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POPs IN EGGS

from two sites in Kenya

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ARNIKA

CEJAD Centre for Environment Justice and Development

IPEN for a toxics-free future

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Abbreviations

BFRs – brominated flame retardants

BTBPE – 1,2-bis(2,4,6-tribromophenoxy)ethane, one of the nBFRs

DBDPE – decabromodiphenyl ethane, one of the nBFRs

DDT – dichlorodiphenyltrichloroethane

DecaBDE – commercial mixture of Decabromodiphenyl ether

dl-PCBs – dioxin-like polychlorinated biphenyls

DP – dechlorane plus

EFSA – the European Food Safety Authority

EU – the European Union

e-waste – electronic waste

HBB – hexabromobenzene, one of the nBFRs

HBCD – hexabromocyclododecane

HCB – hexachlorobenzene

HCBD – hexachlorobutadiene

HCH – hexacyclohexane

IARC – the International Agency for Research on Cancer

IPEN – the International Pollutants Elimination Network

LPCL – Low POPs Content Level

LOQ – level of quantification

MCCPs – medium-chain chlorinated paraffins

MedWI(s) - medical waste incineration (incinerator; incinerators)

NA – not analyzed

nBFRs – novel BFRs

PBDD/Fs – polybrominated dibenzo-p-dioxins and furans, commonly called "brominated dioxins"

PBDEs – polybrominated diphenyl ethers

PCBs – polychlorinated biphenyls

PCDD/Fs – polychlorinated dibenzo-p-dioxins and furans, usually called dioxins and/or chlorinated dioxins

PeCB - pentachlorobenzene

PFASs – per- and polyfluoroalkyl substances

PFHxS – perfluorohexane sulfonic acid

PFOA – perfluorooctanoic acid

PFOS – perfluorooctane sulfonate

POPs – persistent organic pollutants

SCCPs – short-chain chlorinated paraffins

TDI – tolerable daily intake

TEQ – toxic equivalent (established for calculation of dioxin toxicity levels)

UPOPs – unintentionally produced POPs

WI - waste incinerator

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Executive summary

Medical waste incineration is a major source of unintentionally produced persistent organic pollutants (UPOPs) as well as intentionally produced persistent organic pollutants (POPs) that are destroyed during the incineration process, including dioxins and brominated flame retardants, which pose significant risks to human health and the environment. In Kenya, many waste incinerators are located near homes and agricultural areas, often lacking proper pollution controls and safe ash disposal methods. This study assesses contamination levels in free-range chicken eggs collected near two medical waste incinerators (MedWIs) in Nairobi and Mombasa to evaluate the impact of these facilities on food safety.

Key Findings

Eggs collected near MedWIs contained significantly higher levels of toxic chemicals—including dioxins, PCBs, PFASs, and brominated flame retardants—compared to supermarket reference samples.

Dioxin levels exceeded EU food safety limits by 2–3 times, highlighting serious contamination concerns.

The findings suggest that MedWIs are a major source of contamination for dioxins, brominated flame retardants, and other hazardous chemicals detected in the samples.

Open dumping and burning of waste further contribute to pollution, particularly in Mombasa.

Elevated DDT levels near hospitals suggest localized contamination, likely from medical waste or pesticide use.

Conclusions & Recommendations

1) Strengthen regulations and monitoring of medical waste incinerators, ensuring compliance with strict emission controls.
2) Adopt safer waste management solutions, including non-incineration technologies such as autoclaving and microwave treatment.

3) Improve food safety monitoring, establishing national POPs testing capacity and routine surveillance of food sources.
4) Ensure safe disposal of toxic incinerator ash and remediate contaminated sites.
5) Raise public awareness about POPs exposure risks and promote safer waste handling practices.

This study provides strong evidence that MedWIs contribute to significant environmental contamination and underscores the urgent need for policy action to reduce hazardous emissions, protect food safety, and transition to safer, non-toxic waste management solutions in Kenya.

1. Introduction

Persistent organic pollutants (POPs) are a global concern due to their toxicity, environmental persistence, and ability to bioaccumulate in food chains, posing significant risks to both human health and ecosystems. Among the major sources of unintentionally produced POPs (UPOPs), waste incineration is explicitly listed in Annex C of the Stockholm Convention (Stockholm Convention, 2010). This includes pollutants such as polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs). Medical waste incinerators (MedWIs) often lack the advanced technologies necessary to effectively destroy POPs present in treated waste. Consequently, they can act as sources of contamination, releasing undestroyed POPs into the surrounding environment.

This study focuses on POP contamination in free-range chicken eggs collected near two small MedWIs in Kenya. By analyzing the concentrations of various POPs—including PCBs, HCB, PFASs, and PCDD/Fs—the research provides critical insights into local contamination levels and their implications for human health and environmental management. The findings contribute to global efforts to address POP pollution, particularly under the framework of the Stockholm Convention on POPs.

