level of contamination with dioxins as samples from Tropodo, another locality in Java, Indonesia contaminated by incineration of plastic waste used as fuel in tofu production facilities. Dioxin concentrations in these eggs exceeded the EU standard of 2.5 pg TEQ/g fat (European Commission, 2022a) by more than 71- and 43-fold respectively. The EU standard of 40 ng/g for six ndl PCB congeners (European Commission, 2022a) was exceeded in KAR-EGG-2 by more than twice. Higher levels of dioxins in free-range chicken eggs from Asia were observed only in Bien Hoa, a former US Army base in Vietnam contaminated by Agent Orange (Kudryavtseva et al., 2020) or in Tropodo (Ismawati et al., 2021; Petrlik, Bell, et al., 2022).

The concentration of HCB is generally high in a significant portion of samples from Karawang. However, the concentration of HCB in rice may contribute to its entry into the food chain when fed to domestic animals. One sample (KAR-PLA-04) exhibited high concentrations of nBFRs (62.7 ng/g), with DBDPE being the most abundant (48.5 ng/g) and PBT the second most abundant (11.8 ng/g). The same sample also had highest levels of PeCB (0.52 ng/g dm) and HCB (0.41 ng/g dm) among collected plants (see Table 5.2)

KAR-SOIL-1 sample had very high concentrations of BFRs, both regulated (PBDEs) and unregulated (nBFRs) by the SC (Stockholm Convention, 2023a). Their concentration in this sample is much higher compared to levels measured in samples of plastic waste from the locality Karawang II, but it is not possible to monitor BFRs in large volumes of plastic mixed in fuel for lime kilns. BFRs as well as PCBs most likely only evaporate from plastic and rubber waste under temperatures in lime kilns. The level of PBDEs measured in soil sample KAR-SOIL-1 of 1515 ng/g dw exceeds the level measured in mixed soil and ash samples from a plastic waste scrap yard in Bangun and exceeds the background level of 0.04 ng/g dw in soil samples from a clean reference site in Mbeji forest by almost 38 thousand fold[10].

Two ash samples KAR-ASH-2 and 3 contained very high concentrations of HCB and PeCB. HCB levels in these two samples exceeded the level of 34 ng/g measured in ash from Tropodo (Petrlik, Ismawati, et al., 2020) by 29 and 8-fold respectively. PeCB and HCB levels in these ash samples exceed levels observed in ashes from small medical waste incinerators in the Czech Republic (Mach, 2017) and Africa (Jelinek et al., 2023; Petrlik, Adu-Kumi, et al., 2019) by several thousand and almost 250-fold respectively.

Photo 5.5: *Exhaust gases and ash from burning plastic waste in lime kilns in Karawang caused serious POPs contamination of the environment and food chain. Photo: Ondrej Petrlik, Arnika, December 2022.*

Free-range chicken eggs and soil in Karawang are contaminated with POPs as a consequence of incineration of plastic and rubber waste in lime kilns. Pollution occurs by several pathways, via air pollution but also in ash which is dumped next to lime kilns. This pollution is very serious, although the levels of POPs measured in ash produced by lime kilns are below currently established limits for definition of POPs waste by both Basel and Stockholm Conventions, including dioxins (1 or 15 ng TEQ/g), dl PCBs (no limit established yet) or PBDEs (50 or 1000 mg/kg for PBDEs without decaBDE)(Basel Convention, 2023). Despite that, the ashes, which are widespread, represent a serious threat to the environment in Karawang district. This situation repeats similar cases observed in Tropodo (ash from plastic waste incineration in tofu factories) and Kendalsari (ash from aluminum smelters), both in East Java, or Accra in Ghana (medical waste incinerator ash).

5.4 Conclusions

Very serious contamination of the environment and food chain with POPs as result of using plastic and rubber waste as fuel in lime kilns in Karawang Regency was confirmed by measurements of samples of ash, soil and free-range chicken eggs in this study. The contamination of eggs with dioxins represents the highest ever measured levels in Asia and globally. It is necessary to avoid using plastic waste as fuel in facilities like lime kilns or tofu factories in particular. More strict limits for the definition of POPs waste are needed to regulate disposal options for waste produced by waste incineration, including facilities like lime kilns burning plastic waste.

6. POPs Contamination in Bantar Gegang

Jindrich Petrlik, Yuyun Ismawati, Nikola Jelinek, Valeriya Grechko, Annisa Maharani, Miroslava Jopkova, Barbora Skorepova

6.1 Introduction

Many toxic additives in plastic waste can leak into the environment when disposed of or burned, including chemicals listed in the Stockholm Convention (SC) (Stockholm Convention, 2023a), and not yet listed POPs (Matthies et al., 2016; POP RC, 2024; Stockholm Convention, 2024). Other toxic chemicals are generated when plastic waste is incinerated as fuel or burned on dumpsites or landfills, including those listed as unintentionally produced POPs in Annex C to the SC; for example, polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), dioxin-like PCBs (dl PCBs), and hexachlorobenzene (HCB) or pentachlorobenzene (PeCB) (Stockholm Convention, 2023a). Contamination by all these chemicals was documented recently at sites in developing countries where various plastic wastes are often disposed of in an environmentally unsound way, either burned or incinerated, causing severe toxic contamination (Haarr et al., 2023; Mach et al., 2018; Paddock, 2019; Pathak et al., 2023; Petrlik et al., 2024; Petrlik, Bell, et al., 2022; Velis & Cook, 2021). We focused this chapter on mapping pollution by POPs in the Bantar Gebang area, one of the largest landfills in Indonesia, and surrounding areas with many sites sorting mainly plastic waste. It is also the area where the Merah Putih waste incinerator is located, as well as some other potential sources of POPs such as metallurgical or galvanization plants (see Chapter 3).

Photo 6.1: *A large municipal waste landfill in Bantar Gebang is surrounded by small and medium enterprises that may contribute to overall contamination of the environment with toxic chemicals. Photo: Jindrich Petrlik, Arnika, December 2022.*

***Photos 6.2 and 6.3:** Sampling of soil at a tea plantation and sediment in a wild river upstream in Cisarua. Photos: Ondrej Petrlik, Arnika, December 2022.*

6.2 Sampling

Six pooled samples of free-range chicken eggs, seven pooled soil samples, one sediment sample, and one brick made of fly ash and fly ash sample from the Merah Putih waste incinerator were chosen for POPs analyses from Bantar Gebang. We also used pooled egg samples from a convenience store in Karawang Regency and a supermarket in Jakarta as reference samples to exhibit background levels of POPs, following precedents from other studies (DiGangi & Petrlik, 2005; Dvorská, 2015). More information about sampling and samples from Bantar Gebang can also be found in Chapters 2, 4 and 7.

Cisarua was chosen for obtaining reference samples of soils and sediments. Two pooled soil samples and two pooled sediment samples were taken at this locality. A forest area near a camping area was chosen for soil sample CIS-SOIL-REF-1/22, and a tea plantation area was chosen for soil sample CIS-REF-2/22. Sediment samples were taken from the river at two different sites. The first one (CIS-SED-REF-1/22) was near the camping area of the reference soil sample, while the other one (CIS-SED-REF-2/22) was near a restaurant on another part of the river. A soil sample in Mbeji Forest was taken during one of the previous projects in the eastern part of Java in November 2019 (Petrlik, Ismawati, et al., 2020). The soil sample was taken at the spring-water forest Sumber Beji entranceway, also called “Mbeji Forest”. That reference site is located at Sranten, Panglungan Village, a mountainous area 600 to 800 meters above sea level. We added this reference sample to this study as localities in Cisarua did not seem to eliminate all anthropogenic activities.

All samples were analysed for their content of individual PCDD/Fs and dl PCBs using GC/HRMS. Toxic equivalency factors (TEFs) defined in 2005 (van den Berg et al., 2006) were used to evaluate dioxin toxicity in all samples.

Analyses of PBDEs, HBCD, TBBPA, nBFRs, 17 PFASs, SCCPs, MCCPs, 13 PCN congeners, two stereoisomers of DP, DDT and its metabolites, 3 HCH setereoisomers, PeCB, HCB, HCBD, and ndl PCBs were conducted in a Czech certified laboratory at the Department of Food Chemistry and Analysis of the University of Chemistry and Technology in Prague. The analytical methods are described in Chapter 2.2 of this book.

The results of POPs analyses in eggs were also compared with EU and Indonesian standards set for foodstuff (European Commission, 2022a, 2022b; Republik Indonesia, 2018). The carry-over rates, which were determined by the Dutch National Laboratory (Hoogenboom et al., 2006), were used for re-calculation of PCDD/F and PCB congener profiles in eggs for better comparison with profiles in ash and soil samples. The carry-over rates for PCDD/Fs are described in Chapter 2.2.

Tables 6.1 and 6.2 present results for individual samples. They also show which compounds were analysed in these samples.

6.3 Results and discussion

Results of chemical analyses for pooled samples of free-range chicken eggs, ash, brick made of fly ash and soil from Bantar Gebang and reference eggs samples are summarized in Table 6.1. Results of analyses from reference sites Cisarua and Mbeji Forest are summarized in Table 6.2.

Photo 6.4: *A look inside the bunker of Merah Putih waste incinerator in Bantar Gebang. Photo: Ondrej Petrlik, Arnika, December 2022.*

Table 6.1: *Results of the analyses for POPs in pooled samples of eggs, soils, sediment, ash and brick made of ash from localities in Bantar Gebang, and reference samples of eggs. All results for egg samples are expressed per gram of fat, except PFASs, which are expressed per gram of fresh weight. Results are in ng/g if not marked otherwise.*

Locality	**Units**	**Bantar Gebang**						**Karawang**	**Jakarta**
Sample ID (eggs)		**EGG-DUMPSITE**	**BEK-EGG-03/22**	**BEK-EGG-05/22**	**BEK-EGG-04/22; B-EGG-3**	**B-EEG-1**	**B-EGG-4**	**KAR-EGG-R**	**JAK-SUP**
Eggs in pool sample	Number	2	2	2	4	6	6	3	6
Fat content	%	14.8	16.1	15.5	17.9	17.8	21.5	17.4%	9.53
PCDD/Fs	pg WHO-TEQ/g fat	14.6	20.0	19.7	33.9	10.0	3.8	0.23	0.001
dl PCBs		7.8	7.5	8.4	20.2	4.3	2.0	0.02	0.002
PCDD/Fs/dl PCBs		22.4	27.4	28.1	54.1	14.3	5.8	0.25	0.003
PeCB	ng/g fat	2.1	1.0	0.74	3.1	1.3	0.36	1.9	<0.1
HCB		3.7	40.9	2.0	5.3	3.9	0.89	5.0	<0.1
HCBD		<0.1	<0.1	<0.1	0.3	<0.1	<0.1	2.1	<0.1
7 PCB		16.1	3.5	4.4	10.5	1.5	0.62		0
6 PCB		14.6	3.2	4.1	6.4	1.5	0.62	4.8	< LOQ
SCCP C_{10}-C_{13}		NA	NA	NA	<50	309	<50	151	136
MCCP C_{14}-C_{17}		NA	NA	NA	1,921	2,345	<100	NA	NA
sum of HBCD		5.0	<4.2	<4.2	<4.2	<4.2	<4.2	< LOQ	< LOQ
sum of PBDEs		31.4	28.4	3.2	9.9	8.0	6.3	< LOQ	1.4
decaBDE		26.4	22.6	2.5	9.9	8.0	6.3	<5.0	<1.0
7 BDE congeners		2.2	0.30	0.7	<LOQ	<LOQ	<LOQ	<LOQ	1.4
sum of N-BFRs		1.0	5.5	<LOQ	<LOQ	<LOQ	3.6	<LOQ	< LOQ
TBBPA		NA	NA	NA	NA	NA	NA	NA	<4.2
sum of DP		2.7	2.3	<0.3	<0.3	<0.3	<0.3	NA	NA
sum of PFASs	ng/g fresh weight	6.4	4.2	1.3	2.8	1.2	1.5	0.052	0.1
PFOA		0.11	0.01	0.03	0.03	0.01	<0.006	0.007	<0.01
PFOS		4.5	1.9	0.38	1.7	0.31	0.86	<0.006	<0.01
PFHxS		0.046	0.007	0.018	0.024	0.079	0.019	<0.006	<0.01

Locality		Bantar Gebang							
Sample ID (eggs)	**Units**	**BEK-SED-01/22**	**BEK-SOIL-01/22**	**BEK-SOIL-02/22**	**BEK-SOIL-03/22**	**BEK-SOIL-04/22**	**BEK-SOIL-05/22**	**BEK-SOIL-06/22**	**BEK-SOIL-07/22**
Matrix		Sediment	Soil						
PCDD/Fs	pg WHO-TEQ/g wet weight	NA	4.9	NA	NA	0.58	NA	NA	1.2
dl PCBs		NA	0.63	NA	NA	0.06	NA	NA	0.20
PCDD/Fs/dl PCBs		NA	5.5	NA	NA	0.64	NA	NA	1.40
PeCB	ng/g dm	<0.02	<0.02	<0.02	<0.02	<0.02	0.15	0.06	0.07
HCB		<0.02	<0.02	<0.02	<0.02	<0.02	0.31	<0.02	0.06
HCBD		<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
7 PCB		<0.02	<0.02	<0.02	0.08	<0.02	<0.02	<0.02	0.16
6 PCB		<0.02	<0.02	<0.02	0.08	<0.02	<0.02	<0.02	0.16
SCCP C_{10}-C_{13}		<5	79.8	<5	<5	<5	<5	<5	9.5
MCCP C_{14}-C_{17}		<10	848	<10	<10	<10	12.2	<10	12.5
sum of HBCD		<0.75	1.1	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75
sum of PBDEs		9.31	14.0	0.66	<LOQ	<LOQ	<LOQ	<LOQ	15.5
decaBDE		9.3	14.0	<5.0	<5.0	<5.0	<5.0	<5.0	15.5
7 BDE congeners		<0.01	<0.01	0.50	<LOQ	<LOQ	<LOQ	<LOQ	0.06
sum of nBFRs		<LOQ	1.5	1.6	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
TBBPA		9.0	6.0	14.5	<1.5	<1.5	<1.5	<1.5	<1.5
sum of DP		0.6	1.2	0.39	0.25	<0.01	0.27	<0.01	0.30
sum of PFASs		0.57	1.37	<0.3	0.80	<0.3	<0.3	<0.3	<0.3
PFOA		<0.3	0.52	<0.3	0.33	<0.3	<0.3	<0.3	<0.3
PFOS		0.57	0.85	<0.3	0.47	<0.3	<0.3	<0.3	<0.3
PFHxS		<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3

Locality		**Bantar Gebang**	
Sample ID (eggs)		**BEK-WASTE-01/22**	**BEK-ASH-01/23**
Matrix		brick from fly ash	(most likely) fly ash
PCDD/Fs	pg WHO-TEQ/g wet weight	27.5	63.8
DL PCBs		1.3	1.9
PCDD/Fs/dl PCBs		28.8	65.7
PeCB	ng/g dm	1.1	0.06
HCB		2.00	0.64
HCBD		<0.02	<0.02
7 PCB		0.06	0.03
6 PCB		0.06	0.03
SCCP C_{10}-C_{13}		<5	<5
MCCP C_{14}-C_{17}		<10	<10
sum of HBCD		<0.75	<0.75
sum of PBDEs		<LOQ	<LOQ
decaBDE		<5.0	<5.0
7 BDE congeners		<LOQ	<LOQ
sum of nBFRs		<LOQ	<LOQ
TBBPA		<1.5	NA
sum of DP		<0.01	<0.01
sum of PFASs		<0.3	<0.02
PFOA		<0.3	<0.02
PFOS		<0.3	<0.02
PFHxS		<0.3	<0.02

Table 6.2: *Results of the analyses for POPs in pooled samples of soils and sediments from reference sites. Results are in ng/g if not marked otherwise.*

Locality		**Cisarua**	**Cisarua**	**Cisarua**	**Cisarua**	**Mbeji Forest**
Sample ID (eggs)	**Units**	**CIS-SOIL-REF-01/22**	**CIS-SOIL-REF-02/22**	**CIS-SED-REF-01/22**	**CIS-SED-REF-02/22**	**MBEJI-S**
Matrix		soil	soil	sediment	sediment	soil
PCDD/Fs	pg WHO-TEQ/g wet weight	2.8	12.8	NA	NA	0.71
DL PCBs		0.10	0.10	NA	NA	0.07
PCDD/Fs/dl PCBs		2.9	12.9	NA	NA	0.78
PeCB	ng/g dm	<0.02	<0.02	<0.02	<0.02	0.16
HCB		<0.02	<0.02	<0.02	<0.02	0.08
HCBD		<0.02	<0.02	<0.02	<0.02	<0.02
7 PCB		0.06	0.05	0.07	0.05	0.00
6 PCB		0.06	0.05	0.07	0.05	
SCCP C_{10}-C_{13}		NA	<5	NA	<5	2.4
MCCP C_{14}-C_{17}		NA	<10	NA	<10	NA
Sum of HBCD		<0.75	<0.75	<0.75	<0.75	<0.75
sum of PBDEs		<LOQ	<LOQ	<LOQ	<LOQ	0.04
decaBDE		<5.0	<5.0	<5.0	<5.0	<5.0
7 BDE congeners		<LOQ	<LOQ	<LOQ	<LOQ	0.04
sum of nBFRs		<LOQ	<LOQ	<LOQ	<LOQ	0.07
TBBPA		<1.5	<1.5	<1.5	<1.5	NA
sum of DP		NA	<0.01	NA	<0.01	NA
sum of PFASs		0.67	<0.3	<0.3	<0.3	<0.3
PFOA		<0.3	<0.3	<0.3	<0.3	NA
PFOS		<0.3	<0.3	<0.3	<0.3	NA
PFHxS		<0.3	<0.3	<0.3	<0.3	NA

***Photo 6.5:** Detail of the bottom ash heap in front of the Merah Putih waste incinerator in Bantar Gebang.*

***Photo 6.6:** Bricks made of fly ash from a waste incinerator, and their use within the area of the facility itself at the bottom. Photos: Jindrich Petrlik and Nikola Jelinek, Arnika, December 2022.*

At both selected reference sites in the Cisarua area, higher concentrations of dioxins were measured in the soil than in the vicinity of the landfill in Bantar Gebang. In the case of the reference locality CIS-SOIL-REF-02/22, this may be due to pesticide use, as suggested by the dioxin congeners pattern, particularly OCDD predominance (see Figure 6.1) (Holt et al., 2008; Petrlik, Bell, et al., 2022). In the case of sample CIS-SOIL-REF-01/22, the contamination source could be waste or wood burning at campfire sites near the camping area. Only the sample from Mbeji Forest showed lower concentrations of PCDD/Fs and dl PCBs than the two analysed soil samples from Bantar Gebang (BEK-SOIL-01/22 and BEK-SOIL-07/22), with the third sample BEK-SOIL-04/22 showing comparable concentrations. Elevated concentrations (near the LOQ) were found for some of the analysed POPs in the soil sample BEK-SOIL-07/22. This primarily included ndl PCBs, SCCPs, MCCPs, and PBDEs. Soil sample BEK-SOIL-07/22 was collected in a larger open space used as a playground.

Among the soil samples analysed for PCDD/Fs and dl PCBs, the highest values were found in sample BEK-SOIL-01/22, which also exhibited the highest concentrations of SCCPs, MCCPs, PBDEs, DP, and PFASs among all analysed soil samples from Bantar Gebang. Thus, this sample can be considered the most POPs-contaminated among the soil samples collected. Conversely, samples

BEK-SOIL-04/22, BEK-SOIL-05/22, and BEK-SOIL-06/22 mostly had values below the LOQ or slightly above it for most analysed POPs. However, this contrasts with the levels of POPs in a composite egg sample BEK-EGG-04/22;B-EGG-3, which showed some of the highest POPs values among the studied egg samples from Bantar Gebang, despite being collected at the same location as soil sample BEK-SOIL-04/22. This suggests that soil contamination levels may not correspond to egg contamination levels, as chickens also consume significant amounts of dust from plants or waste processed at individual homes in Bantar Gebang. It also confirms that monitoring soil contamination may not accurately reflect the level of contamination of a specific location with these substances.

The concentrations of PCDD/Fs and dl PCBs in ash and brick samples from the Merah Putih waste incinerator were very low compared to concentrations in ash from European or Chinese incinerators, resembling concentrations in a mixture of ash and washed ash from a municipal waste incinerator in Liberec. However, even in ash from a small medical waste incinerator in Islamabad, Pakistan, concentrations were at a comparable level of several tens of pg WHO-TEQ/g dm (Jelinek et al., 2023; Khwaja & Petrlik, 2006). Neither the concentrations of PeCB nor HCB were high in these samples.

A more detailed comparison of egg sample concentrations is discussed in another part of this report specifically focused on POPs in egg samples from multiple locations on the island of Java, including one site from Sulawesi Island. It indicates that for some POPs, egg contamination from Bantar Gebang is very severe. For instance, the contamination of eggs with PFASs, dioxins and dioxin-like compounds is particularly concerning. In all free-range chicken egg samples, the EU limit for PCDD/Fs/dl PCBs set for eggs as food at the level of 5 pg WHO-TEQ/g fat (European Commission, 2022a) was exceeded, with only a slight excess in sample B-EGG-4.

The second highest ever measured level of HCB (41 ng/g fat) from Asian countries was confirmed in one of the pooled free-range egg samples from Bantar Gebang (BEK-EGG-01/22). MCCPs, measured for the first time in Indonesian food, reached much higher levels than SCCPs in eggs from Bantar Gebang, ranging from below the Limit of Quantification (LOQ) to 2,345 ng/g fat, comparable to levels observed in eggs from neighborhoods near waste disposal sites in Tanzania. For a more detailed analysis, please refer to Chapter 7.