2. Background of the Study

The challenges posed by POPs are particularly severe in Africa, where inadequate waste management systems, importation of toxic substances, and unsafe disposal practices exacerbate the problem. Medical waste, containing both hazardous and non-hazardous materials, is a significant contributor to these risks (Jelinek, Mochungong, et al., 2023; Kungu et al., 2016; MENR, 2006). In Kenya, the open burning and uncontrolled incineration of waste release various POPs, including polychlorinated biphenyls (PCBs), hexachlorobenzene (HCB), and per- and polyfluoroalkyl substances (PFASs). Additionally, these practices generate UPOPs, such as polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) (MENR, 2006).

The complexity of municipal solid waste (MSW) management, driven by rapid urbanization, compounds these challenges and underscores the need for effective hazardous waste management, particularly in the healthcare sector (Amugsi et al., 2022; MENR, 2006).

The placement and construction of waste incinerators are critical factors influencing their environmental impact.

Photo 1: *Medical waste collection in one of African hospitals. Photo: CEJAD, archive.*

A study by Kungu et al. (2016) found that most waste incinerators in Kenya are located in areas close to human habitation and agriculture. Specifically, 62.5% are situated near farms, while 50% are placed in valleys or ridges, increasing the dispersion of pollutants. Only 37.5% of incinerators were located in wooded areas. Moreover, 62.5% of health centers had protective shelters for their burners, but only half had constructed pits for proper ash disposal. Combustion at these facilities releases harmful chemicals, and the resulting ash often contains heavy metallic pollutants, highlighting the urgent need for stricter regulations and improved waste management practices (Kungu et al., 2016).

Considering these challenges, environmental monitoring is essential for assessing contamination levels and identifying pollution sources. Free-range chicken eggs have proven to be effective bioindicators of POP contamination, as they integrate pollutants from soil, air, and water into the food chain. Studies have consistently shown that eggs collected near pollution hotspots often contain contaminant levels exceeding safety thresholds for human health. This underscores the direct pathways through which environmental pollution impacts human exposure, making eggs a valuable tool for assessing and mitigating environmental risks (Arkenbout, 2014; DiGangi & Petrlik, 2005; Hoogenboom et al., 2006; Jelinek, Mochungong, et al., 2023; Petrlik, Bell, et al., 2022; Pirard et al., 2004; Van Eijkeren et al., 2006).

***Photo 2:** Medical waste incinerator in Kenya.*
Source: ***https://essentialapparatus.co.ke***

3. Persistent Organic Pollutants (POPs)

Persistent Organic Pollutants (POPs) are chemicals that remain in the environment for extended periods, bioaccumulate, and can be transported long distances. These pollutants adversely affect both human health and ecosystems. As of May 2023, the Stockholm Convention on Persistent Organic Pollutants regulates 34 chemicals. The Convention initially targeted 12 substances, known as the "dirty dozen," and has subsequently expanded to include additional chemicals of global concern. The most recent additions, listed in Annex A without specific exemptions, are Methoxychlor, Dechlorane Plus, and UV-328, following decisions made at the eleventh meeting of the Conference of the Parties in May 2023 (Stockholm Convention, 2023a, 2023b, 2023c). Additional chemicals, such as medium-chain chlorinated paraffins (MCCPs), long-chain perfluorocarboxylic acids (PFCAs), and chlorpyrifos, have been identified for potential future action (Stockholm Convention, 2024). Our report examines 18 POPs currently listed under the Stockholm Convention, as well as six novel BFRs and two groups of substances not yet listed: MCCPs and polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs). Additionally, within the group of PFASs, the analysis included certain POPs that are not yet listed under the Stockholm Convention.

Our study categorizes POPs into intentionally and unintentionally produced groups. Intentionally produced POPs include substances used in agriculture as pesticides and in industries such as electronics, automotive, or as plastic additives. Key examples include non-dioxin-like polychlorinated biphenyls (PCBs), which were widely used in electrical equipment and other industrial applications until the 1980s, and short-chain chlorinated paraffins (SCCPs), which are added to plastics and lubricants. Brominated flame retardants (BFRs), such as polybrominated diphenyl ethers (PBDEs), also fall into this category and are associated with reproductive and developmental toxicity. Other flame retardants, such as novel BFRs (nBFRs), are increasingly detected in the environment, posing similar risks. Examples of pesticides include DDT and hexachlorocyclohexane (HCH), with lindane being the gamma isomer of HCH.

Per- and polyfluoroalkyl substances (PFASs), another group of intentionally produced POPs, include chemicals such as

PFOS, PFOA, and PFHxS, which have been linked to health issues including cancer, thyroid dysfunction, and reproductive problems. These substances are widely used in products such as textiles, food packaging, and firefighting foams. PFASs are extremely persistent and bioaccumulate, with primary exposure occurring through contaminated food, water, and consumer products.

Unintentionally produced POPs, which are by-products of industrial processes and waste disposal, also pose significant concerns. These include polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) and dioxin-like polychlorinated biphenyls (dl-PCBs), both of which are highly toxic and associated with serious health effects, such as cancer, diabetes, and immune system disruption. Additionally, polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs) are emerging concerns due to the widespread use of brominated flame retardants, although they are not yet regulated under the Stockholm Convention.

Overall, this study highlights the persistent risks posed by both intentionally and unintentionally produced POPs, underscoring the need for global cooperation to reduce their impact on human health and the environment. A more detailed analysis of POPs and their effects is available in our previous study, which focused on the contamination of eggs and consumer products made from plastics in Kenya (Petrlik et al., 2023), as well as in the report "Toxic Hot Spots in Java" (Petrlik et al., 2020).

4. Materials and methods

We have chosen free-range chicken eggs from the vicinity of two small MedWIs in two cities of Kenya, its capital Nairobi and Mombasa, to follow potential exposure to POPs.

The eggs were collected from three families in each case. Two families live closer to the hospitals (100 meters) in both cases and one in a bit further distance (200 - 300 meters). Samples from those families living closer were mixed and analyzed as pooled samples Nai-eggs-1+3; Mom-eggs-1+3. Also eggs from more distant living family were analyzed in another pooled sample. So, we analyzed 4 pooled samples of eggs in the end. In case of Mombasa, open burning of waste in a custom area could contribute to the contamination of eggs. In Nairobi there was also a small transformer nearby sampling area. Open dumping of waste occurs in the surrounded areas as well.

We also used sample of eggs from supermarket in Nairobi from previous research in order to have reference sample for comparison as suggested in some previous studies (DiGangi & Petrlik, 2005b; Dvorská, 2015; Labunska et al., 2013).

We sampled more eggs from various hens at one site and analyzed them as a pooled sample in order to get more representative results. There was 2 – 6 eggs in each of the pooled samples (see Table 1). This way was proven in previous studies (Arkenbout & Bouman, 2021; DiGangi & Petrlik, 2005b; Grechko et al., 2021; Hogarh et al., 2019; Ismawati et al., 2021; Labunska et al., 2015). The eggs were boiled before their transport to laboratories based in Europe. Samples preparation is described elsewhere (Hegyi et al., 2005; Petrlik, Boontongmai, et al., 2022). The eggs were analyzed for following POPs: polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs)[1], polychlorinated biphenysl (PCBs)[2], polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs)[3], hexachlorobenzene (HCB), pentachlorobenzene (PeCB), hexachlorobutadiene (HCBD), short- and medium-chain chlorinated paraffins

1 Dioxins in short.
2 There were analyzed PCB congeners representing both groups intentionally as well as unintentionally produced ones. First group is represented by six or seven indicator PCB congeners, second is expressed by 12 dioxin-like PCB congeners concentrations in samples.
3 Brominated dioxins in short.

Photos 3 – 8: *Ilustrative photos taken during sampling at sites marked as Nairobi 1, 2, and 3 (photos 3-5) and Mombasa 1,2, and 3 (photos 6-8). Photos by CEJAD.*

(SCCPs and MCCPs), 3 isomers of hexachlorocyclohexane (HCH)[4], 6 isomers of dichlorodiphenyltrichloroethane (DDT), 3 isomers of hexabromocyclododecane (HBCD), polybrominated diphenyl ethers (PBDEs)[5], six novel brominated flame retardants (nBFRs)[6], two isomers of dechlorane plus (DP) and per- and polyfluoroalkyl substances (PFASs)[7]. Their properties, and potential health effects are briefly described in Chapter 3, but they are covered in greater detail in Annex 1 of one of the previous studies from Kenya (Petrlik et al., 2023), Indonesia (Petrlik et al., 2020) or Thailand (Dvorska et al., 2023). For PBDD/Fs, PCDD/Fs, and dioxin-like PCBs (dl-PCBs), only two out of the four pooled free-range chicken egg samples, as well as the supermarket egg sample, were analyzed.

4 Alfa-, beta- and gamma- isomers were analyzed. Gamma isomer is also called as lindane.

5 16 congeners representing commercial mixtures of Penta-, Octa-, and DecaBDE were analyzed.

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

7 17 PFASs and/or their groups were analyzed, including linear (L-PFOS) as well as branched (br-PFOS) perfluorooctane sulfonate isomers, perfluoro-n-octanoic acid (PFOA) and perfluorohexane sulfonic acid (PFHxS).

All samples were analyzed in certified laboratories in Czechia, Netherlands or Germany[8]. Chemical analyses for POPs in these laboratories were described in previous studies (Kalachova et al., 2013; Petrlik, Bell, et al., 2022; Petrlik et al., 2020). Besides chemical analyses, two samples were also subjected to a bioassay analysis for dioxin activity. Two pooled egg samples were sent to the Dutch ISO 17025-certified laboratory, BioDetection Systems (BDS), for cell-based screening analysis using the DR CALUX method, in accordance with the European Standard EC/644/2017. The procedure for the BDS DR CALUX bioassay has been described in detail by Besselink et al. (2004), and it has also been used for a large number of free-range chicken egg samples previously (Jelinek, Behnisch, et al., 2023).

Results of the analyses are summarized in Table 1.

8 Dioxins, brominated dioxins and dl PCBs were analyzed in MAS laboratory based in Muenster, Germany; dioxin-activity by DR CALUX method was measured in BDS Amsterdam, Netherlands; all other POPs were analyzed in University of Chemistry and Technology, Faculty of Food and Biochemical Technology, Department of Food Analysis and Nutrition, based in Prague, Czech Republic.