Photo 6.7: *Sorted as well as unsorted waste is everywhere in Bantar Gebang. Photo: Ondrej Petrlik, Arnika, December 2022.*

For the contamination of the environment around the landfill and waste incineration plant in Bantar Gebang, it is important to examine the patterns of PCDD/F and dl PCB congeners. These are compared in the graphs in Figures 6.1 and 6.2. It is equally important to compare these patterns with those for soil samples in which PCDD/Fs and dl PCBs were analysed. The difference between the profile of PCDD/F congeners in the egg and soil samples from Bantar Gebang is evident,

Figure 6.1: *PCDD/F patterns in samples from Bantar Gebang and reference soil samples from Cisarua.*

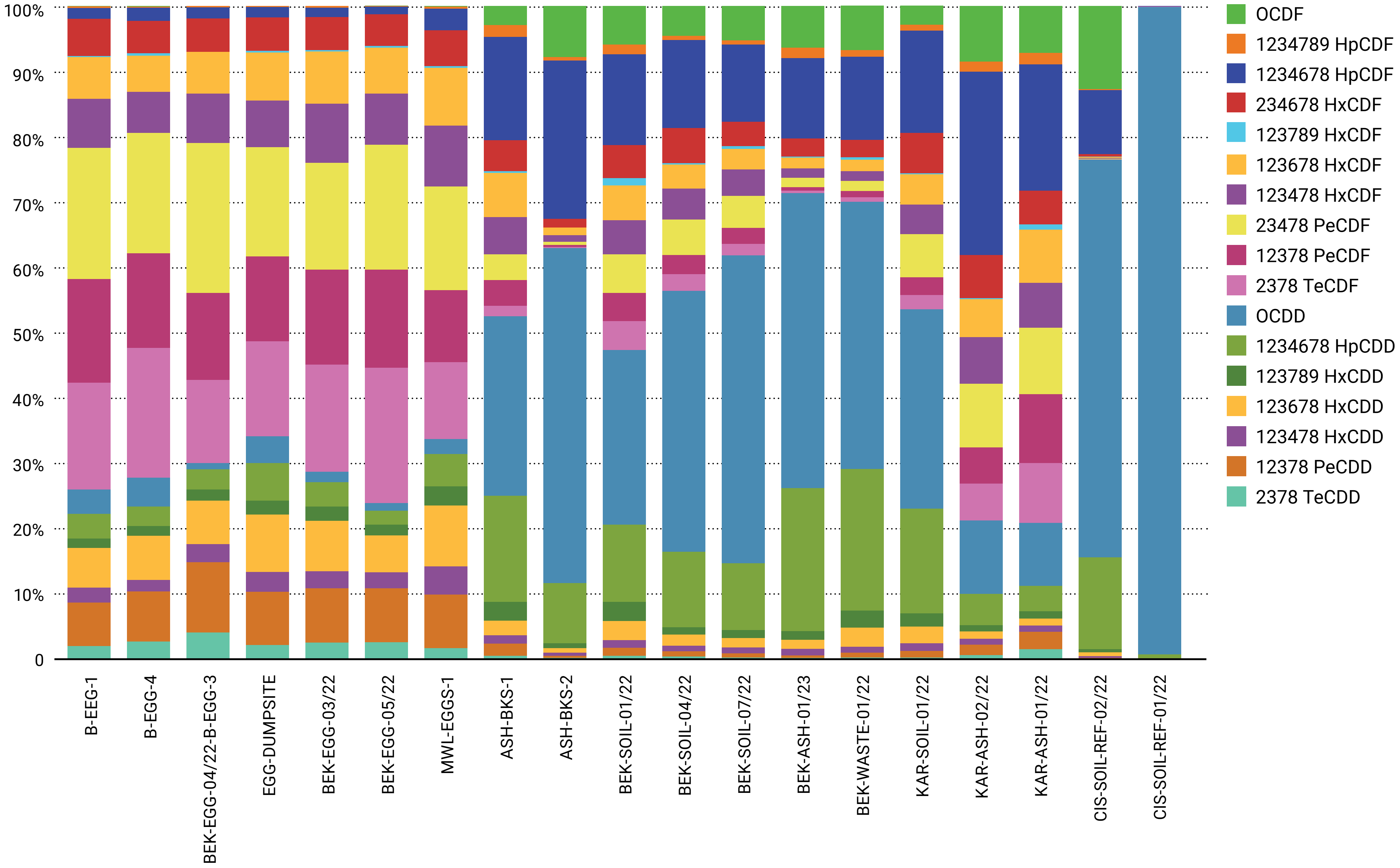
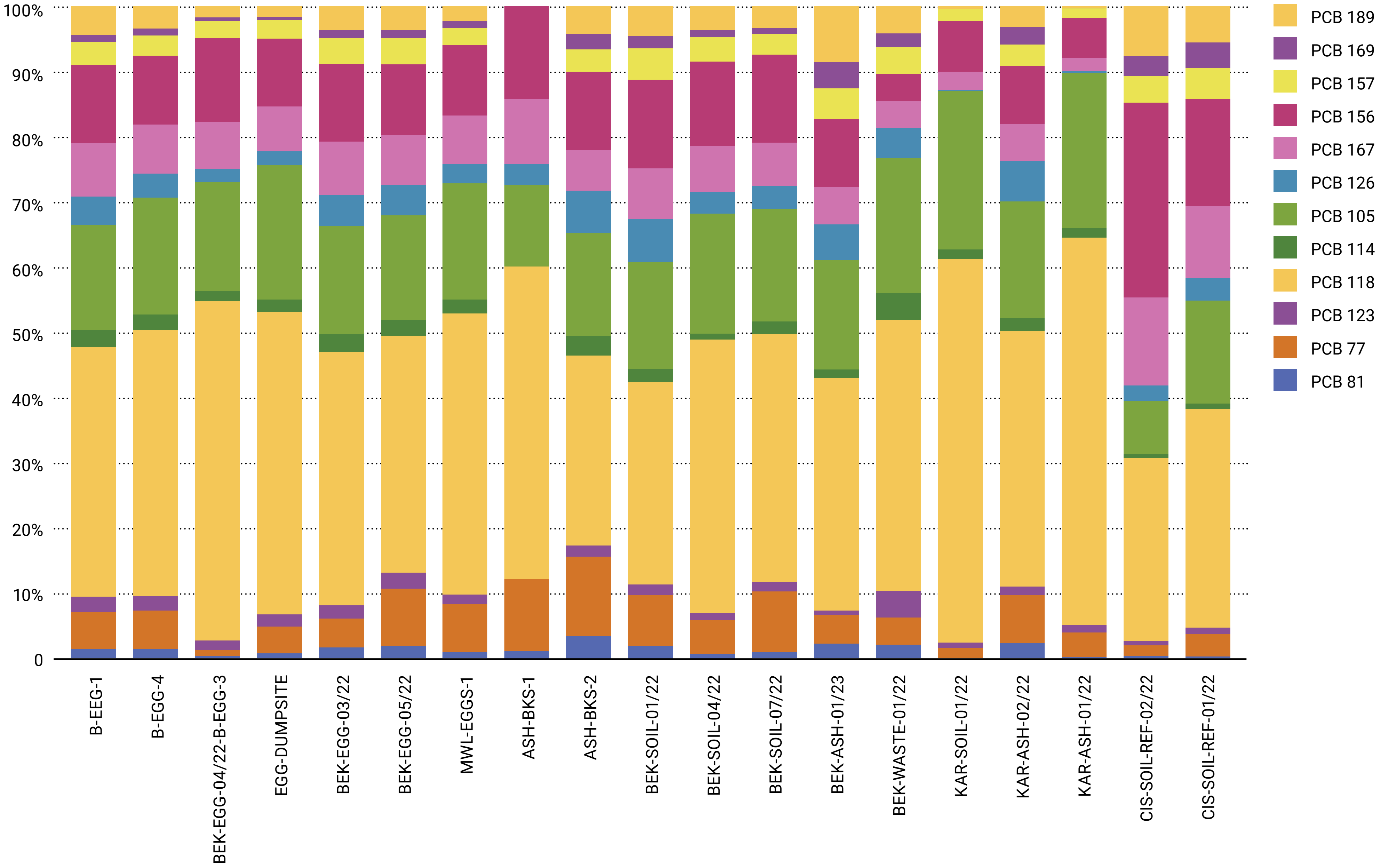


Figure 6.2: *Dioxin-like PCB patterns in samples from Bantar Gebang and reference soil samples from Cisarua.*



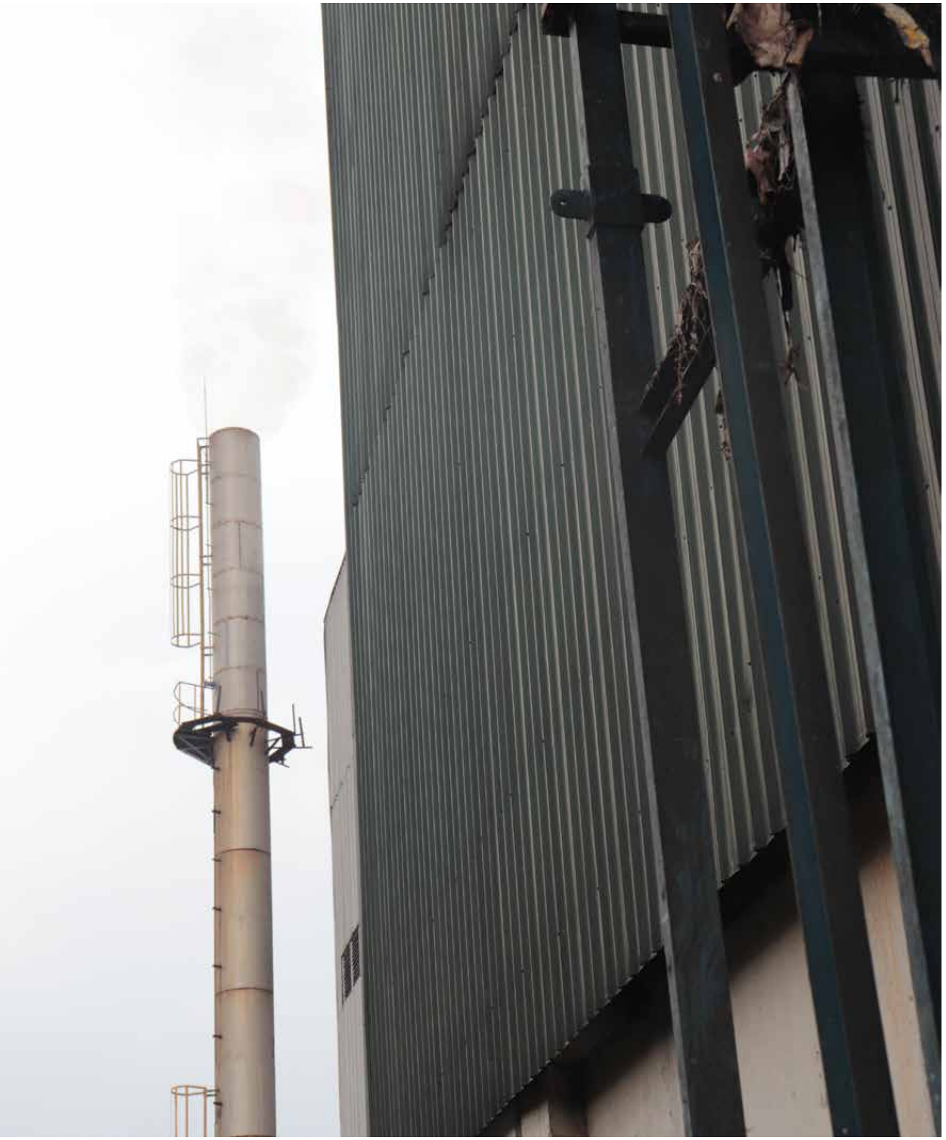


Photo 6.8: *Merah Putih waste incinerator.*
Photo: Jindrich Petrlik, Arnika, December 2022.

which only confirms that there are multiple sources of egg contamination, as the chickens consume large amounts of dust and simultaneously forage in the waste.

Among the egg samples, sample BEK-EGG-04/22;B-EGG-3 stands out, which not only had the highest concentration of PCDD/Fs/dl PCBs in TEQ, but also had a higher proportion of dl PCBs contributing to the total TEQ (see graph at Figure 7.1, in Chapter 7.2.1). Additionally, the profile of dl PCB congeners in this sample differs from other egg samples from Bantar Gebang. Furthermore, 2378-TCDD, 12378-PeCDD, and 2378-TCDF contribute to the total concentration of PCDD/Fs in the sample to a greater extent compared to other egg samples from Bantar Gebang. It thus appears that the contamination of this sample may involve a slightly different source than other samples from Bantar Gebang. When examining the Bantar Gebang area around this sample, additional combustion sources can be found, from which both PCDD/Fs and (especially) dl PCBs may be released. These sources include galvanizing plants or metal processing facilities, which are located about 200 m south-east to south from the sampling site of the pooled eggs sample.

A Chinese study focused on hot dip galvanizing industries stated that: *"The contributions of 2,3,7,8-TCDD, 1,2,3,7,8-PeCDD, and 2,3,4,7,8-PeCDF dominated the TEQs of PCDD/Fs"* (Lv et al., 2011). The same applies to the egg sample BEK-EGG-04/22;B-EGG-3.

6.4 Conclusions

The POPs contamination of soil in samples from Bantar Gebang was lower than in free-range chicken eggs. Only one soil sample, BEK-SOIL-01/22, showed higher POPs values, particularly MCCPs.

For some POPs, egg contamination from Bantar Gebang is very severe. For example, the contamination of eggs with PFASs, dioxins and dioxin-like compounds is particularly concerning. In all free-range chicken egg samples, the

Photo 6.9: *Bantar Gebang. Photo: Ondrej Petrlik, Arnika, December 2022.*

EU limit for PCDD/Fs/dl PCBs set for eggs as food at the level of 5 pg WHO-TEQ/g fat was exceeded. In one of the samples, the second-highest measured concentration of HCB (41 ng/g fat) in chicken eggs from Asian locations was found.

Analysis of the egg sample BEK-EGG-04/22; B-EGG-3, which showed the highest concentration of dioxins and dioxin-like substances from the Bantar Gebang site, indicated that sources contributing to POPs contamination likely include not only the landfill and incinerator, but also galvanizing plants and metal processing.

Reference soil samples from the Cisarua area were found to be affected by local human activities (camping, wood and waste burning, pesticide use on tea plantations) to such an extent that dioxin concentrations in soils exceeded those found in samples from Bantar Gebang. Therefore, from the perspective of these substances, only Mbeji Forest can be considered a background concentration site.

7. POPs in Free Range Eggs from Indonesia

Jindrich Petrlik, Yuyun Ismawati, Nikola Jelinek, Valeriya Grechko, Annisa Maharani, Barbora Skorepova, Krishna Bayumurti Zaki

7.1 Introduction

Nineteen pooled samples of free-range chicken eggs were collected from seven localities in Java, with an additional sample obtained from the Morowali site in Sulawesi. Two reference samples were purchased from a supermarket in Jakarta and a convenience store in Karawang, respectively. The number of individual eggs in each pooled sample ranged from 2 to 9 in this study.

All samples were analysed for their content of individual PCDD/Fs and dl PCBs using GC/HRMS, and following the methods prescribed for controlling levels of these substances in foodstuffs according to EU regulations (European Commission, 2012). The results are presented in pg WHO-TEQ per gram of fat. Toxic equivalency factors (TEFs) defined in 2005 (van den Berg et al., 2006) were used to evaluate dioxin toxicity in all samples.

Analyses of PBDEs, HBCD, TBBPA, nBFRs, 17 PFASs, SCCPs, MCCPs, 13 PCN congeners, two stereoisomers of DP, DDT and its metabolites, 3 HCH setereoisomers, PeCB, HCB, HCBD, and ndl PCBs were conducted in a Czech certified laboratory at the Department of Food Chemistry and Analysis of the University of Chemistry and Technology in Prague. The analytical methods are described in Chapter 2.2 of this book.

The results of POPs analyses in eggs were also compared with EU and Indonesian standards set for food stuff (European Commission, 2022a; Republik Indonesia, 2018). The carry-over rates, which were determined by the Dutch National Laboratory (Hoogenboom et al., 2006), were used for re-calculation of PCDD/F and PCB congener profiles in eggs for better comparison with profiles in ash and soil samples (see also Chapter 2.2).

This study focused mainly on analyses of free-range chicken eggs sampled in 2020 – 2024 at localities of Karawang, Bantar Gebang, and Morowali, but also includes earlier analyses of samples from Bangun, Kendalsari, Sumberwuluh, Tangerang and Tropodo, published in two previous studies (Ismawati et al., 2021; Petrlik, Ismawati, et al., 2020; Petrlik, Ismawati, et al., 2019). Some samples from Karawang were included in another previous study presented at the Dioxin 2022 Conference (Petrlik, Ismawati, et al., 2022).

7.2 Results and discussion

Results of chemical analyses for pooled samples of free-range chicken eggs are summarized in Tables 7.1 and 7.2. The results of POPs analysed in chicken egg samples were compared with EU and Indonesian standards set for eggs as foodstuff (European Commission, 2022a, 2022b; Republik Indonesia, 2018). A more detailed summary of the results is in Table in Annex III.

Table 7.1: *Results of the POPs analyses in pooled egg samples from various locations in Java and from Morowali, Sulawesi – first set of chemicals (unintentionally produced POPs and chlorinated paraffins). Levels exceeding limit values set for eggs as food in EU are marked in yellow.*

Locality	**Sample ID (eggs)**	**N**	**Fat**	**PCDD/Fs**	**dl PCBs**	**PCDD/F/dl PCBs**	**PeCB**	**HCB**	**SCCPs**	**MCCPs**
-	**Units**		**%**	**pg TEQ/g fat**			**ng/g fat**			
Bangun	BAN-E-1	3	9.5	9.5	5.1	14.6	2.2	3.6	97	NA
	Bangun 1	3	13	10.8	3.1	13.9	1.1	2.7	153	NA
Bantar Gebang	B-EEG-1	6	17.8	10.0	4.3	14.3	1.3	3.9	309	2,345
	B-EGG-4	6	21.5	3.8	2.0	5.8	0.36	0.89	<50	<100
	BEK-EGG-03/22	2	16.1	20	7.4	27.4	0.97	41	NA	NA
	BEK-EGG-04/22; B-EGG-3	4	17.9	34	20	54	3.1	5.3	<50	1,921
	BEK-EGG-05/22	2	15.5	20	8.4	28.4	0.74	2.0	NA	NA
	EGG-DUMPSITE	2	14.8	14.6	7.8	22.4	2.1	3.7	NA	NA
Karawang	KAR-EGG-01/22	3	14.9	3.2	1.1	4.3	0.85	1.8	<50	732
	KAR-EGG-1	4	13.8	11	1.7	12.7	0.70	4.6	<50	NA
	KAR-EGG-2	4	13.5	178	34	212	6.1	16	69	NA
	KAR-EGG-3	4	16.7	109	10	119	3.5	4.8	237	NA
Kendalsari	KEN 01	9	27.4	49	35	84	1.1	1.5	NA	NA
	KEN-E-1/19	6	14.3	41	20	61	1.3	2.5	160	NA
Morowali	MWL-EGGS-1	3	11.2	5	1.1	6.1	0.43	1.7	<50	<100
Tangerang	SEM-E-1	3	16.2	54	18	72	3.6	6.1	153	NA
	TAN-ESIN-01	5	13.7	20.4	7.4	27.8	NA	NA	NA	NA
Sumberw.	SUM-E-1_2	6	14.1	11	2	13	0.26	0.58	50	NA
Tropodo	TROP-E-1	6	13.9	140	32	172	1.7	4.1	97	NA
	Tropodo 1	3	15	200	32	232	1.9	5.5	65	NA
Minimum	-	-	-	3.2	1.1	4.3	0.26	0.58	<50	<100
Maximum	-	-	-	200	35	232	6.1	41	309	2,345
EU/Indonesia limit(1)	-	-	-	2.5	-	5.0/2.5	-	10	-	-
Reference samples	JAK-SUP	6	9.5	0.001	0.002	0.003	<0.1	<0.1	136	NA
	KAR-EGG-R	3	17.4	0.23	0.02	0.25	5	1.9	151	NA

(1) Sources of limits: (European Commission, 2008, 2022a; Republik Indonesia, 2018)

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[10] There is a maximum residues level set in the EU for HCB of 20 ng/g ww. None of the samples, exceeded this level.