5. Results

Major results of the analyses of free-range chicken eggs for POPs are summarized in Table 1. Their comparison with results from other countries and from previous studies is discussed in chapter 6. Discussion.

Table 1. *Summary of the results of analyses of chicken eggs from the locations of hospitals in Nairobi and Mombasa for POPs.*

Locality	**Units**	**Nairobi –sup.**	**Nairobi - hospital**		**Mombasa - hospital**	
Sample ID (eggs)		**KE_SUP**	**Nai-eggs-1+3**	**Nai-eggs-2**	**Mom-eggs-1+3**	**Mom-eggs-2**
Number of eggs in pooled sample		6	5	2	4	2
Fat content	%	10.00%	11.18%	9.75%	8.51%	8.59%
PCDD/Fs		0.22	7.94	NA	5.00	NA
dl-PCBs	pg WHO-TEQ/g fat	0.05	4.60	NA	1.66	NA
PCDD/F + dl PCBs		0.27	12.54	NA	6.66	NA
PBDD/Fs		0.043	7.13	NA	4.28	NA
DR CALUX	pg BEQ/g fat	NA	21	NA	18	NA
HCB		<0.1	1.89	0.58	1.44	0.73
PeCB		<0.1	0.70	<0.1	0.26	<0.1
HCBD		0.71	<0.1	<0.1	<0.1	<0.1
7 PCB		11	8.25	4.10	10.77	8.16
6 PCB		8.10	7.03	3.27	9.32	7.21
SCCPs		1441	114	73	<50	108
MCCPs	ng/g fat	NA	5310	165	321	330
sum HCH		<0.1	0.35	<0.1	1.00	<0.1
sum DDT		0.96	70	8.4	218	15.1
sum HBCD		<4.2	<4.2	10.1	<4.2	<4.2
sum of PBDEs		< LOQ	431	52	121	8.1
sum of nBFRs		< LOQ	258	13	158	8.9
sum DP		NA	0.34	6.5	4.9	2.8

Locality	**Units**	**Nairobi –sup.**	**Nairobi - hospital**		**Mombasa - hospital**	
Sample ID (eggs)		**KE_SUP**	**Nai-eggs-1+3**	**Nai-eggs-2**	**Mom-eggs-1+3**	**Mom-eggs-2**
sum of PFASs	ng/g fresh weight	0.34	1.98	2.35	1.23	1.47
L-PFOS		0.06	1.07	0.72	0.50	0.67
br-PFOS		0.014	0.131	0.056	0.086	0.183
PFNA		0.019	0.035	0.161	0.022	0.028
PFOA		<0.01	0.05	0.09	0.02	0.02
PFH_xS		<0.01	0.02	<0.006	0.01	0.02
EFSA 4 PFAS		0.093	1.30	1.03	0.64	0.92

L-PFOS – linear PFOS, br-PFOS – branched PFOS.

6. Discussion: Comparison of egg samples analyses with results from other studies

The analyzed levels of POPs in eggs from the vicinity of waste incinerators in Nairobi and Mombasa exceeded those measured in the reference sample from a supermarket in Nairobi for PeCB, HCB, the sum of HCH, and PFASs by several times. The sample from Nairobi hospital (Nai-eggs-1+3) also showed elevated levels of HBCD, whereas other samples from hospital vicinities did not. Levels of PCDD/Fs, dlPCBs, PBDD/Fs, the sum of DDT, PBDEs, and nBFRs in samples from the vicinity of hospitals were significantly higher than those in the supermarket reference sample. In contrast, levels of HCBD, indicator PCBs, and SCCPs were either lower or comparable to those in the supermarket sample.

Interestingly, SCCPs were an order of magnitude higher in the supermarket reference sample, a phenomenon observed in similar cases and in other countries. However, the situation is different in the case of MCCPs, which were found in a very high concentration of 5,310 ng/g fat in an egg sample from near MedWI in Nairobi. This concentration

***Photo 9:** Sampling near Phuket WI in 2022.*
Photo: Ondrej Petrlik, Arnika.

is significantly higher than the 1,590 ng/g fat measured in an egg sample from the vicinity of the WI on Phuket Island and several times higher than the concentration of 346 ng/g fat found in eggs from a supermarket in Thailand (Jelinek, Behnisch, et al., 2023).