***Table 7.2:** Results of the POPs analyses in pooled egg samples from various locations in Java and from Morowali, Sulawesi – second set of chemicals (flame retardants and PFASs). Levels exceeding limit values set for eggs as food in EU are marked in yellow.*

Locality	Sample ID (eggs)	sum HBCD	sum of PBDEs	nBFRs	DP	PFASs	PFOA	PFOS	PFHxS	EFSA-PFASs
-	**Units**	**ng/g fat**				**ng/g ww**				
Bangun	BAN-E-1	538	1,457	124	NA	97	0.05	92	0.05	93
	Bangun 1	5.2	91	NA	NA	26	0.39	17.7	0.06	19
Bantar Gebang	B-EEG-1	<4.2	8	<LOQ	<0.3	1.2	0.01	0.31	0.08	0.44
	B-EGG-4	<4.2	6.3	3.6	<0.3	1.5	<0.006	0.86	0.02	0.92
	BEK-EGG-03/22	<4.2	28	5.5	2.3	4.2	0.01	1.9	0.007	2
	BEK-EGG-04/22; B-EGG-3	<4.2	10	<LOQ	<0.3	2.8	0.03	1.7	0.02	1.9
	BEK-EGG-05/22	<4.2	3.2	<LOQ	<0.3	1.3	0.03	0.38	0.02	0.47
	EGG-DUMPSITE	5.0	31	1.0	2.7	6.4	0.11	4.5	0.05	4.8
Karawang	KAR-EGG-01/22	<4.2	10	<LOQ	2.0	0.67	<0.006	0.36	0.01	0.39
	KAR-EGG-1	48	<LOQ	<LOQ	NA	0.85	0.01	0.14	<0.006	0.18
	KAR-EGG-2	39	73	18.4	NA	4.2	0.03	1.1	0.02	1.2
	KAR-EGG-3	36	<LOQ	<LOQ	NA	2.3	0.01	0.31	<0.006	0.37
Kendalsari	KEN 01	<4.2	6.2	<LOQ	NA	NA	NA	NA	NA	NA
	KEN-E-1/19	<4.2	149.6	12.2	NA	0.35	<0.01	0.14	<0.01	0.16
Morowali	MWL-EGGS-1	<4.2	10.8	<LOQ	<0.3	NA	NA	NA	NA	NA
Tangerang	SEM-E-1	844	320.8	33	NA	6.2	0.27	2.5	0.03	3.3
Sumberw.	SUM-E-1_2	4.5	8.2	0.87	NA	0.46	0.01	0.26	<0.01	0.29
Tropodo	TROP-E-1	<4.2	27,2	2,166	NA	0.30	<0.01	0.14	<0.01	0.16
	Tropodo 1	<4.2	65	NA	NA	2.7	0.10	1.0	<0.01	1.3
Minimum	-	<4.2	<LOQ	<LOQ	<0.3	0.30	<0.006	0.14	<0.006	0.16
Maximum	-	844	27.2	2,166	2.7	97	0.39	92	0.08	93
EU limit (1)	-	-	-	-	-	-	0.30	1.0	0.30	1.7
Reference samples	JAK-SUP	<4.2	1.4	<LOQ	NA	0.1	<0.01	<0.01	<0.01	<0.01
	KAR-EGG-R	<4.2	<LOQ	<LOQ	NA	0.05	0.007	<0.006	<0.006	0.007

(1) Sources of limits: (European Commission, 2008, 2022a; Republik Indonesia, 2018)

Photo 7.1: *Sumberwuluh, one of the sites for free-range chicken eggs sampling from a previous study, was included in this summarizing evaluation as well. Photo: Jindrich Petrlik, Arnika, November 2019.*

Results are compared with limit values set for POPs in eggs as food in Tables 7.1 and 7.2 as well. All free-range eggs samples exceeded an EU limit for PCDD/Fs of 2.5 pg WHO-TEQ/g fat (European Commission, 2022a) and also the Indonesian limit for PCDD/Fs/dl PCBs of 2.5 pg WHO-TEQ/g fat (Republik Indonesia, 2018). One sample exceeded the limit of 0.3 ng/g ww set in the EU for PFOA (European Commission, 2022b), eight samples exceeded the limit value of 1 ng/g ww set for PFOS (European Commission, 2022b), and six samples exceeded the limit of 1.7 ng/g ww set for 4 PFASs (European Commission, 2022b) evaluated by the European Food Safety Authority (EFSA) (EFSA CONTAM Panel et al., 2020). Only the limit values of 0.3 ng/g ww for PFHxS (European Commission, 2022b) were not exceeded in any of analysed pooled free-range egg samples in this study.

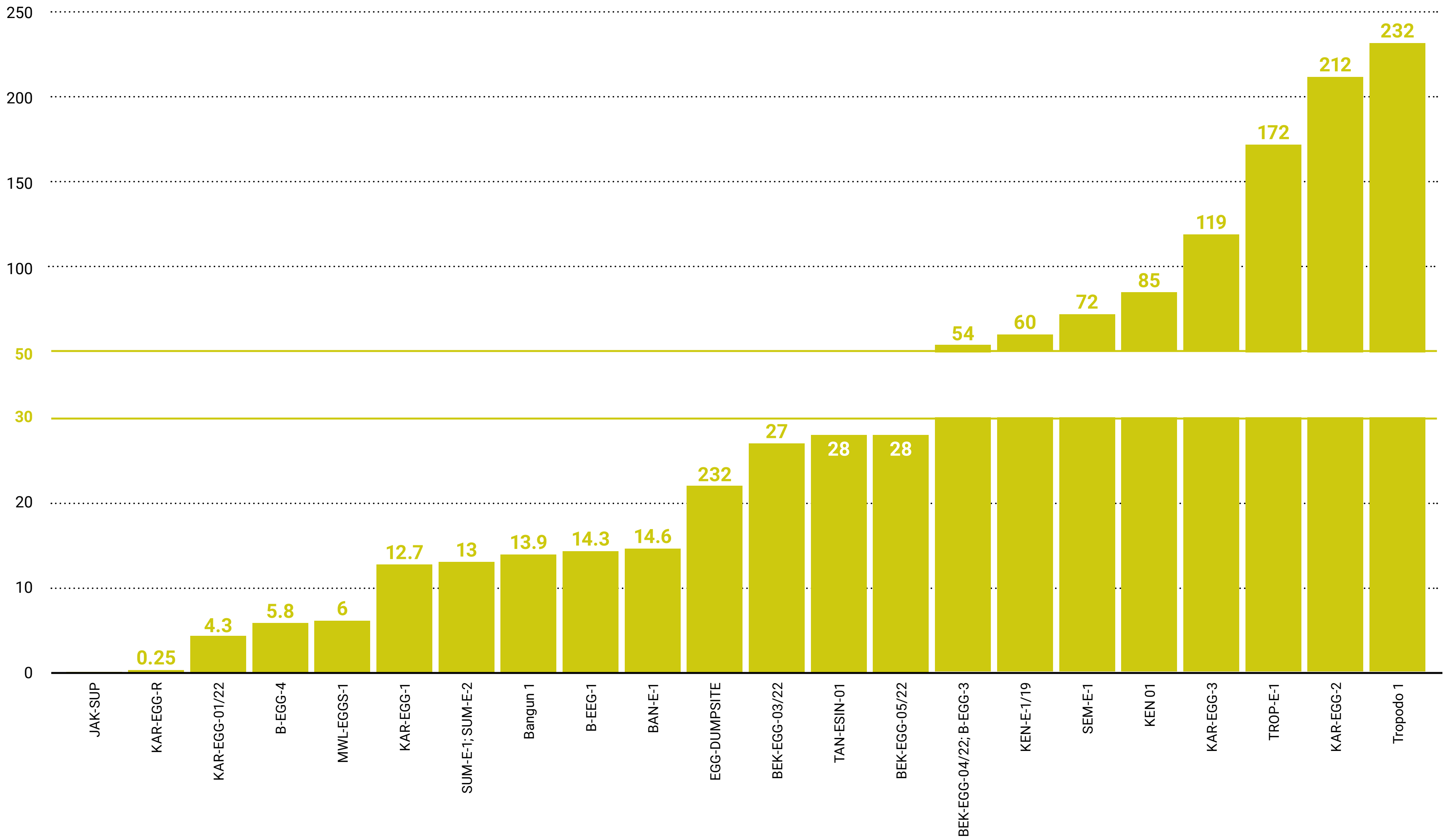
7.2.1 Dioxins (PCDD/Fs) and polychlorinated biphenyls (PCBs)

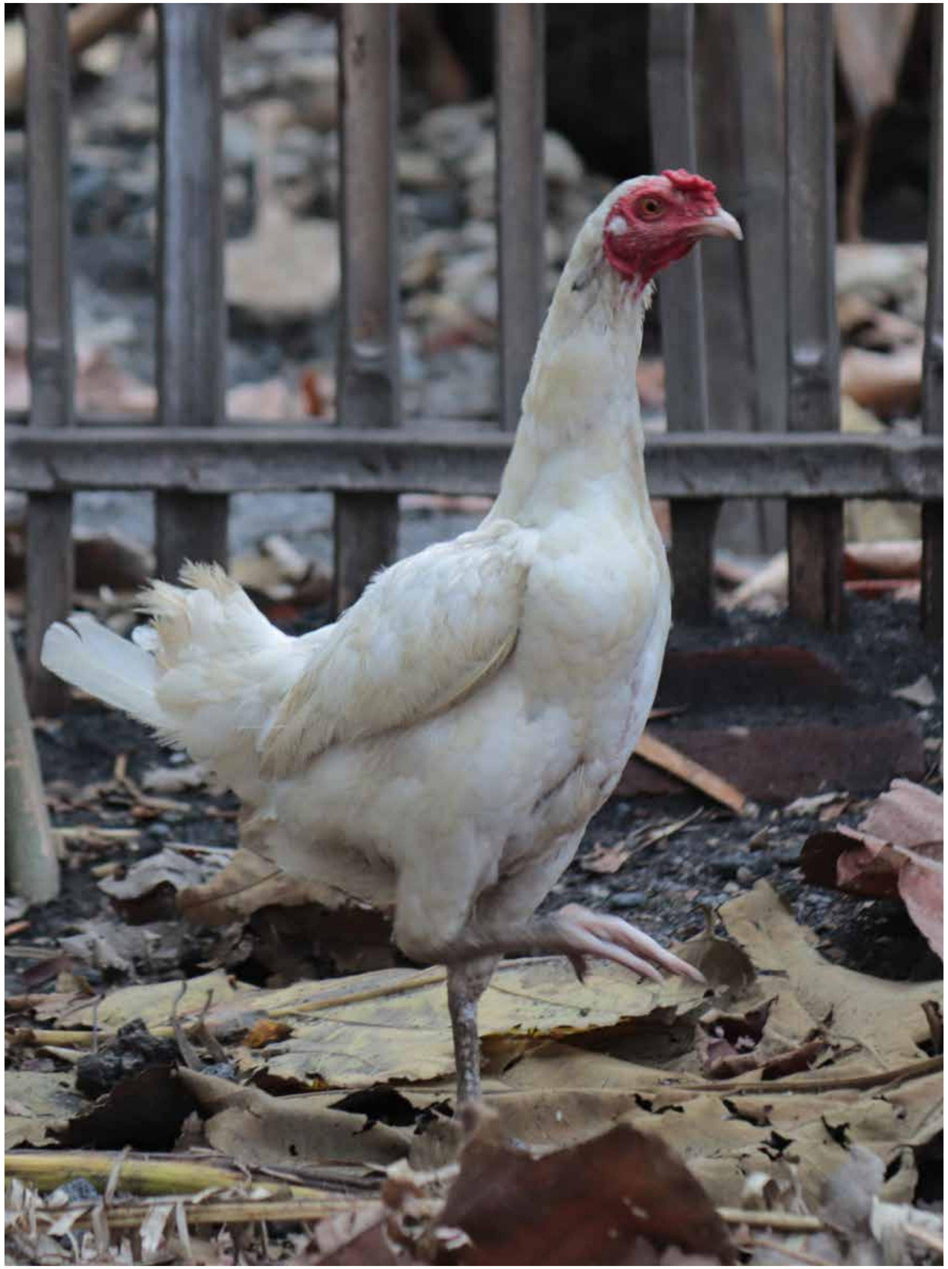
Polychlorinated dibenzo-p-dioxins, dibenzofurans (PCDD/Fs) and polychlorinated biphenyls were analysed in all 20 free-range and two reference chicken egg samples in this study. Summarized levels of PCDD/Fs and dl PCBs are presented in Figure 7.1.

The sums of PCDD/Fs and dl PCBs in all free-range eggs, except for sample KAR-EGG-01/22 from Karawang, exceeded the standard set for eggs as food in the EU, which is established at a level of 5 pg WHO-TEQ/g fat (European Commission, 2022a). All free-range egg samples exceeded the limit value set by Indonesia for the sum of PCDD/Fs/dl PCBs at a level of 2.5 pg WHO-TEQ/g fat (Republik Indonesia, 2018). Higher levels were observed in localities affected by combustion processes such as plastic waste incineration in Tropodo and Karawang, aluminum smelters in Kendalsari, and galvanization or metallurgical plants in Bantar Gebang (sample BEK-EGG-04/22; B-EGG-3). However, levels in eggs from sites potentially affected by open burning of waste, such as Bangun or Bantar Gebang landfill, are also high and exceed the EU and Indonesian standards by two or more and by four or more folds respectively. Sample EGG-DUMPSITE was collected at a site potentially most affected by the operation of the Merah Putih waste incinerator next to the landfill in Bantar Gebang; see prevailing wind directions in Bekasi (Weather Spark, 2024). The level of PCDD/Fs/dl PCBs in this egg sample exceeded the EU standard by more than three times, and the level of PCDD/Fs in this sample (14.6 pg WHO-TEQ/g fat) exceeded the EU standard for PCDD/Fs, set at a level of 2.5 pg WHO-TEQ/g fat (European Commission, 2022a), by almost six times. The EU standard for PCDD/Fs was exceeded even more in samples BEK-EGG-03/22 and BEK-EGG-05/22, by almost 8 times.

In the free-range chicken egg samples presented in this study, four (Tropodo-1, KAR-EGG-2, TROP-E-1, and KAR-EGG-3) were measured as the fourth, fifth, sixth, and seventh highest levels of PCDD/Fs in eggs from Asia and seventh, eighth, ninth, and eleventh highest levels globally, respectively, in comparison with other samples included in the global review and scientific literature (Petrlik, Bell, et al., 2022). They exhibit the same level of contamination from both localities contaminated by incineration of plastic waste used as fuel in tofu (Tropodo) and lime

Figure 7.1: *Levels of PCDD/Fs + dl PCBs in pooled egg samples from Indonesia presented in this study.*





Photos 7.2 and 7.3: *Ash from aluminum smelters containing PCDD/Fs is everywhere in Kendalsari (Petrlik, Ismawati, et al., 2020), so hens have direct access to ash, what is a significant pathway for contamination of eggs with PCDD/Fs there. Photos: Jinrich Petrlik, Arnika, November 2019.*

(Karawang) production facilities, respectively. Dioxin concentrations in these eggs exceeded the EU standard of 2.5 pg TEQ/g fat by approximately 80, 71, 56, and 44-fold, respectively. Higher levels of dioxins in free-range chicken eggs from Asia were observed only in Bien Hoa, a former US Army base in Vietnam contaminated by Agent Orange (Kudryavtseva et al., 2020).

The EU standard of 40 ng/g for six ndl PCB congeners (European Commission, 2022a) was exceeded in KAR-EGG-2 by more than twice.

Photos 7.4 and 7.5: *Waste incinerator ash was most likely the source of the contamination of free-range chicken eggs collected in WI neighborhood (photo 7.5) in Wuhan, China. Source of the photo 7.4: Zhang et al., 2015. Photo 7.5: Jindrich Petrlik, Arnika, June 2016.*

7.2.2 Brominated dioxins

Polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs) were analysed in only six out of the 22 samples presented in this study, with only four samples being above the limit of quantification (LOQ). The highest level of 12.8 pg WHO-TEQ/g fat was measured in sample KAR-EGG-01/22, where it contributed to 75% of the overall dioxin-like toxicity. This level is very rare compared to other sites, where PBDD/Fs typically contribute only one-tenth to the total TEQ level. The second-highest level of PBDD/Fs (6.9 pg WHO-TEQ/g fat) was found in egg sample SEM-E-1 from Tangerang, which has been discussed in previous studies. The PBDD/Fs level in eggs from Karawang and Tangerang ranks sixth and tenth highest, respectively, among free-range eggs globally. The level in sample KAR-EGG-01/22 is comparable to the 16 pg WHO-TEQ/g fat measured in eggs from Samut Sakhon, Thailand.

The PBDD/F congener profile is also markedly different in samples KAR-EGG-01/22 and SEM-E-1. However, it bears some similarity to the profile observed in eggs from Samut Sakhon, particularly regarding the dominant OBDF[11] and a significant proportion of 1234678 HpBDF[12] congeners in both samples (see Figure 7.2). Hens at both locations had access to ash from burnt waste, although in Samut Sakhon, it was predominantly e-waste (Bystriansky et al., 2018; Teebthaisong et al., 2018), while in Karawang, it was mainly plastic waste.

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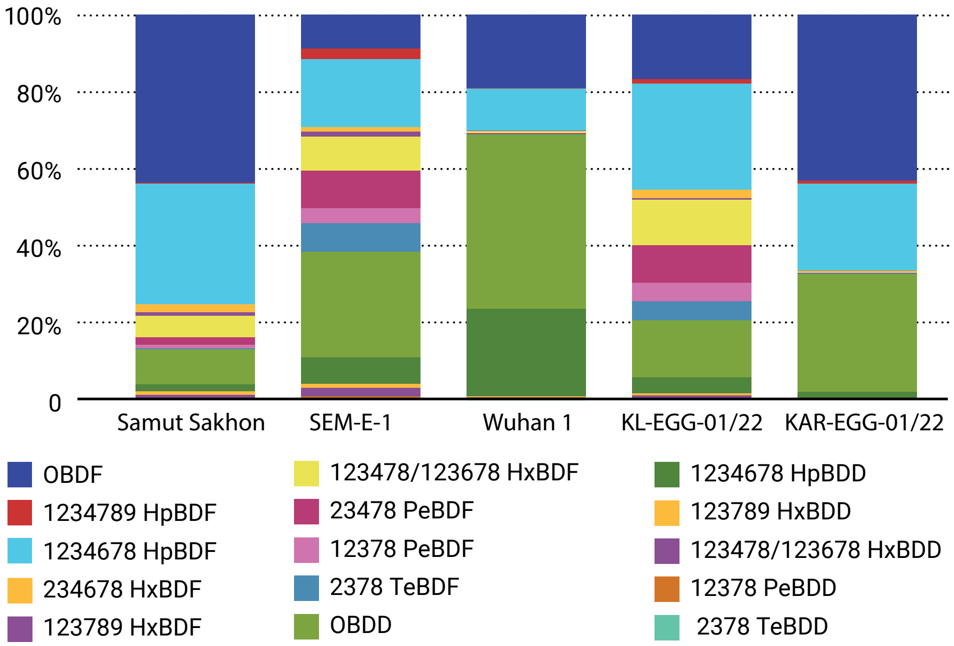
[11] OBDF - Octabromodibenzofuran is one of the PBDD/Fs congeners with eight bromines.

[12] HpBDF – Heptabromodibenzofuran is another PBDD/Fs congener with seven bromines.

***Figure 7.2:** PBDD/Fs congener patterns in free-range eggs samples from Thailand (Samut Sakhon), China (Wuhan 1) and Indonesia (Tangerang: SEM-E-1 and Karawang: KAR-EGG-01/22).*



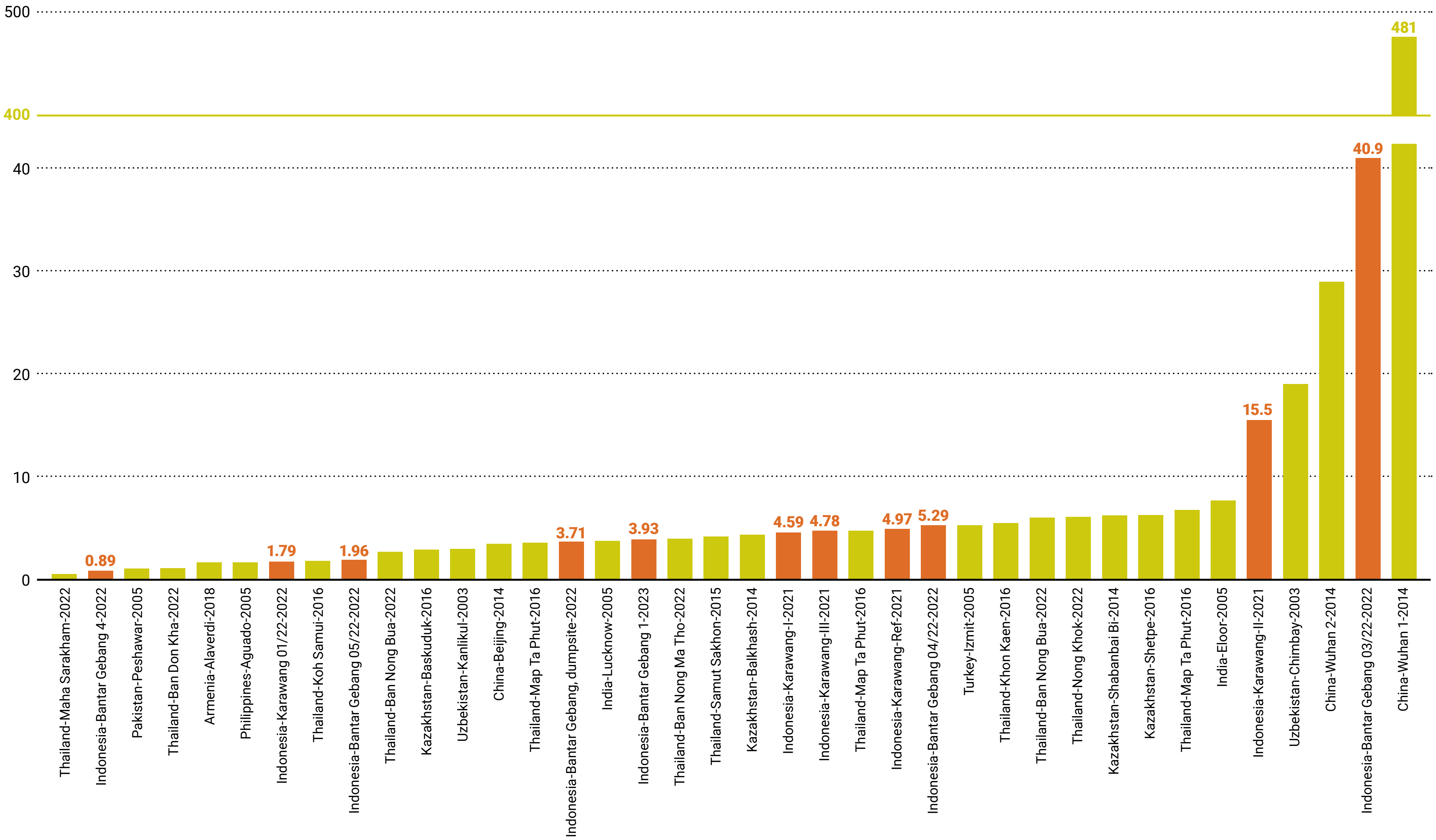
7.2.3 Hexachlorobenzene, pentachlorobenzene and hexachlorobutadiene

Hexachlorobenzene (HCB), pentachlorobenzene (PeCB), and hexachlorobutadiene (HCBD) are considered to be unintentionally produced POPs, as well as POPs pesticides or intentionally produced chemicals (see Annex II to this report), so their sources might vary in samples of eggs. However, in Bantar Gebang, Tropodo, and Karawang, they are mostly generated as unintentional by-products of burnt or incinerated wastes containing chlorinated compounds.