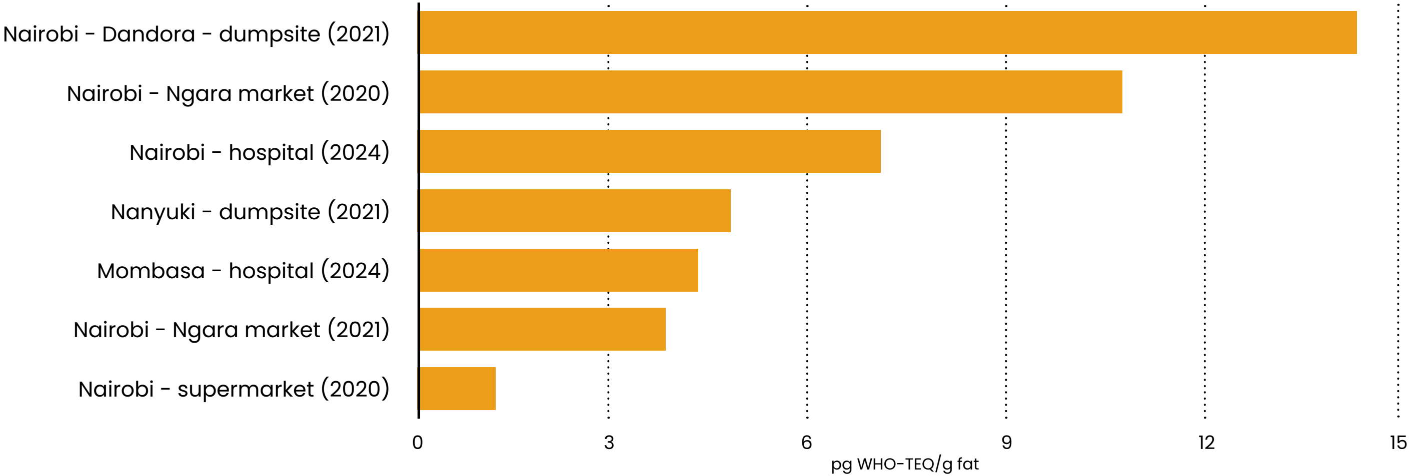
HCB, PeCB, indicator PCBs (7 and/or 6 PCB congeners), the sum of HCH, the sum of DDT, PBDEs, and nBFRs exhibited lower levels in samples collected farther from medical waste incinerators and hospitals in both Nairobi and Mombasa. This suggests that medical waste incinerators are likely sources of contamination with these POPs. While not all of these compounds are unintentionally produced chemicals, they may be present in medical waste. Some UPOPs, such as PCDD/Fs, dl-PCBs, and PBDD/Fs, were measured only in samples collected closer to waste incinerators due to financial limitations of the study. As a result, their levels could not be compared with samples taken from locations farther from medical waste incinerators.

The levels of PCDD/Fs in two free-range egg samples from this study exceeded the EU regulatory limit of 2.5 pg WHO-TEQ/g fat (European Commission, 2016, 2022) by 2–3 times. These levels are comparable to those found in pooled egg samples from the Nanyuki dumpsite but are lower than levels reported in samples from Nairobi – Mirema, the Dandora dumpsite, or Ngara market analyzed in a previous study from Kenya (Ochieng Ochola et al., 2023;

Photo 10: *Dandora dumpsite.*
Photo: Falkue, Creative Commons Wikipedia.

Petrlik et al., 2023). The sum of PCDD/Fs and dl-PCBs was above the EU regulatory limit of 5 pg WHO-TEQ/g fat (European Commission, 2016, 2022) in both analyzed egg samples. The lower level, 6.7 pg WHO-TEQ/g fat, observed in the sample from Mombasa, matched the level measured in eggs from the Nanyuki dumpsite. The higher level, 12.5 pg WHO-TEQ/g fat, observed in the sample from Nairobi, was twice as much. However, these levels were much lower compared to those found in eggs from Ngara market or the Dandora dumpsite in previous studies (Kamande et al., 2005; Ochieng Ochola et al., 2023).

Figure 1: *PBDD/Fs in free range chicken eggs from Kenya and commercial eggs sample from Nairobi, supermarket as reference sample.*



Among the free-range chicken eggs from Kenya analyzed for PBDD/Fs so far, the highest level of 14.4 pg WHO-TEQ/g fat was detected in a sample from the Dandora dumpsite. This was followed by a level of 10.8 pg WHO-TEQ/g fat in eggs collected from Nairobi's Ngara market, an e-waste site (see graph in Figure 1). Another sample in this study, taken near MedWI in Nairobi – a hospital area – showed a measured level of 7.1 pg WHO-TEQ/g fat. Levels in other egg samples from sites at Ngara market, the Nanyuki dumpsite, and Mombasa – hospital were similar, ranging from 3.8 to 4.8 pg WHO-TEQ/g fat (see graph in Figure 1).

These levels were comparable to the 5.6 pg WHO-TEQ/g fat observed in free-range chicken eggs collected near a municipal WI in Phuket, Thailand (Saetang, Wangkiat, Jelinek, Petrlik, & Jopkova, 2024), and higher than the 1.5 pg WHO-TEQ/g fat found in eggs near a hazardous waste incinerator in Aguado, Philippines (Calonzo et al., 2024). Analysis of a reference sample from a supermarket in Nairobi revealed a level of 1.2 pg WHO-TEQ/g fat, which was significantly lower than any of the PBDD/Fs levels measured in free-range chicken eggs from Kenyan hotspots (see graph at Figure 1).

PBDD/Fs can be directly released from plastics containing flame retardants, as they are unintentional contaminants of PBDE and nBFR additives in plastics (Ren et al., 2011; Ren et al., 2017). They can also form during the burning of waste that contains BFRs (Tue et al., 2016). BFRs and PBDD/Fs were also found in consumer products made from recycled e-waste plastic obtained in Kenya in previous studies (Behnisch et al., 2023; Ochieng Ochola et al., 2023).