HCB levels in two egg samples from Bantar Gebang (BEK-EGG-03/22) and Karawang (KAR-EGG-2) rank as the second and fifth highest measured in Asian countries, respectively (see Figure 7.3).

***Photos 7.6 and 7.7:** Open-reared animals, such as ruminants, can become “targets” of contamination with POPs (Amutova et al., 2021). However, we did not collect their milk or meat this time to verify this for the locations where free-range chicken eggs were sampled. There are examples of such contamination from other countries, like the Mangystau region in Kazakhstan (Grechko, Amutova, et al., 2021). Photo 7.6 is from Karawang by Ondrej Petrlik, Arnika in December 2022, and Photo 7.7 is from Tangerang by Jindrich Petrlik, Arnika, in November 2019.*

Figure 7.3: *Comparison of HCB levels in eggs from Asian countries.*
For data outside of Indonesia, look at a report by Petrlik, Boontongmai, et al. (2022).



A surprisingly high level of 5.0 ng/g fat of HCB, comparable to levels found in some free-range egg samples from Karawang (KAR-EGG-1, KAR-EGG-3) or Bantar Gebang (BEK-EGG-04/22; B-EGG-3), was measured in a reference sample of eggs from a convenience store in Karawang. Its source could be the feed provided to the hens at the farm that supplied the eggs. However, a level below the limit of quantification (LOQ) was measured in eggs from a supermarket in Jakarta.

The highest level of PeCB was measured in the egg sample from Karawang (KAR-EGG-2). In general, levels of PeCB were lower compared to those of HCB in this study.

Hexachlorobutadiene (HCBD) was measured above the limit of quantification (LOQ) in three egg samples presented in this study: one sample from Bantar Gebang (BEK-EGG-04/22; B-EGG-3), one from Karawang (KAR-EGG-3), and a reference sample from a convenience store in Karawang, where surprisingly, the highest level of 2.1 ng/g fat was measured. One of the samples from Tangerang was not analysed for HCBD, while all other analysed samples had levels below the LOQ (0.1 ng/g fat).

7.2.4 Polychlorinated naphthalenes

Thirteen PCN congeners were analysed in three free-range chicken egg samples, as well as in a reference sample from Karawang. Only one sample (KAR-EGG-2) contained a level of 2.4 ng/g fat above the limit of quantification (LOQ) (0.20 ng/g fat). This level is probably the highest measured so far in eggs globally; for example, in eggs from Kenya and Ghana, only levels below the LOQ were measured (Petrlik, Adu-Kumi, et al., 2019; Petrlik, Strakova, et al., 2023). Additionally, among samples from Kalasin, an e-waste site in Thailand, only one pooled egg sample had a level above the LOQ, measuring 1.4 ng/g fat of 13 PCN congeners (Dvorska et al., 2023).

7.2.5 Chlorinated paraffins

Short-chain chlorinated paraffins (SCCPs) were analysed in 14 out of 20 free-range egg samples in this study, as well as in both reference samples. Additionally, medium-chain chlorinated paraffins (MCCPs) were analysed in four free-range egg samples. SCCPs and MCCPs ranged from levels below the limit of quantitation (LOQ)[13] to 309 ng/g fat and from levels below LOQ[14] to 2,345 ng/g fat, respectively. The levels of SCCPs above LOQ in 12 free-range eggs, along with two reference samples, are depicted in Figure 7.4. SCCPs concentrations are often quite high in non-free-range egg samples from supermarkets or convenience stores, which originate from large farms where hens don’t have access to soil or grass outside. A source of contamination can be, for example, packaging for feed, as confirmed by a recent study in China (Dong et al., 2020).

Photo 7.8: *The ubiquitous plastic waste in Bantar Gebang can be a source of contamination of chicken eggs with MCCPs and SCCPs. Photo: Ondrej Petrlik, Arnika, December 2022.*

The highest concentration of SCCPs measured in this study in eggs from Bantar

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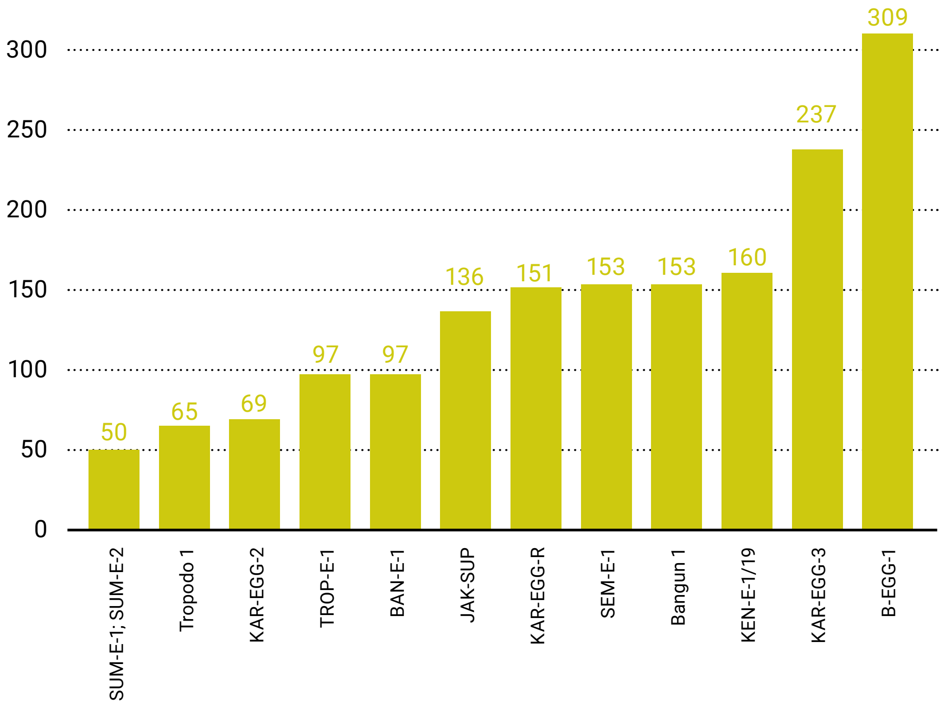
[13] LOQ for SCCPs = 50 ng/g fat

[14] LOQ for MCCPs = 100 ng/g fat

***Figure 7.4:** SCCPs in egg samples from Indonesia included in this study.*



Gebang (B-EGG-1), at 309 ng/g fat, is approximately half the level of 641 ng/g fat measured in a reference sample from a supermarket in Maha Sarakham for a study in Thailand (Petrlik, Boontongmai, et al., 2022). The maximum level of SCCPs in eggs from this study is one quarter of the SCCPs concentration in eggs from Nong Khok near an e-waste disposal site in Thailand. However, there is not as high a concentration of SCCPs either in the soil or sediments from Bantar Gebang as was found in Nong Khok (Petrlik, Boontongmai, et al., 2022). Eggs in sample B-EGG-1 also had SCCPs at a level more than 6-fold lower compared to samples from Baskuduk, Kazakhstan (1,950 ng/g fat), or Agbogbloshie, Ghana (2,067 ng/g fat) (Adu-Kumi et al., 2019). Baskuduk, as well as Agbogbloshie, are sites affected by the disposal of large volumes of plastic and other wastes, similar to the situation in Bantar Gebang.

MCCPs reached much higher levels than SCCPs in eggs from Bantar Gebang, ranging from below LOQ to 2,345 ng/g fat, and are comparable to levels observed in eggs from neighborhoods near waste disposal sites in Tanzania (Haarr et al., 2023).

7.2.6 Organochlorine pesticides

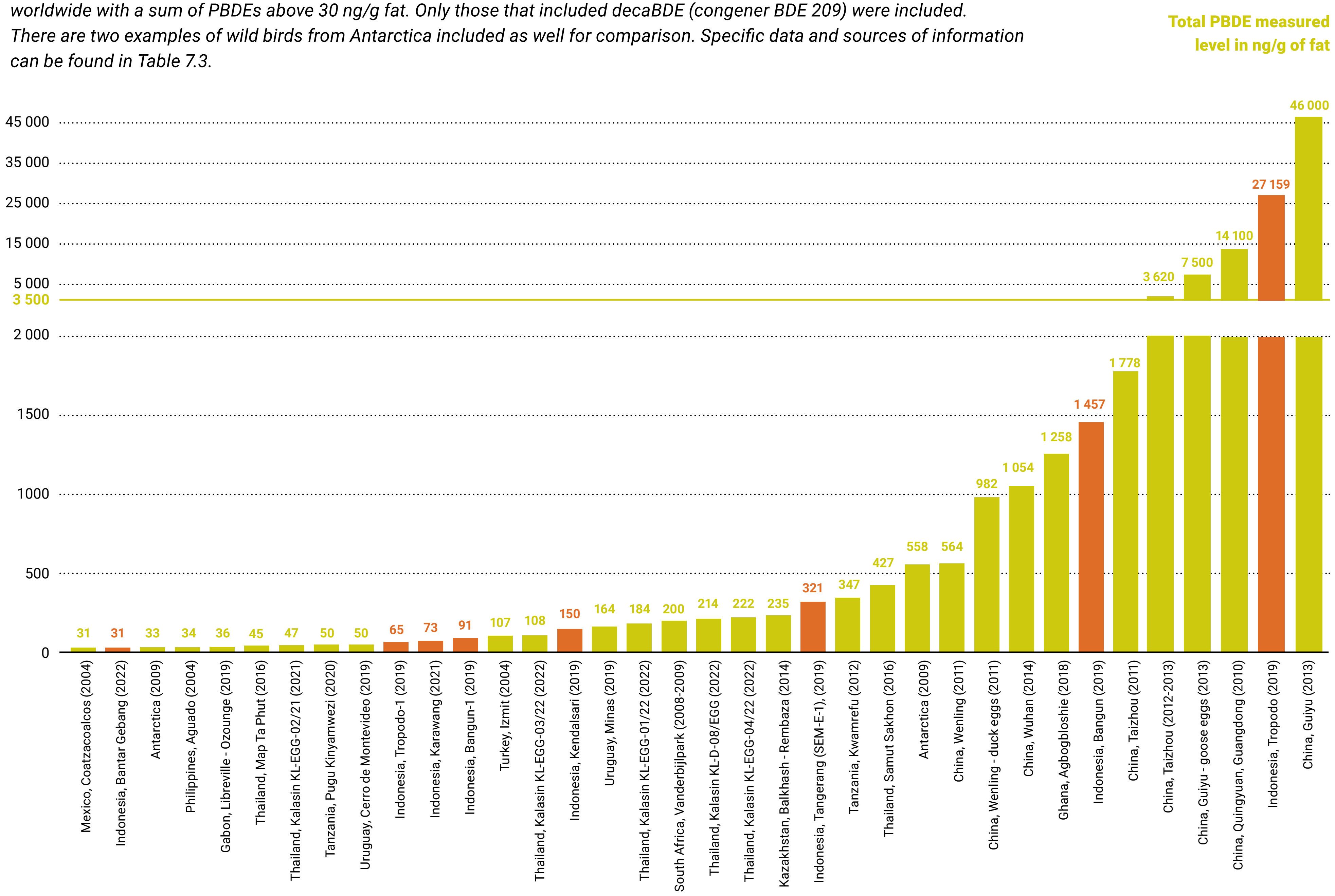
Organochlorine pesticides such as DDT or HCH were not expected to be major contaminants at the sampled localities; therefore, they were analysed in nine free-range egg samples out of a total of 20, and in only one reference sample. They were found to be low in most of the samples, except for two from Kendalsari, in which significant levels of 59.8 and 104.6 ng/g fat of a sum of DDT and its metabolites were measured. In the remaining six analysed samples, the sum of DDT was within the range of below LOQ to 10.8 ng/g fat. HCH levels were low in all analysed samples, ranging from below LOQ to 4.68 ng/g fat.

7.2.7 Polybrominated diphenyl ethers

The highest levels of PBDEs in this study were measured in the eggs from Tropodo and Bangun sampled in October/November 2019. The level in the sample from Bangun is higher than levels observed in eggs from Agbogbloshie, an e-waste scrapyard site, or from Wuhan, in the vicinity of a municipal solid waste incinerator. It is also the seventh-highest ever measured level of PBDEs in free-range eggs (see graph in Figure 7.5). The level exceeding 27,000 ng/g fat of PBDEs measured in eggs from Tropodo is the second-highest ever measured level in eggs globally (see graph in Figure 7.5 and data in Table 7.3). The PBDEs in eggs from Tropodo and Bangun were in the same range as in egg samples from e-waste sites in China.

Levels of PBDEs in eggs from Karawang and Bantar Gebang were much lower compared to those from Tropodo and Bangun, and also lower than a level of 321 ng/g fat in the pooled eggs sample from Tangerang. Maximum levels in eggs from Karawang and Bantar Gebang were 73 and 31 ng/g fat respectively. Levels in eggs from Bantar Gebang were all above LOQ, while they were below in two out of four pooled samples from Karawang. Also, a reference sample from Karawang had a level of PBDEs below LOQ, and it was 1.4 ng/g fat in a reference sample from a supermarket in Jakarta.

Figure 7.5: *Graph showing levels of PBDEs in ng/g fat measured in free-range chicken, goose or duck eggs in different studies worldwide with a sum of PBDEs above 30 ng/g fat. Only those that included decaBDE (congener BDE 209) were included. There are two examples of wild birds from Antarctica included as well for comparison. Specific data and sources of information can be found in Table 7.3.*



There is more discussion about PBDEs in free-range eggs from Bangun, Kendalsari, Sumberwuluh, Tangerang and Tropodo in our previous report about Toxic Hot Spots in Java (Petrlik, Ismawati, et al., 2020).

***Table 7.3:** Levels of PBDEs in ng/g fat measured in free-range chicken eggs in different studies worldwide with a sum of PBDEs above 30 ng/g fat. Only those samples that were also analysed for decaBDE (congener BDE 209) have been included. There are two examples of samples from wild birds in Antarctica and some from duck or goose eggs included as well for comparison. All samples other than chicken eggs are marked by specification of the bird species in parentheses after the name of the locality.*

Country (year)	Locality	PBDEs in ng/g fat	Source of information
Mexico (2004)	Coatzacoalcos	31	(Blake, 2005)
Indonesia (2022)	Bantar Gebang	31	this study
Antarctica (2009)	King George Island (chinstrap penguin)	33	(Yogui & Sericano, 2009)
Philippines (2004)	Aguado	34	(Blake, 2005)
Gabon (2019)	Libreville – Ozounge	36	(Petrlik et al., 2021)
Thailand (2016)	Map Ta Phut	45	(Bystriansky et al., 2018)
Thailand (2021)	Kalasin	47	(Dvorska et al., 2023)
Tanzania (2020)	Pugu Kinyamwezi	50	(Petrlik, Ochieng Ochola, et al., 2020)
Uruguay (2019)	Cerro de Montevideo	50	(Petrlik et al., 2021)
Indonesia (2019)	Tropodo	65	(Petrlik, Ismawati, et al., 2020)
Indonesia (2021)	Karawang	73	this study
Indonesia (2019)	Bangun (Bangun-1)	91	(Petrlik, Ismawati, et al., 2020)
Turkey (2004)	Izmit	107	(Blake, 2005)
Thailand (2022)	Kalasin	108	(Dvorska et al., 2023)
Indonesia (2019)	Kendalsari	150	(Petrlik, Ismawati, et al., 2020)
Uruguay (2019)	Minas	164	(Petrlik et al., 2021)
Thailand (2022)	Kalasin	184	(Dvorska et al., 2023)
South Africa (2009)	Vanderbijlpark	200	(Quinn, 2010)
Thailand (2022)	Kalasin	214	(Dvorska et al., 2023)
Thailand (2022)	Kalasin	222	(Dvorska et al., 2023)
Kazakhstan (2014)	Balkhash – Rembaza	235	(Petrlik et al., 2017)
Indonesia (2019)	Tangerang (SEM-E-1)	321	(Petrlik, Ismawati, et al., 2020)
Tanzania (2012)	Kwamrefu	347	(Polder et al., 2016)
Thailand (2016)	Samut Sakhon	427	(Petrlik et al., 2017)
Antarctica (2009)	King George Island (south polar skua)	558	(Yogui & Sericano, 2009)
China (2011)	Wenling	564	(Qin et al., 2011)
China (2011)	Wenling (duck)	982	(Labunska et al., 2013)
China (2014)	Wuhan	1,054	(Petrlik, 2016)
Ghana (2018)	Agbogbloshie	1,258	(Hogarh et al., 2019)
Indonesia (2019)	Bangun (BAN-E-1)	1,457	(Petrlik, Ismawati, et al., 2020)
China (2011)	Taizhou (duck)	1,778	(Labunska et al., 2013)
China (2012-2013)	Taizhou	3,620	(Labunska et al., 2014)
China (2013)	Guiyu (goose)	7,500	(Zeng et al., 2016)
China (2010)	Quingyuan, Guangdong	14,100	(Zheng et al., 2012)
Indonesia (2019)	Tropodo	27,159	(Petrlik, Ismawati, et al., 2020)
China (2013)	Guiyu	46,000	(Zeng et al., 2016)

Photos 7.9 and 7.10: *POPs contamination of free-range chicken eggs from hot spots in Java is often comparable to levels found in pooled eggs sample from the Agbogbloshie e-waste scrap yard in Accra, Ghana as it was documented in a report from 2019 (Petrlik, Adu-Kumi, et al., 2019). Photos: Martin Holzknecht, Arnika, December 2018.*

7.2.8 Hexabromocyclododecane

Three isomers of hexabromocyclododecane (HBCD), alpha, beta, and gamma, were analysed in eighteen out of twenty pooled free-range chicken egg samples presented in this study. HBCD was measured at high levels of 844 and 538 ng/g fat in the eggs from Tangerang and Bangun, respectively; both sampled in November 2019. The eggs from Tropodo, Kendalsari, Sumberwuluh, and Bantar Gebang, as well as the earlier sample from Bangun, contained levels of HBCD that were either quite low or even below the limit of quantification (LOQ). The levels of HBCD in the eggs from Tangerang (sample SEM-E-1) and Bangun (sample BAN-E-1) are among the highest levels ever measured in eggs globally. They are higher than the level found in eggs from the vicinity of the municipal waste dumpsite in Baskuduk, Kazakhstan (430 ng/g fat), but lower than the high level found in chicken eggs from a commercial farm bought in a supermarket in Karaganda, Kazakhstan (Petrlik et al., 2017). HBCD in the eggs from Bangun reached almost half of the concentration observed in eggs from the Agbogbloshie e-waste scrapyard (Petrlik, Adu-Kumi, et al., 2019) or in the commercial egg sample from Germany (Hiebl & Vetter, 2007).

The eggs from Karawang reached levels of several tenths of ng/g fat for HBCD. The latest sample from Karawang, sampled in 2022 (KAR-EGG-01/22), was below the LOQ. The contamination of eggs with HBCD is related to insulation foams treated with this flame retardant. Insulation from refrigerators was observed near the site where the eggs were sampled in Tangerang. Another potential source of contamination might be polystyrene foam used in obsolete electronic devices or in their packaging (Abdallah et al., 2018). Polystyrene foams were present at the plastic waste dumpsite in Bangun and may have been present in Tangerang.

7.2.9 Novel brominated flame retardants

An increased level of 32 ng/g fat was measured in a sample from Tropodo analysed for for BTBPE[15]. This is comparable to the findings in eggs from Agbogbloshie (38 ng/g fat) or Wuhan (51 ng/g fat) (Petrlik, 2016; Petrlik, Adu-Kumi, et al., 2019). These levels exceeded the background samples by at least two orders of magnitude. A study from Tanzania found levels of BTBPE four times lower in eggs from the Arusha area (Polder et al., 2016). An extremely high level of DBDPE[16], above 2,000 ng/g fat, was measured in the same free-range egg sample from Tropodo as BTBPE. Additionally, an increased level of DBDPE (106 ng/g fat) was measured in the egg sample from Bangun, and it was the only nBFR measured above LOQ in sample KAR-EGG-2 from Karawang at a level of 18.4 ng/g fat. This, together with a very high level of PBDEs, indicates that a larger volume of e-waste plastic or other items treated with BFRs was likely brought to the plastic waste yard in Bangun and then burned in Tropodo. DBDPE was below LOQ in previously studied localities in Kazakhstan, Thailand, China, or Africa (Petrlik, Adu-Kumi, et al., 2019; Petrlik et al., 2017), or found in a much lower level of 6 ng/g fat in eggs from Ireland (Tlustos et al., 2010).

Analyses for nBFRs have shown levels above LOQ only in three and one pooled free-range eggs samples from Bantar Gebang and Karawang.

7.2.10 Dechlorane plus

Two stereoisomers of dechlorane plus, syn-DP and anti-DP, were analysed in six samples from Bantar Gebang, one sample from Karawang (KAR-EGG-01/22) and in the pooled eggs sample from Morowali. In samples EGG-DUMPSITE, BEK-EGG-03 and KAR-EGG-01/22 were measured at levels of 2.7, 2.3 and 2.0 ng/g fat respectively. All other measured samples had levels below LOQ (0.3 ng/g fat). Higher levels of DP were measured in free-range eggs from e-waste site in Kalasin, Thailand, where maximum and mean levels were 12.6 and 3.9 ng/g fat respectively (Dvorska et al., 2023). Comparable levels to those from Bantar Gebang and Karawang were measured in eggs around waste disposal sites in Tanzania (Haarr et al., 2023).

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[15] BTBPE stands for 1,2-bis(2,4,6-tribromo-fenoxy)ethane. It is one of the family of novel brominated flame retardants used e.g. in electronics, where it has replaced PBDEs. Its accumulation in the eggs highlights the need for more detailed screening of new retardants used as alternatives replacing PBDEs for their potential properties similar to those of POPs.

[16] DBDPE stands for decabromodiphenyl ethane. It is another chemical from the family of nBFRs, used mainly in polystyrene foams as well as being a replacement for DecaBDE in electronic wires since the 1990s. Its accumulation in the eggs also highlights the need for more detailed screening of new retardants used as alternatives replacing HBCD and PBDEs for their potential properties similar to POPs.

7.2.11 Per- and polyfluoroalkylated compounds (PFASs)

Seventeen out of twenty pooled free-range chicken egg samples from Indonesian hot spots were analysed for a range of 17 PFASs[17], including PFOA, PFNA[18], PFOS and PFHxS. The results of the analyses are summarized in Table 7.2, but not all results for all individual PFASs are shown there. The graph in Figure 7.6 shows the sums of the 17 PFASs analysed in eggs presented in this study and compares them with PFOS levels in each pooled egg sample.

PFOS had the highest levels in most of the samples. Sample SEM-E-1 from Tangerang exhibited a more equal presence of all PFASs, although PFOS still contributed 39% of the total PFASs content. PFOS represented 68% and 96%, respectively, in egg samples from Bangun, which also had the highest levels of PFASs measured out of the egg samples in this study, at 26 and 96.5 ng/g fw, respectively, followed by eggs from Bantar Gebang (EGG-DUMPSITE) and Tangerang (SEM-E-1), although their levels of 6.4 and 6.2 ng/g fw respectively are much lower.

Looking at the data obtained from previous research, the levels of PFOS measured in eggs from the rural Bangun dump site are comparable to levels from industrialized areas in European countries, indicating that they are not directly contaminated by the production of PFASs, as seen in eggs from Belgium and the Netherlands (D’Hollander W, 2011; Zafeiraki et al., 2016). This fact demonstrates the high impact of waste imported to Bangun, which is most likely the source of the PFASs contamination there. PFOS-related substances have been used in the packaging and paper industries in both food packaging and commercial applications to impart grease, oil and water resistance to paper, paperboard and packaging substrates (KemI, 2004; Strakova, Brosché, Grechko, et al., 2023).

Photo 7.11: *Free-range chicken eggs from Bangun contained levels of PFASs comparable to industrial sites in Netherlands or Belgium (D’Hollander W, 2011; Zafeiraki et al., 2016). This fact demonstrates the high impact of waste imported to Bangun. Photo: Jindrich Petrlik, Arnika, November 2019.*

The dietary intake of four PFASs evaluated by the European Food Safety Authority (EFSA), namely PFOA, PFNA, PFOS, and PFHxS, shows that the highest risk related to these compounds was found in Bangun, Bantar Gebang, and Tangerang, where eggs contained the highest levels of these four PFASs.

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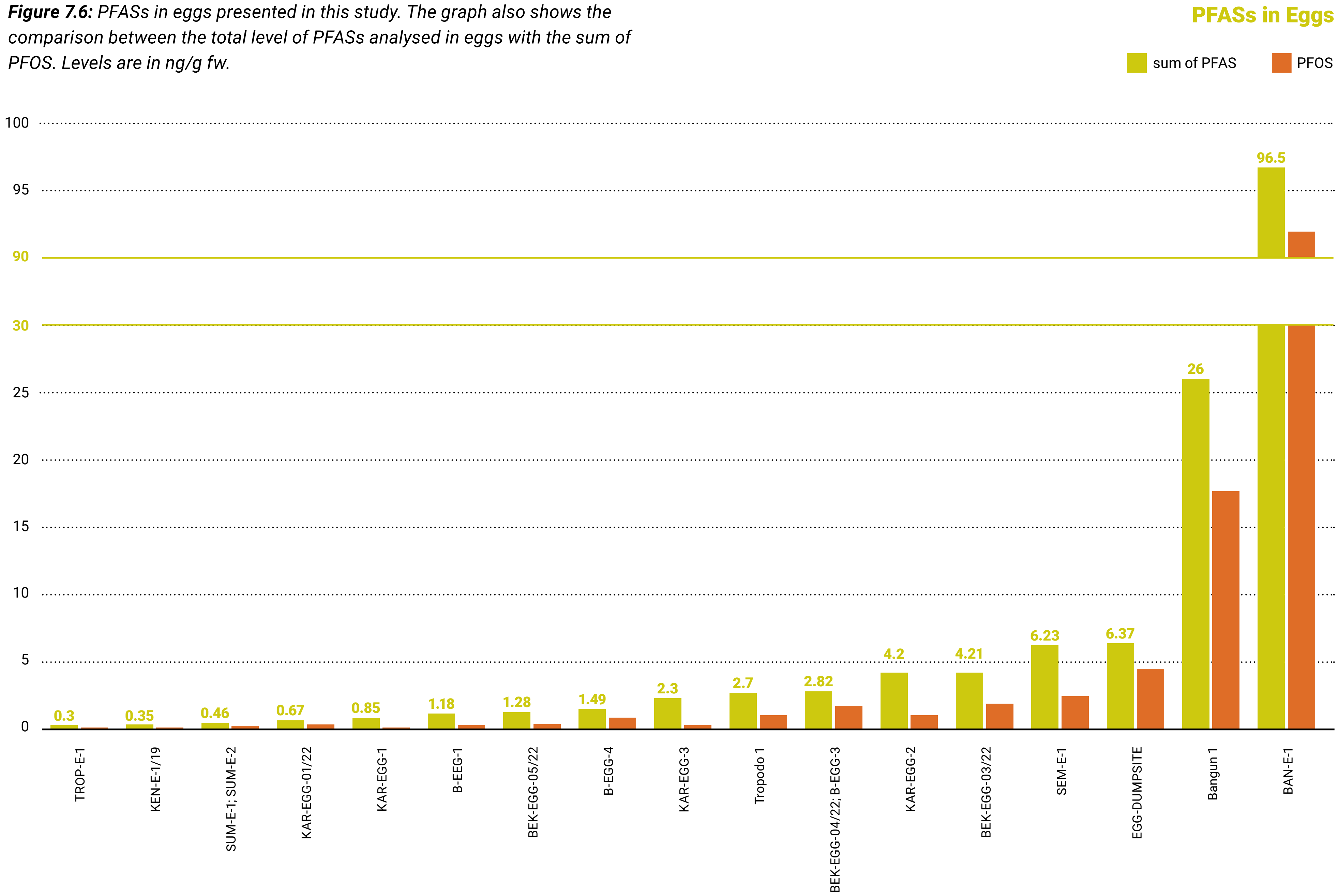
[17] A list of the 17 PFASs included in the analysis: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUdA, PFDoA, PFTrDA, PFTeDA, PFBS, PFHxS, br-PFOS, L-PFOS, PFDS, PFOSA

[18] PFNA - Perfluorononanoic acid is a type of perfluoroalkyl acid, similar to PFOA and PFOS, that has been used in various industrial applications. It is subject to regulation due to its persistence and potential health effects.

Figure 7.6: *PFASs in eggs presented in this study. The graph also shows the comparison between the total level of PFASs analysed in eggs with the sum of PFOS. Levels are in ng/g fw.*



7.2.12 Risks of dietary intake of selected POPs through free-range eggs consumption at presented localities

We tried to estimate dietary intake of PFASs evaluated by EFSA[19] in 2020 (EFSA CONTAM Panel et al., 2020), and for dioxin-like compounds for each pooled egg sample presented in this study. For the calculation we used the same approach as in the previous study on Toxic Hot Spots in Java (Petrlik, Ismawati, et al., 2020).

The egg share in total food consumption in Indonesia in 2007 was close to 1% of the total food basket per day, according to World Atlas – Food Security data [20] (Knoema, 2012), and it has risen by approximately one quarter of its total amount per day (12 g per person per day) every five years. That would mean that for 2022, consumption would be about 20 g per person per day, if the trend remained. The assumption for 2016 was 470 g of eggs per person, per month, according to the World Food Programme, which means approximately 16 g of eggs per person, per day (WFP, 2017). If we count 35 to 40 g per one free-range chicken egg (the typical weight of free-range chicken eggs in Indonesia) as the average weight, it would mean that the consumption of half of such an egg, or a little bit less than that, per person per day, is the general consumption pattern for the Indonesian population these days.

We calculated the dietary intake for the following groups of contaminants per day: 1) dioxin-like compounds, which include PCDD/Fs, dl PCBs, and PBDD/Fs; and 2) PFASs evaluated by EFSA in 2020, which included PFOA, PFNA, PFOS and PFHxS (EFSA CONTAM Panel et al., 2020). The calculation was made by using measured levels of certain chemicals per gram of fresh egg weight and a calculation of the daily intake through consumption of half of a bigger egg per day (20 grams of egg weight). An average body weight was taken from information about average human body weight in different parts of the world, available from Wikipedia (Walpole et al., 2012; Wikipedia, 2020c). The average body weight of 58 kg for an adult person in Asia was applied. The results are summarized in Table 7.4.

The results were then compared with available information about suggested daily intake of the evaluated chemicals.

Photo 7.12: *Children, who belong to the most vulnerable groups affected by POPs contamination in the food chain, are shown here in Karawang. Such contamination can also affect children in other places included in this study. Photo: Ondrej Petrlik, December 2022.*

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[19] EFSA - The European Food Safety Authority is an agency of the European Union that provides independent scientific advice and communicates on existing and emerging risks associated with the food chain.

[20] The food consumption refers to the amount of food available for human consumption as estimated by the FAO Food Balance Sheets. However, the actual food consumption may be lower than the quantity shown, as food availability depends on the magnitude of waste and losses of food in the household. Food consumption per person is the amount of food, in terms of quantity, for each individual in the total population. Food from eggs relates to the quantity of eggs used also for preparation of food such as bakery products.

***Table 7.4** (part 1):*

Sample ID (eggs)	BAN-E-1	Bangun 1	B-EEG-1	B-EGG-4	BEK-EGG-03/22	BEK-EGG-04/22; B-EGG-3	BEK-EGG-05/22	EGG-DUMP-SITE	JAK-SUP	KAR-EGG-01/22	KAR-EGG-1
PFNA (ng/g fw)	0.17	0.81	0.04	0.04	0.09	0.07	0.05	0.15	<0.01	0.03	0.02
PFOA (ng/g fw)	0.05	0.39	0.01	0.00	0.01	0.03	0.03	0.11	<0.01	<0.006	0.01
PFOS (ng/g fw)	92.4	17.7	0.31	0.86	1.9	1.7	0.38	4.5	<0.01	0.36	0.14
PFHxS (ng/g fw)	0.05	0.06	0.08	0.02	0.01	0.02	0.02	0.05	<0.01	0.01	<0.006
EFSA-PFASs-sum in ng/g fw	92.7	18.9	0.44	0.92	2.0	1.9	0.47	4.8	0.04	0.40	0.18
Total content in one egg (40 g) in ng	3706	756.7	17.5	36.9	80.5	74.5	19.0	191.7	1.6	16.0	7.3
Average consumption per kg body weight in ng	31.9	6.5	0.2	0.3	0.7	0.6	0.2	1.7	0.01	0.1	0.1
Exceedance rate of EFSA TDI[21]	50.7	10.4	0.2	0.5	1.1	1.0	0.3	2.6	0.02	0.2	0.1
Dioxin-like compounds pg WHO-TEQ/g fw	1.4	1.8	2.5	1.2	4.4	9.7	4.4	3.3	0.0003	2.5	1.8
Total content in one egg (40 g) in pg	55.0	72.3	101.8	49.9	176.5	387.4	174.2	132.6	0.01	101.9	70.1
Average consumption per kg body weight in pg	0.5	0.6	0.9	0.4	1.5	3.3	1.5	1.1	0.0001	0.9	0.6
Exceedance rate of EFSA TDI	1.9	2.5	3.5	1.7	6.1	13.4	6.0	4.6	0.0004	3.5	2.4

Note: In case of levels below LOQ, the full value of LOQ was included in further calculation.

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[21] TDI - Tolerable Daily Intake represents an estimate of the amount of a specific substance that can be ingested daily over a person’s lifetime without appreciable risk to health.

Table 7.4 *(part 2):*

Sample ID (eggs)	KAR-EGG-2	KAR-EGG-3	KAR-EGG-R	KEN 01	KEN-E-1/19	MWL-EGGS-1	SEM-E-1	TAN-ES-IN-01	TROP-E-1	Tropodo 1	SUM-E-1; SUM-E-2
PFNA (ng/g fw)	0.10	0.05	<0.006	NA	0.02		0.56	NA	0.01	0.12	0.02
PFOA (ng/g fw)	0.03	0.01	<0.006	NA	<0.01		0.27	NA	<0.01	0.10	0.01
PFOS (ng/g fw)	1.05	0.31	<0.006	NA	0.14		2.5	NA	0.14	1.0	0.26
PFHxS (ng/g fw)	0.02	<0.006	<0.006	NA	<0.01		0.03	NA	<0.01	<0.01	<0.01
EFSA-PFASs-sum in ng/g fw	1.20	0.38	0.02	NA	0.18	0.00	3.3	NA	0.18	1.3	0.30
Total content in one egg (40 g) in ng	47.9	15.0	1.0	NA	7.3	0.0	132.7	NA	7.1	50.8	11.9
Average consumption per kg body weight in ng	0.4	0.1	0.0	NA	0.1	0.0	1.1	NA	0.1	0.4	0.1
Exceedance rate of EFSA TDI[22]	0.7	0.2	0.0	NA	0.1	0.0	1.8	NA	0.1	0.7	0.2
Dioxin-like compounds pg WHO-TEQ/g fw	28.6	19.8	0.0	23.1	8.7	0.7	12.8	3.8	23.9	34.8	1.8
Total content in one egg (40 g) in pg	1,144	793.6	1.7	925.9	349.0	27.2	510.5	152.3	957.4	1,392	73.2
Average consumption per kg body weight in pg	9.9	6.8	0.0	8.0	3.0	0.2	4.4	1.3	8.3	12.0	0.6
Exceedance rate of EFSA TDI	39.5	27.4	0.1	31.9	12.0	0.9	17.6	5.3	33.0	48.0	2.5

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[22] TDI - The Tolerable Daily Intake is an estimate of the amount of a specific substance that can be ingested daily over a person’s lifetime without appreciable risk to health.

7.2.12.1 Dietary intake of PFASs by consumption of eggs from sampled sites in Indonesia

EFSA has recently established tolerable levels of intake for four PFASs at a level of 0.63 ng/kg body weight/day (EFSA CONTAM Panel et al., 2020). This sets the limit of 36.5 ng of these four PFASs – namely, PFOA, PFNA, PFOS, and PFHxS – for the average Indonesian adult per day. Only eight pooled free-range egg samples presented in this study do not exceed this limit in a single egg. We have also estimated levels/rates of exceedance of the TDI set by EFSA through the average consumption of eggs from the presented pooled samples. These rates are within the following ranges for each of the localities: Bangun, 10 to 51 times; Bantar Gebang, 0.2 to 2.6 times; Karawang, 0.1 to 0.7 times; Kendalsari, 0.1 times; Tangerang, almost 2 times; Topodo, 0.1 to 0.7 times; and Sumberwuluh, 0.2 times. These estimates highlight the seriousness of the situation at such polluted sites because we must consider that eggs are not the only source of food contaminated with PFASs (EFSA CONTAM Panel et al., 2020; Mikolajczyk et al., 2023; Sznajder-Katarzyńska et al., 2019).

From the perspective of PFAS contamination of eggs as a representative example of the food chain, the most serious situations were observed in Bangun, Bantar Gebang, and Tangerang. Levels in reference egg samples from supermarkets in Jakarta and convenience stores in Karawang were well below the risk threshold.

7.2.12.2 Dietary intake of PCDD/Fs and dioxin-like compounds by consumption of eggs from sampled sites in Indonesia

As for PFASs, EFSA has established a tolerable level of intake for PCDD/Fs and dioxin-like PCBs as well, which is set at a level of 0.25 pg WHO-TEQ/kg body weight/day (EFSA CONTAM, 2018a). This sets the limit of 14.5 pg WHO-TEQ for these compounds for the average Indonesian adult per day. We have also incorporated PBDD/Fs in our calculations, as they are considered to have almost the same health effects and toxicity as chlorinated analogues (PCDD/Fs) (Behnisch et al., 2003; Birnbaum et al., 2003; Kannan et al., 2012; Mason et al., 1987; Piskorska-Pliszczyńska & Maszewski, 2014). None of the 20 pooled free-range egg samples presented in this study were below this limit in a single egg. We have also estimated levels/rates of exceedance of the TDI set by EFSA through the average consumption of eggs from the presented pooled samples. These rates are in the following ranges for each of the localities: Bangun, almost 2 to 2.5 times; Bantar Gebang, 1.7 to 13.4 times; Karawang, 2.4 to 39.5 times; Kendalsari, 12 to 32 times; Morowali, almost 1 time; Tangerang, almost 5.3 to 17.6 times; Tropodo, 33 to 48 times; and Sumberwuluh, 2.5 times. These estimates show that the contamination of food chains at the studied localities is even more serious than with the four PFASs. Also, in the case of dioxins and dioxin-like compounds, we have to take into account that eggs are not the only source of food contaminated with them (EFSA CONTAM, 2018a; Fiolet et al., 2024; Grechko, Amutova, et al., 2021).

From the point of view of contamination of eggs as a representative example of the food chain with dioxins and/or dioxin-like compounds, the most serious situations were in Tropodo, Karawang, and Kendalsari, followed by Tangerang and Bantar Gebang. Levels in reference egg samples were well below the risk threshold. Additional contamination of eggs presented in previous subchapters adds an overall burden of POPs to the health of consumers of locally grown food.

7.3 Conclusions

Severe environmental and food chain contamination with POPs resulting from the use of plastic and rubber waste as fuel in both tofu factories in Tropodo and lime kilns in Karawang Regency has been confirmed through the analysis of free-range chicken egg samples in this study. The contamination of eggs with dioxins and dioxin-like compounds (dl PCBs and PBDD/Fs) represents the highest levels ever recorded in Asia and globally. Furthermore, the contamination of eggs with Per- and Polyfluoroalkyl Substances (PFASs) is particularly concerning, notably in Bangun, Bantar Gebang, and Tangerang, where the highest rates of exceedance of the Tolerable Daily Intake (TDI) by consuming just half an egg per day were estimated based on measured levels of four PFASs evaluated by EFSA in 2020.

By consuming a normal average portion of eggs, which is half an egg from free-range hens at any of the sampled localities in this study, an adult Indonesian can reach or exceed the TDI of dioxins and/or dioxin-like compounds by up to 48 times.

Brominated dioxins were found for the first time to contribute significantly to the overall dioxin-like toxicity, accounting for three-quarters when compared to chlorinated dioxins and dioxin-like PCBs in a pooled egg sample from hens foraging at a site with ash from incinerated plastic waste in Karawang.

The EU standard of 40 ng/g for six non-dioxin-like (ndl) PCB congeners was exceeded in KAR-EGG-2 by more than twice the limit, but was not as high in other samples presented in this study. HCB levels in two egg samples from Bantar Gebang (BEK-EGG-03/22) and Karawang (KAR-EGG-2) rank as the second and fifth highest measured in Asian countries, respectively. MCCPs, measured for the first time in Indonesian food, reached much higher levels than SCCPs in eggs from Bantar Gebang, ranging from below the Limit of Quantification (LOQ) to 2,345 ng/g fat, comparable to levels observed in eggs from neighborhoods near waste disposal sites in Tanzania.

Levels of other POPs (PCNs, HCBD, or OCPs[23]) measured in eggs from the studied localities were relatively low, except for DDT and HCH levels in eggs from Kendalsari. However, any level of food chain contamination with POPs contributes to the overall burden, as it is challenging to evaluate their synergistic effects on human health.

It is imperative to avoid using plastic waste as fuel in facilities such as lime kilns or tofu factories, and to cease uncontrolled plastic waste imports and disposal at large plastic waste yards like Bangun, Tangerang, or even the large landfill in Bantar Gebang. More stringent limits for defining POPs waste are necessary to regulate disposal options for waste produced by waste incineration, including at facilities like lime kilns burning plastic waste.

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[23] OCPs - Organochlorine pesticides are a group of pesticides that contain chlorine atoms bonded to carbon atoms. They were widely used in agriculture and public health programs but have been largely phased out or banned due to their persistence, bioaccumulation, and toxicity.

8. Map: Toxic Hot Spots in Indonesia

Annisa Maharani

In the absence of publicly available comprehensive emissions data from industries, emissions and releases mapping is one way to gauge the magnitude of pollution in Indonesia. Therefore, we developed a "Toxic Hotspot Map" in order to show the distribution of industrial facilities and/or sectors that are pollution sources. Primary and secondary data was used to create the map. Primary data was taken by the Nexus3 and Arnika teams from 4 hotspots of the project's interest; namely Pangkalan Susu, Suralaya, Bantar Gebang, and Morowali. Our method was collecting environmental and biomarker samples and getting them tested in Indonesian, Czech, Dutch, and German laboratories for POPs and heavy metals. Meanwhile, secondary data was obtained from scientific publications, government reports, industry annual environmental reports, and other publicly available sources we can find that show various parameters, ranging from chemical and physical to biological parameters of emissions and releases around pollution sources.