The concentration of dioxin activity (DR CALUX) in two egg samples in this study was 21 and 18 pg BEQ/g fat, exceeding the sum of concentrations of PCDD/Fs, dl-PCBs, and PBDD/Fs, which were 19.6 and 11 pg WHO-TEQ/g fat, measured instrumentally by high-resolution GC-MS. This suggests that these samples likely contained other dioxin-like substances, possibly including polyhalogenated dibenzo-p-dioxins and furans (PXDD/Fs) or biphenyls (PXBs), which contain both chlorine and bromine, or polybrominated biphenyls (PBBs). This is also supported by the presence of high concentrations of BFRs in both samples (see Table 1).

HCH levels were low in all egg samples in this study. They were below the LOQ in samples from the supermarket and in samples collected farther from both MedWIs. In contrast, DDT levels were elevated in samples from families living closer to both MedWIs. A higher level of 218 ng/g fat was detected in eggs from the vicinity of Mombasa hospital, comparable to the highest level of 231 ng/g fat observed in a previous study in eggs from Ngara market (Petrlik et al., 2023). These levels exceeded DDT levels in eggs from the neighborhood of a dumpsite and an area of pesticide application in Senegal but were significantly lower than the level of 7,041 ng/g fat found in the most contaminated egg sample from a site in Vikuge, Tanzania, all sampled in 2005 (Diouf et al., 2005; Dvorska et al., 2009). The sum of DDT in the egg sample from Mombasa hospital is close to the level of 263 ng/g fat observed in free-range eggs collected in 2006 near a pesticide factory in Porto Romano, Albania (Kleger et al., 2006).

Photo 11: *Ngara market. Photo: James Wakibia.*

With regard to isomers, p,p'-DDT showed a high ratio in both egg samples with elevated sums of DDT. However, the ratio was higher in the sample from the vicinity of the Mombasa hospital, suggesting the potential recent use of DDT either within the hospital and its surroundings and/or in waste contaminated with this pesticide. It could also have been used in chicken feed, but the proximity to MedWIs/hospitals indicates that these are the most likely sources of the contamination of eggs with DDT and its isomers (Dvorska et al., 2009).

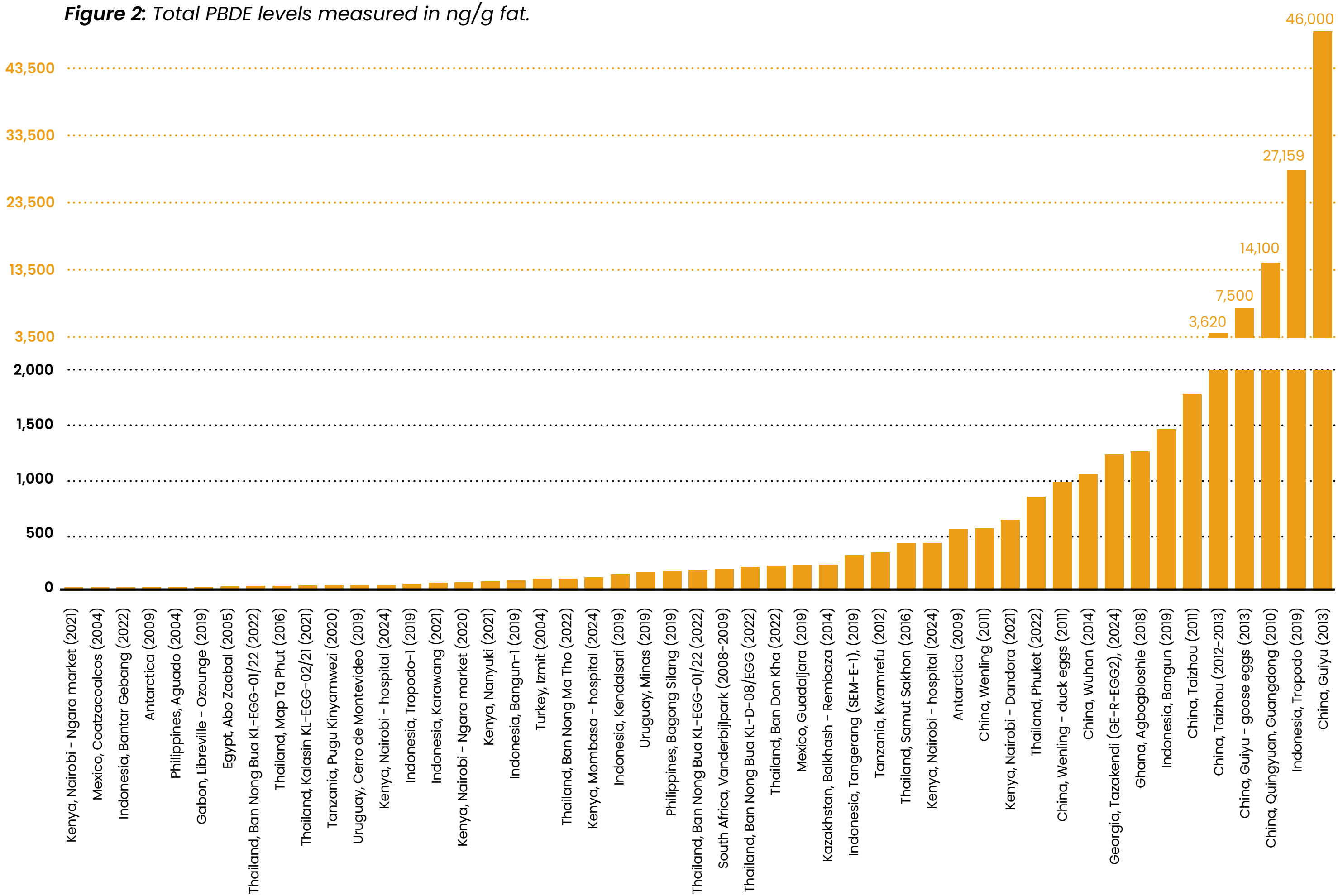
Table 2: *Total PBDE levels measured in poultry eggs globally. Only levels above 30 ng/g fat are included. Samples of eggs of wild birds from Antractica are included for comparison as well. Samples from Africa are highlighted in color.*