This map was created with divisions based on types of sectors, activities and industries as follows:

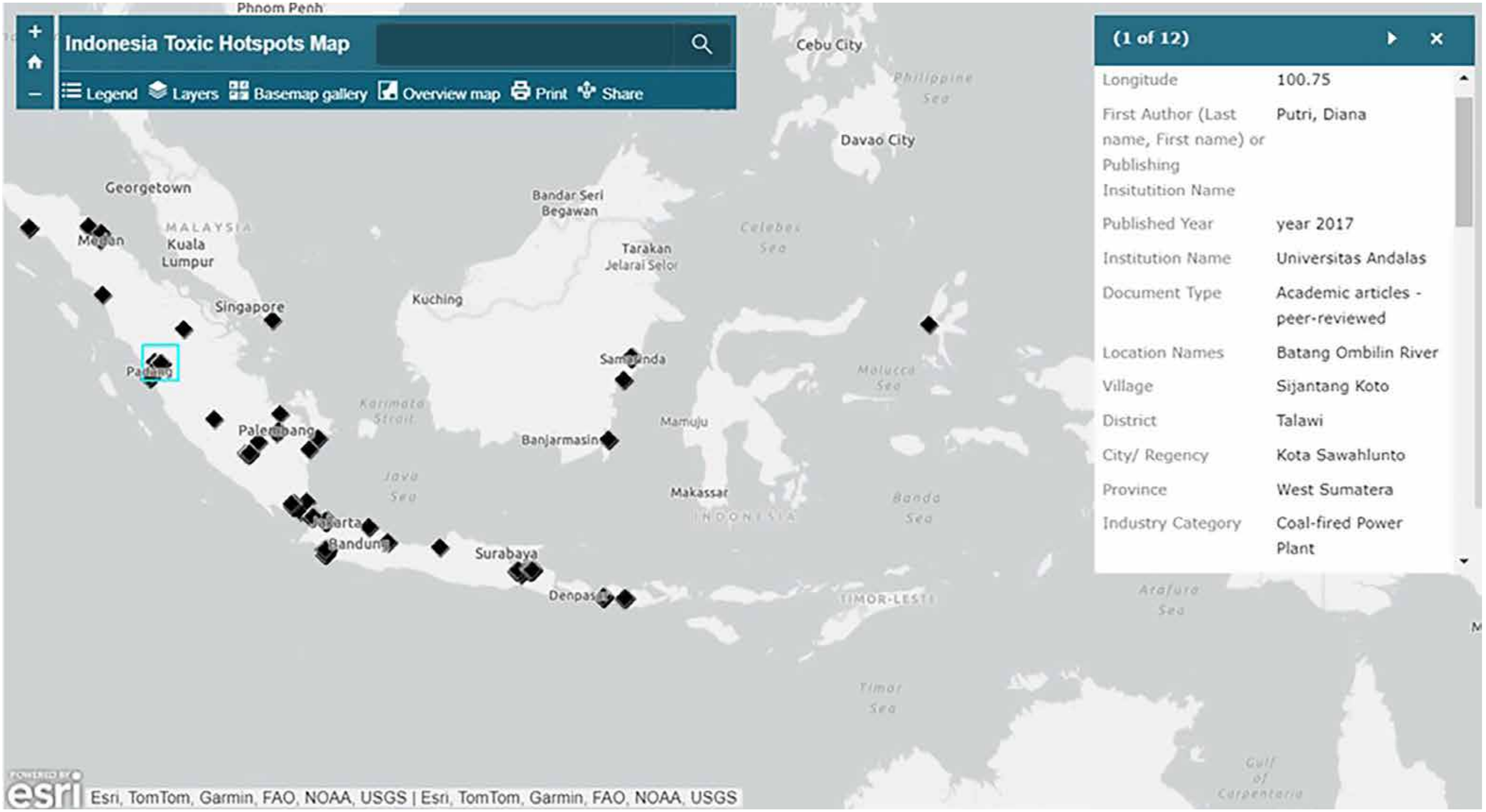
1. Agricultural Sector and Industry
2. Aluminum Industry
3. Asbestos Industry
4. Cement Industry
5. Coal Power Plant (PLTU)
6. Electronics Industry
7. Industrial Area
8. Landfill & Waste Disposal Site
9. Large Scale Mining
10. Nickel Industry
11. Oil Refining Industry
12. Other Industries
13. Other Metal Industries
14. Paint Industry
15. Paper Industry
16. Petrochemical Industry
17. Textile Industry

Through **toxichotspots.id**, pollution data is displayed interactively with detailed information about coordinates, pollution sources, locations, publication years, sample types with collection information, analyzed parameters, and more. The map will be actively updated over time.

Limited publicly available data became the major challenge in creating the map.

The most important data to obtain is industries' annual environmental reports to the government, but this data is not open to the public. All industries are mandated to report emissions and releases from their facilities annually to the government. This data would be useful to gauge the magnitude of emissions in an area, providing a clear and valid pollution estimation for the public, especially for communities in the vicinity. Data from scientific publications often only serves as a one-time analysis, which is understandable since it doesn't serve continual monitoring purposes.

Other challenges include difficulties in finding consistent data over the years and ensuring similar methodologies and parameters across scientific papers. There are a few categories in the map that are not yet filled with data due to the absence of such information. Nevertheless, the toxic hotspot map can still serve its purpose by showing emissions and releases from pollution sources in Indonesia. Information about XXX hot spots in Indonesia was made available through this database before until middle of 2024.



(1 of 12)

Longitude	100.75
First Author (Last name, First name) or Publishing Insitution Name	Putri, Diana
Published Year	year 2017
Institution Name	Universitas Andalas
Document Type	Academic articles - peer-reviewed
Location Names	Batang Ombilin River
Village	Sijantang Koto
District	Talawi
City/ Regency	Kota Sawahlunto
Province	West Sumatera
Industry Category	Coal-fired Power Plant

Figure 8.1: *Toxic hotspots map with detailed information for each pollution point.*

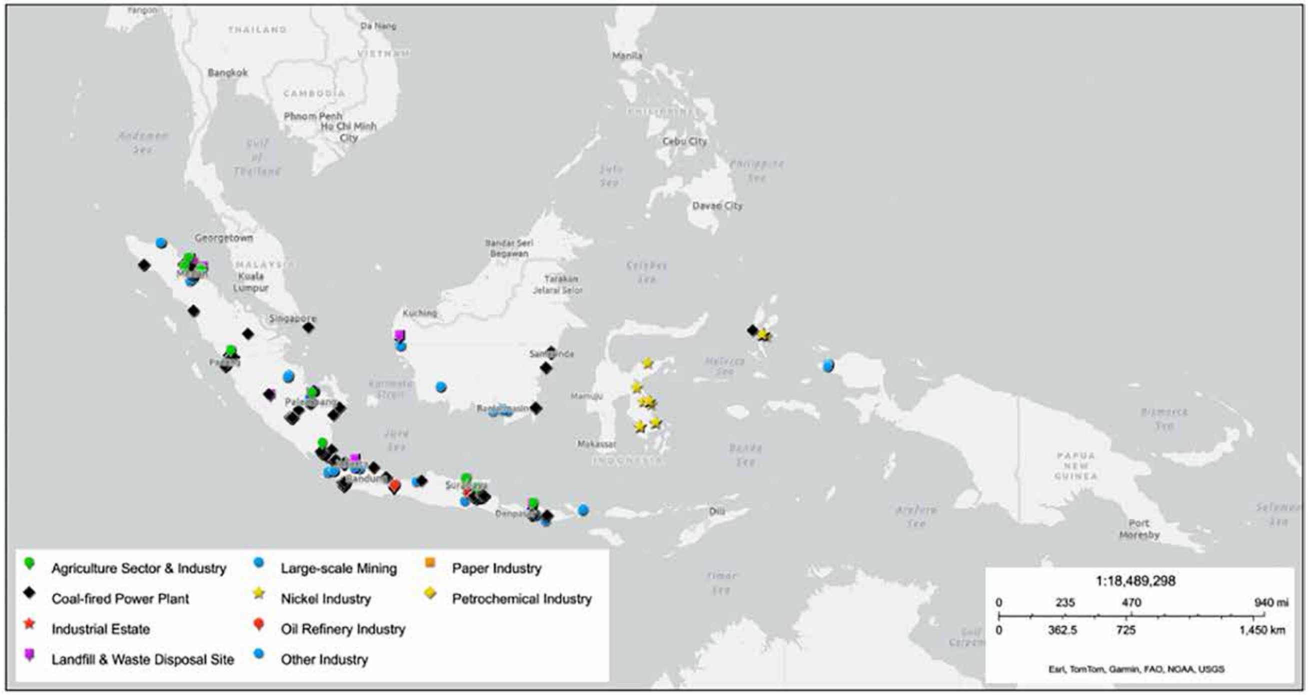


***Figure 8.2:** Toxic hotspots map all categories, with an absence of data from aluminum, asbestos, cement, electronics, other metals, paint and textile industries.*

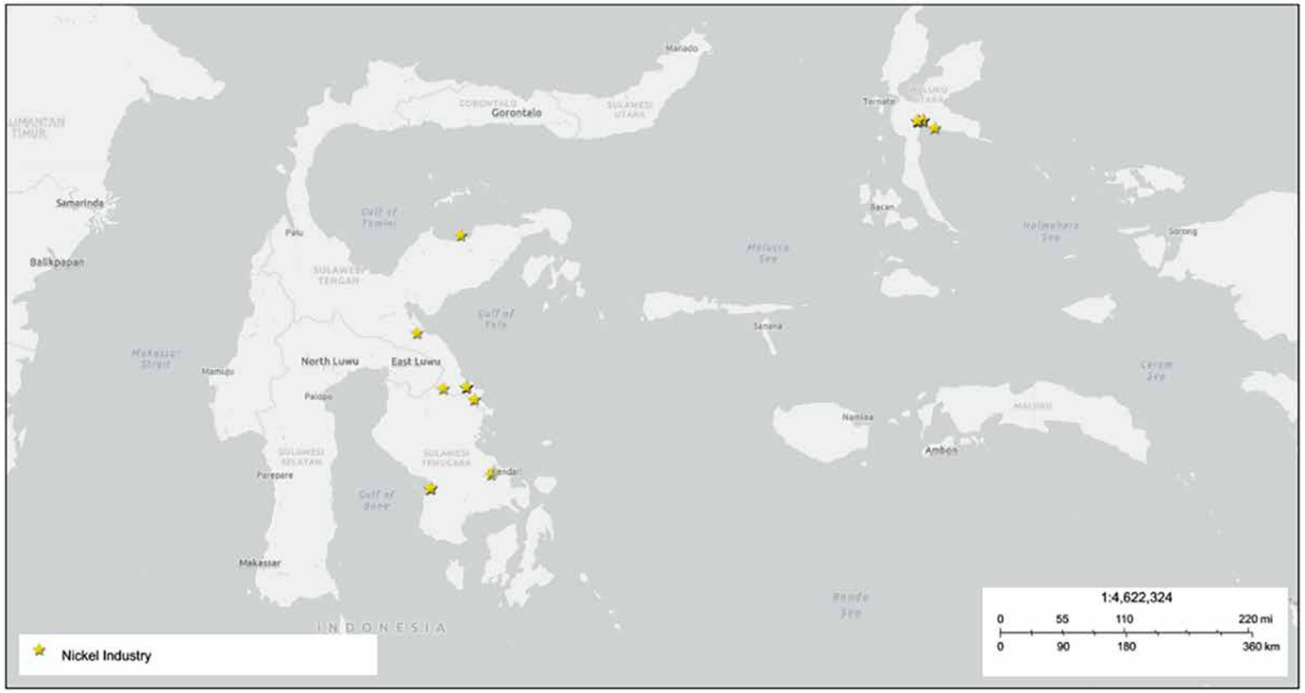


***Figure 8.3:** Emissions and releases data available for the nickel industry.*

9. Conclusions and recommendations

9.1 Conclusions

Very serious contamination of the environment and food chain with POPs and heavy metals resulted from using plastic and rubber waste as fuel in lime kilns in Karawang Regency was confirmed by samples of ash, soil, and free-range chicken eggs in this study. Soil samples show extremely high lead levels, well above global averages and reference sites. This indicates severe contamination that poses significant environmental and health risks.

This study around the Bantar Gebang landfill in Indonesia revealed significant heavy metal contamination in soil and sediment samples. Most heavy metals, including zinc, lead, and copper, were found at concentrations above reference levels, indicating localized contamination from the landfill. Fly ash from incinerators showed high concentrations of zinc and copper, and mirrored the heavy metal profile found in the soil, suggesting that waste incineration significantly contributed to the pollution. The free-range chicken eggs collected near the landfill showed detectable levels of copper, mercury, and zinc, but these levels were below potential health risk thresholds. However, comparisons with other contaminated areas showed that eggs from Bantar Gebang contained relatively higher levels of contamination.

The POPs contamination in soil samples from Bantar Gebang was lower than in free-range chicken eggs. Only one soil sample, BEK-SOIL-01/22, showed higher POPs values, particularly MCCPs.

For some POPs, egg contamination from Bantar Gebang is very severe. For example, the contamination of eggs with PFASs, dioxins and dioxin-like compounds are particularly concerning. All free-range chicken egg samples exceeded the EU limit for PCDD/Fs/dl PCBs set for eggs as food at 5 pg WHO-TEQ/g fat. In one of the samples, the second-highest measured concentration of HCB (41 ng/g fat) in chicken eggs from Asian locations was found.

Analysis of the egg sample BEK-EGG-04/22; B-EGG-3, which showed the highest concentration of dioxins and dioxin-like substances from the Bantar Gebang site, indicated that sources contributing to POPs contamination likely include not only the landfill and incinerator, but also galvanizing plants and metal processing.

Reference soil samples from the Cisarua area were affected by local human activities (camping, wood and waste burning, pesticide use on tea plantations) to such an extent that dioxin concentrations in soils exceeded those found in samples from Bantar Gebang. Therefore, from the perspective of these substances, only Mbeji Forest can be considered a background concentration site.

This study confirmed severe environmental and food chain contamination with POPs resulting from the use of plastic and rubber waste as fuel in tofu factories in Tropodo and lime kilns in Karawang Regency through the analysis of free-range chicken egg samples. The contamination of eggs with dioxins and diox-

Photo 9.1: *Mbeji Forest proven as a clean site with background concentrations of POPs. Photo: Daru Rini, Ecoton, December 2019.*

Photo 9.2: *Cisarua was found to be affected by e.g. tea plantation where pesticides are used and contaminate soil or by open burning of waste at camping sites. Photo: Ondrej Petrlik, December 2022.*

in-like compounds (dl PCBs and PBDD/Fs) represents the highest levels ever recorded in Asia and globally. It is necessary to avoid using plastic waste as fuel in facilities like lime kilns or tofu factories.

Furthermore, the contamination of eggs with per- and Polyfluoroalkyl Substances (PFASs) is particularly concerning, notably in Bangun, Bantar Gebang, and Tangerang, where the highest rates of exceeding the TDI by consuming just half an egg per day were estimated based on measured levels of four PFASs evaluated by EFSA in 2020.

By consuming a normal average portion of eggs, which is half an egg from free-range hens at any of the sampled localities in this study, an adult Indonesian can reach or exceed the TDI of dioxins and/or dioxin-like compounds by up to 48 times. For the first time, brominated dioxins were found to contribute significantly to the overall dioxin-like toxicity, accounting for three-quarters of the total when compared to chlorinated dioxins and dioxin-like PCBs in a pooled egg sample from hens foraging at a site with ash from incinerated plastic waste in Karawang.

The EU standard of 40 ng/g for six non-dioxin-like PCB congeners was exceeded in KAR-EGG-2 by more than twice the limit. HCB levels in two egg samples, one from Bantar Gebang (BEK-EGG-03/22) and one from Karawang (KAR-EGG-2), rank as the second and fifth highest measured in Asian countries, respectively. MCCPs, measured for the first time in Indonesian food, reached levels up to 2,345 ng/g fat in Bantar Gebang eggs, similar to those near waste sites in Tanzania. Other egg POPs were low, except for DDT and HCH in Kendalsari. Any POP contamination adds to health risks due to their synergistic effects.

Photo 9.3: *Karawang. Photo: Ondrej Petrlik, Arnika, December 2022.*

Photo 9.4: *Bantar Gebang. Photo: Ondrej Petrlik, Arnika, December 2022.*

Photo 9.5: *Kendalsari. Photo: Prigi Arisandi, Ecoton, February 2018.*

Photo 9.6: *Bangun. Photo: Ecoton, November 2018.*

Photos 9.3 – 9.6: *Plastic waste incineration in lime kilns in Karawang, plastic waste in Bantar Gebang, aluminum smelters in Kendalsari and a plastic waste yard in Bangun are just examples of very polluting activities and sources of contamination with POPs and heavy metals in Java.*

Photos 9.7 and 9.8: *It is not only large landfill (Photo 9.5) and plastic waste workshops, but also the Merah Putih waste incinerator (Photo 9.6) and other medium enterprises that are sources of POPs contamination in Bantar Gebang revealed in this study. Photos: Ondrej Petrlik, Arnika, December 2022.*

It is crucial to stop using plastic waste as fuel in facilities and to halt uncontrolled imports and disposal of plastic waste. More stringent limits for POPs waste are needed to regulate disposal from waste incineration, including in facilities burning plastic waste.

Limited publicly available data became the major challenge in creating the map of Toxic Hot Spots in Indonesia (http://www.toxichotspots.id). Other challenges include difficulties in finding consistent data over the years and ensuring similar methodologies and parameters across scientific papers. There are a few categories in the map that are not yet filled with data due to the absence of such information. The PRTR system will help fill this gap by providing viable and verified data about the release of a certain number of chemicals.

9.2 Recommendations

Very serious contamination of the environment and the food chain with POPs resulting from the use of plastic and rubber waste as fuel in lime kilns in Karawang Regency was confirmed in this study through measurements of ash, soil, and free-range chicken egg samples. Bantar Gebang and Karawang are additional examples, alongside Bangun, Tangerang, and Tropodo, of many similar sites in Southeast Asia. The study has several recommendations aimed at improving the situation.

On plastics:

- In agreement with a recent study from Kenya (Petrlik, Strakova, et al., 2023), the results of this study also suggest that the new global Plastics Treaty should focus on the chemical content of plastic materials and prohibit materials such as PVC or plastics containing brominated compounds.

- The use of plastic waste as fuel in all small and medium enterprises (SMEs) should be prohibited. These facilities openly burn plastics and lack air pollution control equipment or practices to manage dioxin and other U-POPs emissions.
- Strict enforcement of the new provisions of the Basel Convention to block imports of hazardous waste and regulate transboundary movements of plastic waste or enacting a ban on the import of plastic waste is vital.

On the use of ash:

- All ashes from waste incineration or metallurgical processes should be primarily classified as hazardous waste and monitored for their POPs content. Strict limits for POPs content in wastes should be introduced into national legislation to prevent further contamination of the environment and food chains.
- More strict limits for the definition of POPs waste are needed to regulate disposal options for waste produced by waste incineration globally.

On information available to the public on environmental pollution:

- Based on experiences from other countries, establishing a PRTR system helps monitor the flow of toxic substances and reduce environmental pollution. It will be necessary to include small and medium-sized enterprises (SMEs), such as lime kilns in Karawang, tofu factories in Tropodo, or aluminum smelters in Kendalsari in the PRTR design for Indonesia.
- PRTR should cover heavy metals and POPs, particularly lead, mercury, zinc, copper, dioxins (PCDD/Fs), polychlorinated biphenyls (PCBs), selected brominated flame retardants, hexachlorobenzene (HCB), chlorinated paraffins, and PFASs.

10. Annex I: Heavy metals

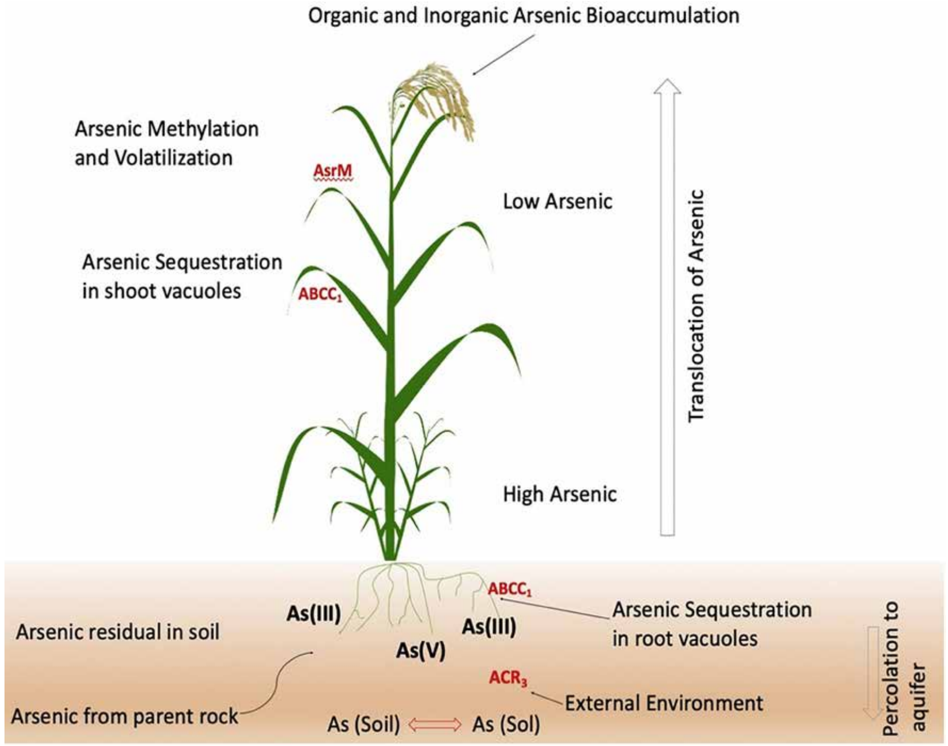
10.1 Arsenic

Significant anthropogenic sources include the mining and metallurgical industries (Rasheed et al., 2016), as well as the burning of lignite coal (Bencko et al., 1995). Acute exposure to arsenic through inhalation can lead to gastrointestinal symptoms and neurological disorders in workers (Rahman et al., 2011; Rodriguez et al., 2003). Chronic exposure primarily causes irritation of the skin and mucous membranes, along with long-term effects on the brain and nervous system (Chen et al., 2013; Tsai et al., 2003; Tseng et al., 2003). The International Agency for Research on Cancer (IARC) classifies arsenic and arsenic trioxide as Group 1 carcinogens, linking them to lung and bladder cancers, with partial evidence of effects on prostate, liver, and kidney cancers (IARC, 2023).