Country/locality (year)	Total PBDE in ng/g of fat	Source of information
Kenya, Nairobi - Ngara market (2021)	**31**	(Ochieng Ochola et al., 2023)
Mexico, Coatzacoalcos (2004)	31	(Petrlik et al., 2021)
Indonesia, Bantar Gebang (2022)	31,4	(Petrlik et al., 2024)
Antarctica (2009)	33	(Yogui & Sericano, 2009)
Philippines, Aguado (2004)	34	(Blake, 2005)
Gabon, Libreville - Ozounge (2019)	**36,4**	(Petrlik et al., 2021)
Egypt, Abo Zaabal (2005)	**37**	(Blake, 2005)
Thailand, Ban Nong Bua KL-EGG-01/22 (2022)	44	(Dvorska et al., 2023)
Thailand, Map Ta Phut (2016)	45	(Bystriansky et al., 2018)
Thailand, Kalasin KL-EGG-02/21 (2021)	47	(Dvorska et al., 2023)
Tanzania, Pugu Kinyamwezi (2020)	**49,7**	(Petrlik et al., 2021)
Uruguay, Cerro de Montevideo (2019)	50	(Petrlik et al., 2021)
Kenya, Nairobi - hospital (2024)	**52**	Unpublished data
Indonesia, Tropodo-1 (2019)	65	(Petrlik et al., 2020)
Indonesia, Karawang (2021)	73	(Petrlik, Ismawati, et al., 2022)
Kenya, Nairobi - Ngara market (2020)	**75**	(Ochieng Ochola et al., 2023)

Country/locality (year)	Total PBDE in ng/g of fat	Source of information
Kenya, Nanyuki (2021)	**85**	(Ochieng Ochola et al., 2023)
Indonesia, Bangun-1 (2019)	91	(Petrlik et al., 2020)
Turkey, Izmit (2004)	107	(Blake, 2005)
Thailand, Ban Nong Ma Tho (2022)	108	(Dvorska et al., 2023)
Kenya, Mombasa - hospital (2024)	**121**	Unpublished data
Indonesia, Kendalsari (2019)	150	(Petrlik et al., 2020)
Uruguay, Minas (2019)	164	(Petrlik et al., 2021)
Philippines, Bagong Silang (2019)	177	(Petrlik et al., 2021)
Thailand, Ban Nong Bua KL-EGG-01/22 (2022)	184	(Dvorska et al., 2023)
South Africa, Vanderbijlpark (2008-2009)	**200**	(Quinn, 2010)
Thailand, Ban Nong Bua KL-D-08/EGG (2022)	213	(Dvorska et al., 2023)
Thailand, Ban Don Kha (2022)	222	(Dvorska et al., 2023; Walaska et al., 2024)
Mexico, Guadaljara (2019)	230	(Petrlik et al., 2021)
Kazakhstan, Balkhash - Rembaza (2014)	235	(Petrlik et al., 2017)
Indonesia, Tangerang (SEM-E-1), (2019)	321	(Petrlik et al., 2020)
Tanzania, Kwamrefu (2012)	**347**	(Polder et al., 2016)
Thailand, Samut Sakhon (2016)	427	(Petrlik et al., 2017)
Kenya, Nairobi - hospital (2024)	**431**	Unpublished data
Antarctica (2009)	558	(Yogui & Sericano, 2009)
China, Wenling (2011)	564	(Qin et al., 2011)
Kenya, Nairobi - Dandora (2021)	**639**	(Ochieng Ochola et al., 2023)
Thailand, Phuket (2022)	850	(Saetang, Wangkiat, Jelinek, Petrlik, Bell, et al., 2024)
China, Wenling - duck eggs (2011)	982	(Labunska et al., 2013)
China, Wuhan (2014)	1054	(Petrlik, 2016)