10.2 Cadmium

Cadmium accumulates in living organisms, including humans, particularly binding to metallothionein in the kidneys, potentially causing organ damage (Prozialeck & Edwards, 2012). Cadmium interferes with calcium absorption, leading to demineralization, reduced bone density, and disrupted vitamin D3 metabolism (Khan et al., 2017). It also adversely affects the hormonal system, particularly sex hormones (Kresovich et al., 2015). The International Agency for Research on Cancer (IARC) classifies cadmium as a Group 1 human carcinogen (IARC, 2023), noting its genotoxicity and teratogenic effects on prenatal development.

Figure 10.1: *Arsenic uptake and bioaccumulation in plants.*
Source: (Bhattacharya et al., 2021).



Evidence supports its role in the development of lung, kidney, mammary, and prostate cancers (Huff et al., 2007).

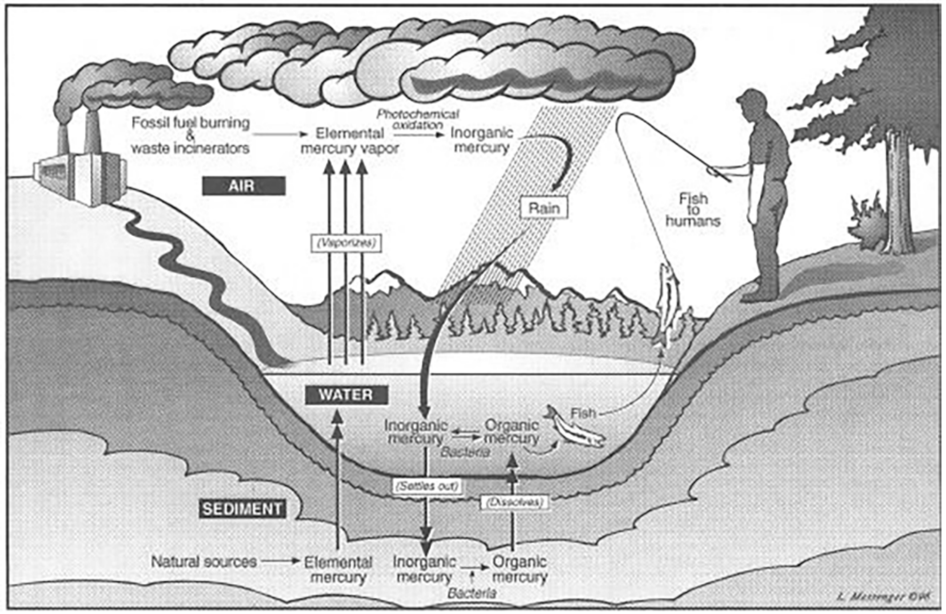
10.3 Copper

Copper occurs naturally primarily as sulphides, oxides, and carbides, and less frequently in its pure metallic form. Its extraction and processing from ores have been historically significant, but can lead to environmental contamination (Ek & Renberg, 2001; Leblanc et al., 2000). Biologically, copper is essential for several enzymatic processes, including cellular respiration and neurotransmitter synthesis (Gaetke et al., 2014). However, excessive exposure to copper poses health risks, including acute toxicity which can be fatal. Chronic exposure to elevated copper levels can cause damage to the liver and kidneys, as well as severe neurological impairments (Handy, 2003; Kodama et al., 2011; Xu et al., 2018). It has also been implicated in the development of Alzheimer's disease due to its potential role in neural pathology (Uriu-Adams & Keen, 2005). Overall, while copper is vital for biological functions, its accumulation in the environment and body can have detrimental health effects.

10.4 Mercury

Mercury naturally occurs in various chemical and physical forms, such as solid or gaseous states, each with a distinct toxicological profile, transport mechanisms, and metabolic outcomes. It is dispersed through rock dust from erosion and weathering, settling on land or in water (Sundseth et al., 2017). Humans primarily encounter mercury through the inhalation of its vapor, with significant contributions from anthropogenic sources like combustion, coal burning, municipal waste processing, and mining (Sundseth et al., 2017). Elemental mercury vapor exposure affects the central and peripheral nervous systems, leading to neurological and behavioral disorders such as tremors, memory loss, and cognitive dysfunction (Clarkson, 1997; Langford & Ferner, 1999). In water, inorganic mercury transforms into methylmercury (MeHg), a highly toxic organic form that accumulates in aquatic life, presenting significant risks when consumed (Harris et al., 2003). Methylmercury damages nervous and cardiovascular systems, impacts liver and kidney functions, and can disrupt hormonal balances, even at low concentrations; it also crosses the placenta, potentially harming fetal brain development (Kumari et al., 2020). The International Agency for Research on Cancer (IARC) classifies methylmercury as a possible human carcinogen (Group 2B) (IARC, 2023), underscoring its potential health risks.

Figure 10.2: *Mercury cycle. Source: (Schettler et al., 2000).*



10.5 Nickel

Nickel is primarily found in the environment in the form of sulphides and silicates, with significant contamination stemming from ore mining and metallurgical activities (Bencko et al., 1995). Chronic oral exposure to high doses of nickel can alter blood composition, reduce iodine in the thyroid, irritate the skin, and displace essential metals like copper, zinc, and iron from enzymes (De Brouwere et al., 2012; Genchi et al., 2020). Animal studies have demonstrated nickel's potential to damage DNA. Additionally, nickel is a potent contact allergen, known for causing dermatitis (Ahlström et al., 2019). The International Agency for Research on Cancer (IARC) has classified certain nickel compounds as confirmed human carcinogens (Group 1). Nickel itself is categorized under Group 2B as a possible carcinogen, indicating its potential risk in causing cancer (IARC, 2023). These classifications reflect the serious health risks associated with nickel exposure, particularly in industrial contexts.

10.6 Lead

Lead is recognized as a persistent global environmental pollutant, and is toxic in all concentrations in the blood, where it acts as a xenobiotic (Sanders et al., 2009). Exposure to high lead levels can impair blood, nervous, immune, renal, and cardiovascular systems, causing gastrointestinal issues and severe damage to the brain and kidneys (Sanders et al., 2009). Developmental neurotoxicity, which includes slow cognitive development and reduced IQ in children, is a critical adverse effect of lead exposure (Grandjean & Herz, 2011). Once ingested, lead distributes throughout the body, particularly accumulating in the bones (Pemmer et al., 2013). The IARC classifies inorganic lead compounds as “likely” carcinogens (Group 2A), based on animal studies showing sufficient but limited evidence (IARC WG, 2006).

10.7 Zinc

Zinc is an essential trace element. It is considered to be relatively non-toxic, particularly if taken orally. Rather than zinc toxicity, zinc deficiency is observed (Bagherani & Smoller, 2016). However, manifestations of toxicity symptoms (nausea, vomiting, epigastric pain, lethargy, and fatigue) will occur with extremely high zinc intakes. Excessive zinc concentrations may lead to the deterioration of copper or iron metabolism (Kondaiah et al., 2019).

11. Annex II: Persistent Organic Pollutants (POPs)

Persistent organic pollutants (POPs) represent a large group of chemicals that persist a long time in the environment, bioaccumulate, have potential for long-range environmental transport, and have adverse effects to human health or the environment (Stockholm Convention, 2010). Thirty-two individual chemicals or their groups have already been listed under the SC (Stockholm Convention, 2022, 2023a, 2023b, 2023c). This covers some but not all chemicals that have the properties of POPs. Their basic characteristics follow. We focused on both intentionally and unintentionally produced POPs.

11.1 Intentionally produced POPs

Intentionally produced POPs considered in our study are 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.

11.1.1 Organochlorine pesticides (OCPs)

Organochlorine pesticides (OCPs) in our study represent substances such as DDT, HCH (including lindane), and HCB. All were used in large quantities, and many places are still contaminated by them today. These are substances that individually affect human health, but it is also not possible to exclude their synergistic effects. For example, one study has reported OCP to trigger anti-androgenic effects in men and estrogenic effects in women (Freire et al., 2014).

11.1.1.1 Dichlorodiphenyltrichloroethane (DDT)

Dichlorodiphenyltrichloroethane (DDT), a globally recognized organochlorine insecticide in use since 1945, has played a significant role in agriculture and the control of vector-borne diseases, particularly malaria since 1955. Its inclusion in the initial list of Persistent Organic Pollutants (POPs) regulated by the SC led to restrictions on its use, with the WHO permitting its reintroduction solely for vector-borne disease control in select tropical countries in 2006. The physicochemical properties of DDT, coupled with its remarkable persistence—characterized by a half-life of up to 30 years—contribute to its association with various health and societal problems. These issues stem from DDT's accumulation in the environment and its biomagnification in living organisms, as highlighted by Mansouri et al. (2017). The SC, listing DDT in Annex B, strictly regulates its production and use (Stockholm Convention, 2010).

The term DDT generally refers to the commercial pesticide formulation that includes several related compounds. Consequently, the usage of DDT implies the release of at least six derivatives in the following relative amounts: p,p=-DDT> o,p=-DDT> p,p=-DDE> o,p=-DDE> p,p=-DDD> o,p=-DDD (Haller et al., 1945). Each para, para p,p=-substituted isomer is more abundant than the corresponding ortho, para o,p=-substituted one. The three major components, p,p=-DDT, p,p=-DDE, and p,p=-DDD are generally referred to in the literature as DDT, DDE, and DDD, respectively, and as isomers (or metabolites, although not always correct or the case); (Hellou et al., 2013).[24] Our use of DDT, DDE, and DDD without a prefix relates to both p,p=isomers and o,p=isomers.

One of the most well-known toxic effects of DDT is eggshell thinning in birds, particularly birds of prey, as documented in Rachel Carson's influential work, "Silent Spring" (Carson, 1962). This impact led to bans on DDT in numerous countries during the 1970s. [25] Despite these bans, DDT continues to be detected in food globally. Although residues in domestic animals have diminished, food-borne DDT remains a primary exposure source for the general population. Long-term exposure to DDT has been associated with chronic health effects. Its detection in breast milk raised concerns about infant health (Stockholm Convention, 2019). The findings of Carson are echoed in environmental literature such as "Our Stolen Future" (Colborn et al., 1997), emphasizing reproductive effects linked to DDT exposure (Hellou et al., 2013).

DDT exposure poses significant risks to human health, manifesting in neurological effects, liver effects, reproductive effects, and immunological effects, including neurodevelopmental impacts (ATSDR, 2022; Dallaire et al., 2004). Additionally, DDT and its derivatives are recognized as endocrine-disrupting chemicals (Turusov et al., 2002). Compounds like DDE and DDD, proposed to be more persistent than the parent compound (Teeyapant et al., 2014), exhibit higher toxicity and ecotoxicity (Johnson & Finley, 1980; Mansouri et al., 2017). DDT is a probable human carcinogen (2A); (IARC, 2023).

High levels of DDT in sediments have been observed in the vicinity of contaminated sites, legacy production areas, and obsolete pesticide stockpiles (Jayakumar et al., 2005; Kohušová et al., 2010; Petrlik et al., 2006). This observation underscores the persistent environmental impact of DDT, necessitating ongoing monitoring and management efforts.

11.1.1.2 Hexachlorocyclohexanes (HCHs)

Lindane (the gamma isomer of HCH) has been used as a broad-spectrum insecticide for seed and soil treatment, foliar applications, tree and wood treatment, and against ectoparasites in both veterinary and human applications (POP RC, 2006b). Lindane is persistent, easily bioaccumulates in the food chain, and bioconcentrates rapidly. There is evidence of long-range transport and toxic effects (immuno-

Photo 11.1: *POPs pesticides can accumulate at sites of their storage and preparation, as seen in one building in Klatovy, Czech Republic, which was found highly contaminated with DDT and lindane (Dvorská et al., 2007; Møller, Straková, et al., 2020). The photo shows a contaminated part of the wall. Photo: Jindrich Petrlik, Arnika, October 2010.*

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[24] The chemical nomenclature for these three prevalent structures is 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane for p,p DDT, 1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene for p,p DDE, and 1,1-dichloro-2,2-bis (p-chlorophenyl)ethane for p,p DDD

[25] Environmental research on organochlorine contaminants (OCs) has been ongoing since the 1940s. One book, Silent Spring by Rachel Carson (1962), is unanimously cited as raising awareness of the dual role of synthetic chemicals, "the good and the bad sides". The book describes the eggshell thinning discovered in birds when the spraying of dichlorodiphenyltrichloroethane (DDT) was initiated to eradicate disease, especially malaria. This book played a major role in generating environmental awareness in the population at large, including scientists, because it was written in an accessible style.

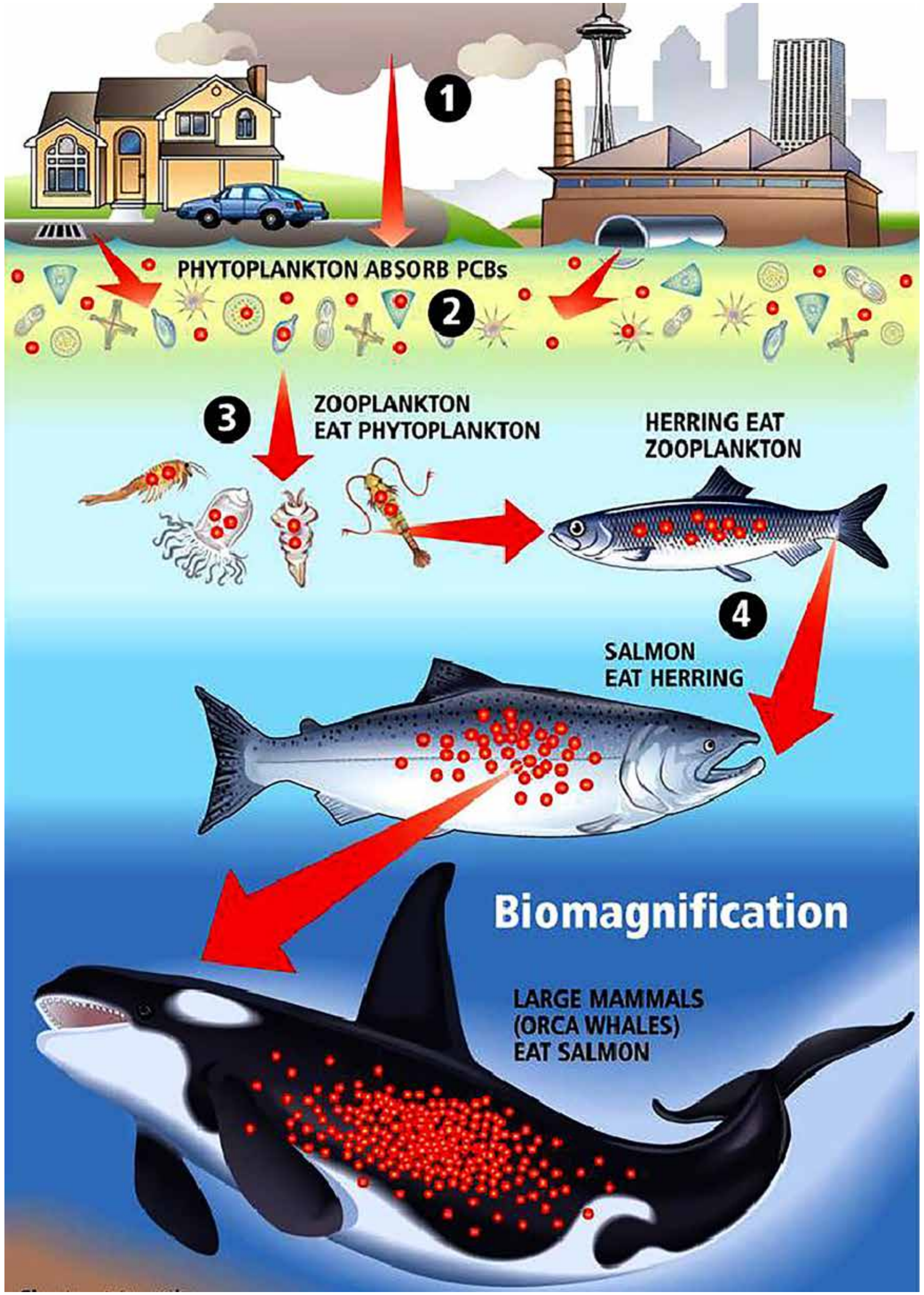

Figure 11.1: *PCBs biomagnification in the marine food chain. Similar process of biomagnification and bioaccumulation in the food web can be seen in terrestrial ecosystems. Source: (blue-growth.org, 2018).*

toxic, reproductive, and developmental effects) in laboratory animals and aquatic organisms. Lindane is classified as a human carcinogen (Group 1) by IARC (2023).

Alpha- and Beta-HCH are highly persistent in water in colder regions and may bioaccumulate and biomagnify in biota and Arctic food webs. These chemicals are subject to long-range transport, classified as probable human carcinogens (2B) to humans (IARC, 2023), and have adverse effects on wildlife and human health in contaminated regions (UNEP, 2020). Lindane is highly toxic to wildlife, including fish, bees, birds, and mammals (US EPA, 2002). The half-life of lindane in humans is less than a day, while the half-life of its major metabolite (beta-HCH) is seven years. Therefore, it is more reliable to measure the latter.

Prenatal exposure to β-HCH has been correlated with altered thyroid hormone levels, which could affect brain development. Studies have shown that all isomers of HCH might reasonably be anticipated to cause cancer in humans (US EPA, 2002). Cox et al. (2007) linked β-HCH to increase prevalence of diabetes.

Lindane is listed in Annex A to the SC with specific exemptions for the use of lindane as a human health pharmaceutical for the control of head lice and scabies as a second-line treatment (decision SC-4/15). Alpha- and beta-HCH are listed in Annex A to the SC without specific exemptions (decisions SC-4/10, SC-4/11) (UNEP, 2020).

11.1.2 Non-dioxin-like polychlorinated biphenyls (ndl-PCBs)

Polychlorinated biphenyls (PCBs) are a group of 209 different congeners[26] that can be divided into two subgroups according to their toxicological properties. Most of the PCB congeners do not exhibit dioxin-like toxicity and are referred to as non-dioxin-like PCBs (European Commission, 2011).

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[26] Congeners are chemical substances related to each other by origin, structure, or function.

PCBs were produced until 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). There were approximately 1.3 to 2 million metric tonnes of PCBs industrially produced in various countries from 1929 to the 1980s (Breivik et al., 2002; Weber et al., 2018a). Technical mixtures of PCBs are represented by six[27], sometimes seven[28] indicator PCB congeners. Maximum levels in food are set for six indicator PCB congeners in food in the EU (European Commission, 2012, 2016).

11.1.3 Polychlorinated naphthalenes (PCNs)

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. PCNs can induce toxic effects typical for dioxin-like compounds, e.g. they have been concluded to be potentially foetotoxic and teratogenic. A number of short and medium term tests prove high acute toxicity, i.e. weight loss, liver damage and delayed deaths at relatively low concentrations (>3mg/kg). Evidence for teratogenic effects and endocrine disrupting effects and effects on fertility have been described in rats. Occupational studies have proven negative effects on human health; some of them were also experienced in animal studies (dermal effects, liver disease, death). Some evidence for an association with the excess of specific cancers has been shown (POP RC, 2012b).

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. None of them exceeded LOQ level in measured samples.

11.1.4 Chlorinated paraffins (CPs)

Chlorinated paraffins (CPs) are complex mixtures of certain organic compounds containing chloride: polychlorinated n-alkanes. Chlorinated paraffins can be subdivided into short chain (SCCP), medium chain (MCCP), and long chain (LCCP) chlorinated paraffins. The global production volumes of MCCPs are nowadays suspected to be much higher than those of S- and LCCPs, and the few available studies on the environmental occurrence of chlorinated paraffins report often higher MCCP than S- or LCCP concentrations in the environment (Glüge et al., 2018).

11.1.4.1 Short chain chlorinated paraffins (SCCPs)

SCCPs were added by governments to the SC for global elimination in 2017. 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 Indonesia. They were often used in the manufacture of wires and cables (POP RC, 2009).

11.1.4.2 Medium chain chlorinated paraffins (MCCPs)

There is a lot of evidence supporting that MCCPs with more than 46% chlorine are persistent and toxic (Glüge et al., 2018). In April 2021, the United Kingdom submitted a proposal to list chlorinated paraffins (CPs) with carbon chain lengths in the range C_{14-17} and chlorination levels at or exceeding 45% chlorine by weight in Annexes A, B and/or C of the Convention (Stockholm Convention, 2024). The available monitoring data generally show widespread occurrence of "MCCPs" in surface water, sediment, soil, biota, sludge and air, in multiple regions of the world, including remote regions. The substance can be widely detected in wildlife including predators, as well as human tissues. Adverse effects observed in rodents' offspring, such as internal hemorrhaging and death, suggest that MCCPs may cause potential adverse effects in mammalian wildlife (POP RC, 2023).

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[27] PCB 28, PCB 52, PCB 101, PCB 138, PCB 153 and PCB 180

[28] PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153 and PCB 180.

11.1.5 Dechlorane Plus (DP)

Dechlorane Plus (DP) is a polychlorinated flame retardant that has been in use since the 1960s. It is used in electrical wire and cable coatings, plastic roofing materials, connectors in TV and computer monitors, and as a non-plasticizing flame retardant in polymeric systems, such as nylon and polypropylene plastic. DP is released to the environment during production, processing and use, as well as from waste disposal and recycling activities. Since the listing of the polybrominated diphenyl ethers (PBDEs) under the SC for global elimination, increased production, use and environmental detection has been seen for DP (Rauert, Schuster et al. 2018).

DP is persistent, i.e. it is chemically stable in various environmental compartments with minimal or no abiotic degradation. It is expected to bind to organic carbon in soil and sediments, reducing its bioavailability for microorganisms and hence the potential for biodegradation. Available scientific data show that DP is also bioaccumulative and is transported to locations far from production sites and places of use. Studies show that DP has adverse effects on the environment and that it can be toxic to mammals and humans. Studies have reported effects such as oxidative damage, indications for neurodevelopmental toxicity and potential for endocrine disruption. The endocrine effects have also been seen in epidemiology studies, where associations between DP and effects on the sex- and thyroid hormone pathways were found (POP RC 2021). DP was listed in Annex A to the SC in 2023 (Stockholm Convention, 2023b).

11.1.6 Brominated flame retardants (BFRs)

11.1.6.1 Polybrominated diphenyl ethers (PBDEs)

Polybrominated diphenyl ethers (PBDEs) are a group of brominated flame retardants that include substances listed in the SC for global elimination such as PentaBDE (2009), OctaBDE (2009) and DecaBDE (2017)[29]. PBDEs are additives mixed into plastic polymers that are not chemically bound to the material and therefore leach into the environment. They have already been identified in samples from other localities in Southeast Asia (Bystriansky et al., 2018; Petrlik et al., 2017; Petrlik et al., 2020).

Photo 11.2: *Brominated flame retardants are used in electronics in large amounts. Electronic waste at an e-waste scrap yard in Agbogbloshie, Ghana. Photo: Martin Holzknecht, Arnika, December 2028.*

PBDEs have adverse effects on reproductive health as well as developmental and neurotoxic effects (POP RC, 2006a, 2007a, 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 been used mainly 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 appli-

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[29] In brackets is the year of listing for each group of the PBDEs.

Photo 11.3: *PBDEs can still be found in a number of products made from e-waste plastic. This children's toy contained them, as did many others collected in Europe in 2018 (Straková et al., 2018). Photo: Markéta Šedivá, independent photographer for Arnika, August 2018.*

ances. As this study examines samples from sites affected by the presence of e-waste and/or by its incineration, all of the mentioned PBDEs were part of the main focus of our investigation.

11.1.6.2 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 behavior 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 SC for global elimination with a five-year specific exemption for use in building insulation that expired for most Parties in 2019 (Stockholm Convention, 2013).

11.1.6.3 Tetrabromobisphenol A (TBBPA)

Tetrabromobisphenol A (TBBPA) is the largest-volume flame retardant used worldwide (Kodavanti & Loganathan, 2019) covering around 60% of the total global BFR market (R. J. Law et al., 2006). While the majority of TBBPA is chemically bonded to the polymer matrix of printed circuit-boards, it is also applied 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 (Abou-Elwafa Abdallah, 2016; POP RC, 2008a). 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 estrogen signalling (Birnbaum & Staskal, 2004; Kitamura et al., 2002). It is also classified as very toxic to aquatic organisms and is on the OSPAR Commission's List of Chemicals for Priority Action due to its persistence and toxicity (OSPAR Commission, 2011).

Recent studies have identified this chemical as "probably carcinogenic to humans" (Grosse et al., 2016; IARC, 2020).

Human exposure studies have revealed dust ingestion and diet as the major pathways of TBBPA exposure in the general population (Abou-Elwafa Abdallah, 2016). However, more recent study concluded that: *"Studies on exposure routes in humans, a combination of detection methods, adsorbent-based treatments and degradation of TBBPA are in the preliminary phase and have several limitations"* (Miao et al., 2023).

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

11.1.6.4 Novel brominated flame retardants (nBFRs)

Six novel BFRs (nBFRs) were chosen for analysis in this study, i.e. 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE), decabromodiphenyl ethane (DBDPE), hexabromobenzene (HBBz), octabromo-1,3,3-trimethylpheny-1-indane (OBIND), 2,3,4,5,6-pentabromoethylbenzene (PBEB) and pentabromotoluene (PBT).

Novel BFRs are a group of chemicals that replaced, in many cases, already restricted BFRs. Different sources list different chemicals among this group, but only some of them are measured in environmental matrices. Studies have shown that nBFRs have become widespread in the environment, including in food, particularly in some Asian countries (Shi et al., 2016). The scientific panel of the EFSA (European Food Safety Authority) suggested that: *“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). The more recent review suggested that: *“The toxicity data of nBFRs show that several nBFRs can cause adverse effects through different modes of action, such as hormone disruption, endocrine disruption, genotoxicity, and behavioral modification”* (Xiong et al., 2019). HBBz, PBEB and PBT have shown bioaccumulation potential in aquatic species from a natural pond in south China (Wu et al., 2011; Xiong et al., 2019).

Decabromodiphenyl ethane (DBDPE) was introduced in the early 1990s as an alternative to DecaBDE in plastic and textile applications (Ricklund et al., 2010). It was used mainly in wire coatings and polystyrene, in both cases as replacement of DecaBDE. This widespread contaminant is a highly hydrophobic compound (Covaci et al., 2011).

The novel brominated flame retardant 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE) was first produced in the 1970s and is used as a replacement for OctaBDEs (Hoh et al., 2005). It has the ability to bioaccumulate and to biomagnify in aquatic food webs (K. Law et al., 2006; Wu et al., 2011). Similar to DecaBDE, the commercial mixture of BTBPE was found to contain brominated dioxins (PBDD/Fs) and/or to support their formation during treatment of ABS plastic (Ren et al., 2017; Tlustos et al., 2010; Zhan et al., 2019).

HBBz has commonly been used for the manufacture of paper, woods, textiles, plastics and electronic goods (Watanabe & Sakai, 2003; Yamaguchi et al., 1988).

PBEB is a flame retardant that was used mainly in the 1970s and 1980s under the name FR-105. It was used in polymers and has been poorly characterized toxicologically, but the substance is a brominated analogue of ethyl benzene, a carcinogen (de Wit et al., 2010; Straková et al., 2018).

PBT is used in polystyrene casings for electronics, ABS plastics and other plastic polymers, and sold under the name FR-105 or Flammex (de Wit et al., 2010; Straková et al., 2018). Studies confirmed histologic changes on laboratory rats (Chu et al., 1987).

OBIND is another replacement for PBDEs that is used in different plastics of electronic products (Straková et al., 2018). There is a little information available on OBIND. It has previously been manufactured by Dead Sea Bromine Group (now ICL Industrial Products) as FR-1808 (de Wit et al., 2010).

11.1.7 Per- and Polyfluoroalkyl Substances (PFASs)

PFASs in 2018 comprised a diverse class of over 4,500 persistent fluorinated chemicals, including PFOS, widely used in packaging, textiles, and plastics (OECD, 2018). Concerns about their environmental prevalence led to international calls for limiting production and developing safer alternatives (Blum et al., 2015). More recently, NIEHS published that PFASs are a group of nearly 15,000 synthetic chemicals, according to a chemicals database maintained by the U.S. Environmental Protection Agency (NIEHS, 2023). In this study, samples were analysed for 31 individual PFAS or their groups. Two major manufacturing methods, electrochemical fluorination (ECF) and telomerisation, produce PFASs. ECF results in complex mixtures, while telomerisation produces purer linear or isopropyl forms (van Hees, 2016).

In animal studies, long-chain PFASs exhibit adverse effects such as liver toxicity, disruption of lipid metabolism, immune and endocrine system disruption, neurobehavioral effects, neonatal toxicity, and tumors (Lau et al., 2007; Post et al., 2012). The European Food Safety Authority (EFSA) significantly reduced the permitted intake of PFOS due to health concerns (EFSA CONTAM, 2018b).

We can encounter PFASs in various consumer items, including single-use paper food packaging, cosmetics or clothing (Dewapriya et al., 2023; Strakova, Brosché, Brabcová, et al., 2023; Strakova, Brosché, Grechko, et al., 2023; Strakova et al., 2021). PFAS remain in the environment for an unknown amount of time (NIEHS, 2023), which is why they are also referred to as 'forever chemicals'.

11.1.7.1 Perfluorooctanesulfonic Acid (PFOS)

PFOS and its salts, listed in the SC, are extremely persistent and associated with cancer, neonatal mortality, developmental delays, and endocrine disruption (Du et al., 2013; Jacquet et al., 2012; Luebker et al., 2005; POP RC, 2006c; Thomford, 2002a, 2002b). In animal studies, PFOS has been shown to cause cancer, neonatal mortality, delays in physical development, and endocrine disruption. PFOS-related substances have been used in the packaging and paper industries in both food packaging and consumer products.

11.1.7.2 Perfluorooctanic Acid (PFOA)

Governments added PFOA to the SC in 2019 for global elimination. PFOA, with diverse uses, is linked to delayed pregnancy, reduced semen quality, and various human health issues (Di Nisio et al., 2018; Fei et al., 2009; Joensen et al., 2009; POP RC, 2016).

11.1.7.3 Perfluorohexane Sulfonate (PFHxS)

PFHxS, used in various applications, was the last of the PFASs substances added to the SC (Stockholm Convention, 2022). It persists in the environment, with exposure primarily through food, water, and consumer products, causing immune system suppression and various health impacts (Ali et al., 2019; POP RC, 2019).

11.2 Unintentionally produced POPs

There is a large group of POPs that are not produced intentionally nor added to any products, but they occur as unintentional by-products at any phase of production of chemicals or disposal (including incineration) of waste containing halogenated compounds. These POPs are listed in Annex C to the SC (Stockholm Convention, 2010). We also polybrominated dioxins (PBDD/Fs) in our study that are not listed in Annex C yet.

Photo 11.4: *U.S. wartime use of defoliant in Vietnam. PCDD/Fs were contaminants of Agent Orange, and they are in high concentrations in eggs from former U.S. military base Bien Hoa (Kudryavtseva et al., 2020). Source of the photo: Britannica, The Editors of Encyclopedia. "Agent Orange". Encyclopedia Britannica, 24 Jun. 2024,* **https://www.britannica.com/science/Agent-Orange**. *Accessed 23 July 2024.*

11.2.1 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 often expressed in total toxic equivalents (TEQ[30]), calculated according to toxic equivalency factors (TEFs) set by a WHO expert panel in 2005 (van den Berg et al., 2006).

Polychlorinated dioxins and furans (PCDD/Fs) are known to be extremely toxic. Numerous epidemiologic 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 altered immune system response among others (Schecter, 2012; White & Birnbaum, 2009). 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).

11.2.2 Dioxin-like polychlorinated biphenyls (dl-PCBs)

Out of 209 congeners, twelve PCB congeners are considered as dioxin-like PCBs (dl-PCBs) for their effects and similar properties to PCDD/Fs (European Commission, 2012; van den Berg et al., 2006). They are suggested to be a part of the total TEQ levels (van den Berg et al., 2006), and this study includes their levels into total PCDD/Fs + dl-PCBs TEQ concentrations.

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

With the broad use of BFRs, the question has arisen about the presence of polybrominated dibenzo-*p*-dioxins and dibenzofurans (PBDD/Fs) in the food chain, as they are found in different environmental compartments (Kannan et al., 2012). The WHO expert panel has concluded that PBDD/Fs 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 et al., 2013).

PBDD/Fs have been known to be potential byproducts of commercial PBDE mixtures since 1986 (Buser, 1986). They were also found to be byproducts of some nBFRs like DBDPE (Brenner & Knies, 1990) or BTBPE (Ren et al., 2017; Zhan et al., 2019). This is similar to PCDD/Fs 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 disposal/recycling processes of flame-retarded consumer products (Kajiwara et al., 2008). PBDD/Fs were also found around an open burning site (Gullett et al., 2010). PBDD/Fs are similar to the 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 as their chlorinated analogues (PCDD/Fs) (Behnisch et al., 2003; Birnbaum et al., 2003; Kannan et al., 2012; Mason et al., 1987; Piskorska-Pliszczyńska & Maszewski, 2014). They can, for example, affect brain development, damage the immune system and fetus, or induce carcinogenesis (Kannan 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 et al., 2003).

Despite this, PBDD/Fs are less regulated than PCDD/Fs and are not currently listed under the SC (Stockholm Convention, 2010), although PCDD/Fs have been listed in Annex C of the Convention since its origin in 2001. Switzerland suggested listing polyhalogenated dioxins (PXDD/Fs), including PBDD/Fs, in Annex C of the SC (POP RC, 2024).

11.2.4 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 byproduct during the production of various chlorinated hydrocarbons or pesticides. In the past, they were produced intentionally as pesticides or technical substances. 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, 2008b).

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[30] The "Toxic Equivalent" (TEQ) scheme weighs the toxicity of the less toxic compounds as fractions of the toxicity of the most toxic TCDD (2,3,7,8-tetrachlordibenzodioxin). Each compound is attributed a specific "Toxic Equivalency Factor" (TEF).

In high doses, HCB is lethal to some animals and, at lower levels, adversely affects their reproductive success. Researchers also found out that HCB, similar to other organochlorinated compounds, has a transplacental transfer (Sala et al., 2001). Reed et al. (2007) 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 moderately toxic to humans, very toxic to aquatic organisms, and may cause long-term adverse effects in the aquatic environment (POP RC, 2007b).

Hexachlorobutadiene (HCBD) occurs as a byproduct during the production of the same chlorinated hydrocarbons as PeCB and HCB. It is also formed unintentionally during 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 (Balmer et al., 2019; Pohl et al., 2001; POP RC, 2012a).

HCBD is toxic after repeated and chronic exposure at low exposure levels (i.e. 0.2 mg/kg). The target organ of toxicity is the kidney; biotransformation to reactive compounds leads to organ toxicity, genotoxicity and carcinogenicity after lifelong dietary exposure conditions (POP RC, 2012a).

12. Annex III: Results of chemical analyses for pooled egg samples

Results of chemical analyses for pooled samples of free-range chicken eggs are summarized in Table 12.1.

Table 12.1: *Results of the analyses for POPs in pooled samples of eggs from various locations in Java, and from Morowali, Sulawesi. Results are in ng/g fat if not marked otherwise.*

Locality	**Bangun**		**Bantar Gebang**						**Karawang**			
Sample ID (eggs)	**Bangun 1**	**BAN-E-1**	**B-EGG-4**	**B-EEG-1**	**EGG-DUMP-SITE**	**BEK-EGG-03/22**	**BEK-EGG-05/22**	**BEK-EGG-04/22; B-EGG-3**	**KAR-EGG-01/22**	**KAR-EGG-1**	**KAR-EGG-3**	**KAR-EGG-2**
Number of eggs in pooled sample	3	3	6	6	2	2	2	4	3	4	4	4
Fat content (%)	13	9.5	21.5	17.8	14.8	16.1	15.5	17.9	14.9	13.8	16.7	13.5
PCDD/Fs (pg TEQ/g fat)	10.8	9.5	3.8	10	14.6	20	19.7	33.9	3.2	11	109	178
dl PCBs (pg TEQ/g fat)	3.1	5.1	2.0	4.3	7.8	7.45	8.4	20.2	1.1	1.7	9.8	34
Total PCDD/F + dl PCBs (pg TEQ/g fat)	13.9	14.6	5.8	14.3	22	27	28	54	4.3	12.7	119	212
PBDD/Fs (pg TEQ/g fat)	< 21.3	NA	NA	NA	NA	NA	NA	NA	12.8	NA	NA	NA
PeCB	1.1	2.2	0.36	1.3	2.1	0.97	0.74	3.1	0.85	0.70	3.5	6.1
HCB	2.7	3.6	0.89	3.9	3.7	40.9	2.0	5.3	1.8	4.6	4.8	15.6

Locality	**Bangun**		**Bantar Gebang**						**Karawang**			
Sample ID (eggs)	**Bangun 1**	**BAN-E-1**	**B-EGG-4**	**B-EEG-1**	**EGG-DUMP-SITE**	**BEK-EGG-03/22**	**BEK-EGG-05/22**	**BEK-EGG-04/22; B-EGG-3**	**KAR-EGG-01/22**	**KAR-EGG-1**	**KAR-EGG-3**	**KAR-EGG-2**
HCBD	< 0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.34	<0.1	<0.10	0.13	<0.10
7 PCB	15.4	16.9	0.62	1.5	16.1	3.5	4.4	10.5	17.8	NA	NA	NA
6 PCB	12.3	14.0	0.62	1.5	14.6	3.2	4.1	6.4	12.9	4.5	5.7	98
13 PCN congeners	NA	NA	NA	NA	NA	NA	NA	NA	NA	<LOQ	<LOQ	2.4
SCCP C_{10}-C_{13}	153	97.2	<50	309	NA	NA	NA	<50	<50	<50	237	69
MCCP C_{14}-C_{17}	NA	NA	<100	2,345	NA	NA	NA	1,921	732	NA	NA	NA
sum HCH	0.9	< LOQ	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
sum DDT	4.3	4.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
sum HBCD	5.2	537.9	<4.2	<4.2	5.0	<4.2	<4.2	<4.2	<4.2	47.6	36.5	39
sum of PBDEs	91.0	1,456	6.3	8.0	31.4	28.4	3.2	9.9	10.2	<LOQ	<LOQ	73
209-BDE (decaBDE)	54.4	1,265	6.3	8.0	26.4	22.6	2.5	9.9	10.2	<1.5	NA	41.5
7 BDE congeners	19.4	32.0	<LOQ	<LOQ	2.2	0.30	0.71	<LOQ	<LOQ	<LOQ	<LOQ	24.9
sum of nBFRs	NA	124.3	3.6	<LOQ	1.0	5.5	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	18.4
sum of DP	NA	NA	<0.3	<0.3	2.7	2.3	<0.3	<0.3	2.0	NA	NA	NA
sum of PFASs (ng/g fw)	26.0	96.5	1.5	1.2	6.4	4.2	1.3	2.8	0.67	0.85	2.3	4.2
PFOA (ng/g fw)	0.39	0.05	<0.006	0.01	0.11	0.01	0.03	0.03	<0.006	0.01	0.01	0.03
PFNA (ng/g fw)	0.81	0.17	0.04	0.04	0.15	0.09	0.05	0.07	0.02	0.02	0.05	0.10
PFOS (ng/g fw)	17.7	92.4	0.86	0.31	4.5	1.9	0.38	1.7	0.36	0.14	0.31	1.1
PFHxS (ng/g fw)	0.06	0.05	0.02	0.08	0.05	0.007	0.02	0.02	0.006	<0.006	<0.006	0.021

Locality	Kendalsari		Morowali	Sumberwuluh	Tangerang		Tropodo		Jakarta	Karawang
Sample ID (eggs)	**KEN-E-1/19**	**KEN 01**	**MWL-EGGS-1**	**SUM-E-1; SUM-E-2**	**TAN-ESIN-01**	**SEM-E-1**	**TROP-E-1**	**Tropodo 1**	**JAK-SUP**	**KAR-EGG-R**
Number of eggs in pooled sample	6	9	3	6	5	3	6	3	6	3
Fat content (%)	14.3	27.4	11.2	14.1	13.7	16.2	13.9	15	9.5	17.4
PCDD/Fs (pg TEQ/g fat)	40.9	49.3	4.9	11.0	20.4	54.2	139.9	200	0.001	0.23
dl PCBs (pg TEQ/g fat)	19.6	35.3	1.1	2.0	7.4	17.6	32.1	32	0.002	0.02
Total PCDD/F + dl PCBs (pg TEQ /g fat)	60	85	6.1	13.0	28	72	172	232	0.003	0.25
PBDD/Fs (pg TEQ/g fat)	0.57	NA	NA	NA	NA	6.9	0.33	< 21.3	NA	NA
PeCB	1.3	1.1	0.43	0.26	NA	3.6	1.7	1.9	<0.1	1.9
HCB	2.5	1.5	1.7	0.58	NA	6.1	4.1	5.5	<0.1	5.0
HCBD	<0.1	<0.1	<0.1	<0.1	NA	<0.1	<0.1	< 0.1	<0.1	2.1
7 PCB	3.7	7.0	0.62	0	NA	3.4	2.9	5.3	0	NA
6 PCB	2.9	5.1	0.50	0	NA	3.4	2.9	4.4	< LOQ	4.8
13 PCN congeners	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.20
SCCP C_{10}-C_{13}	160.1	NA	<50	49.9	NA	152.8	96.6	65	136	151
MCCP C_{14}-C_{17}	NA	NA	<100	NA	NA	NA	NA	NA	NA	NA
sum HCH	< LOQ	< LOQ	< LOQ	< LOQ	NA	4.7	< LOQ	0.8	< LOQ	NA
sum DDT	104.6	59.8	0.69	5.1	NA	3.9	3.4	10.8	< LOQ	NA
sum HBCD	< LOQ	< LOQ	< LOQ	4.5	NA	844.4	< LOQ	< LOQ	< LOQ	< LOQ
sum of PBDEs	149.6	6.2	10.8	8.2	NA	320.8	27,159	65	1.4	< LOQ
209-BDE (decaBDE)	74.7	< 2	8.5	7	NA	76.7	24,610	4.14	<1.0	<5.0

Locality	**Kendalsari**		**Morowali**	**Sumberwuluh**	**Tangerang**		**Tropodo**		**Jakarta**	**Karawang**
Sample ID (eggs)	**KEN-E-1/19**	**KEN 01**	**MWL-EGGS-1**	**SUM-E-1; SUM-E-2**	**TAN-ESIN-01**	**SEM-E-1**	**TROP-E-1**	**Tropodo 1**	**JAK-SUP**	**KAR-EGG-R**
7 BDE congeners	44.6	6.2	0.98	0.97	NA	181.3	142.6	51.7	1.4	<LOQ
sum of nBFRs	12.2	< LOQ	< LOQ	0.87	NA	33.4	2,165	NA	< LOQ	<LOQ
sum of DP	NA	NA	< 0.3	NA	NA	NA	NA	NA	NA	NA
sum of PFASs (ng/g fw)	0.35	NA	NA	0.46	NA	6.2	0.30	2.7	0.1	0.05
PFOA (ng/g fw)	<0.01	NA	NA	0.01	NA	0.27	<0.01	0.10	<0.01	0.007
PFNA (ng/g fw)	0.02	NA	NA	0.02	NA	0.56	0.01	0.12	<0.01	<0.006
PFOS (ng/g fw)	0.14	NA	NA	0.26	NA	2.5	0.14	1.04	<0.01	<0.006
PFHxS (ng/g fw)	<0.01	NA	NA	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.006

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, as well as these 7 BDE congeners: BDE 28, BDE 47, BDE 99, BDE 100, BDE 153, BDE 154, and BDE 183

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