Country/locality (year)	Total PBDE in ng/g of fat	Source of information
Georgia, Tazakendi (GE-R-EGG2), (2024)	1231	Unpublished data
Ghana, Agbogbloshie (2018)	**1258**	(Petrlik et al., 2019)
Indonesia, Bangun (2019)	1457	(Petrlik et al., 2020)
China, Taizhou (2011)	1778	(Labunska et al., 2013)
China, Taizhou (2012-2013)	3620	(Labunska et al., 2014)
China, Guiyu - goose eggs (2013)	7500	(Zeng et al., 2016)
China, Quingyuan, Guangdong (2010)	14100	(Zheng et al., 2012)
Indonesia, Tropodo (2019)	27159	(Petrlik et al., 2021)
China, Guiyu (2013)	46000	(Zeng et al., 2016)

Figure 2: *Total PBDE levels measured in ng/g fat.*



In Table 2 and the graph in Figure 2, the highest concentrations of PBDEs found in free-range poultry eggs from around the world are shown. Concentrations of 431 and 121 ng/g fat of PBDEs in the samples Nai-eggs-1+3 and Mom-eggs-1+3 from the vicinity of MedWIs, analyzed in this study, represent the third and sixth highest concentrations of the sum of PBDEs found in free-range eggs in Africa, and they are also among the highest concentrations in eggs globally. Only concentrations of 1258 and 639 ng/g fat in egg samples from e-waste scrapyards in Agbogbloshie and from the Dandora dumpsite exceeded those from the vicinity of MedWI in Nairobi. Along with the high concentrations of the sum of six nBFRs in both discussed samples, this points to the presence of waste with high concentrations of BFRs, likely from materials treated with these flame retardants. The lower concentrations in samples farther from MedWI also suggest that these small incinerators are probable sources of BFR contamination in eggs. Of the six nBFRs, the highest concentrations measured in the eggs were for BTBPE, at 221 and 111 ng/g fat, followed by concentrations of DBDPE, at 37 and 48 ng/g fat in Nai-eggs-1+3 and Mom-eggs-1+3, respectively. Concentrations of HBBz, OBIND, PBEB, and PBT were lower than the LOQ in all egg samples in this study. HBCD was measured above the LOQ in only one sample from the vicinity of Nairobi hospital.

Levels of the sum of two isomers of DP were not as high as other flame retardants in all eggs, and unlike BFRs, its concentration in samples from the vicinity of Nairobi Hospital increased with distance. Therefore, it is not certain that MedWIs were the main source of contamination by this flame retardant. Its concentration in eggs from an e-waste site in Kalasin Province, Thailand, ranging from below the LOQ to 12.6 ng/g fat, were not much higher (Dvorska et al., 2023; Walaska et al., 2024).

Photo 12: *Sampling in Kalasin Province, Thailand in 2022. Photo: Jindrich Petrlik, Arnika.*

The highest level of PFASs, 2.35 ng/g fresh weight, was measured in eggs from the vicinity of a hospital in Nairobi, but also in samples from families located farther from the hospital. PFAS concentrations in samples from Mombasa were lower than those from Nairobi. At the same time, it cannot be ruled out that the sources of PFAS contamination in the eggs were not limited to emissions or WI residues from MedWIs, as the concentrations of PFAS in samples farther from hospitals were slightly higher. Overall, the concentrations were comparable to those measured in egg samples from Nairobi – Mirema and the Nanyuki dumpsite – but significantly lower than the 6.65 ng/g fresh weight measured in a pooled egg sample from the Ngara market in a previous study from Kenya. The PFAS concentrations in eggs in this study were four to eight times higher compared to the reference sample of supermarket eggs from Nairobi.

7. Conclusions and recommendations

7.1 Conclusions

This study highlights significant contamination of free-range chicken eggs near medical waste incinerators (MedWIs) and hospitals in Nairobi and Mombasa with persistent organic pollutants (POPs) and unintentionally produced POPs (UPOPs). Eggs collected near MedWIs contained levels of PeCB, HCB, HCH, PFASs, PCDD/Fs, dl-PCBs, and brominated flame retardants that were several times higher than those in the supermarket reference sample, underscoring the role of waste incineration in environmental contamination. Open dumping contributes to contamination in both Nairobi and Mombasa, while open burning can serve as an additional source of pollution in Mombasa.

Concentrations of PCDD/Fs in two samples exceeded EU regulatory limits by 2–3 times, with dioxin-like activity suggesting additional unidentified toxic compounds. MCCPs and brominated flame retardants, including PBDEs and novel BFRs, were found in alarmingly high concentrations, pointing to improper disposal or burning of waste containing these substances. Elevated DDT levels near hospitals further suggest localized contamination, likely linked to medical waste or pesticide use.

PBDD/Fs, as unintentional contaminants or by-products of waste incineration involving brominated flame retardants, were found to significantly contribute to the overall dioxin toxicity in samples. Their presence underscores the complexity of toxic emissions from waste incineration and highlights their role in amplifying health risks associated with POPs exposure. Elevated levels of PBDD/Fs in samples near MedWIs call for further research and targeted interventions to minimize their release.

The results emphasize the urgent need for stricter controls on waste incineration practices in Kenya and advocate for the adoption of non-combustion technologies.

7.2 Key Recommendations

Strengthen Regulations & Monitoring

- Enforce **continuous emissions monitoring** and **strict pollution controls** for medical waste incinerators (MedWIs).
- Mandate **independent audits** with public reporting of emissions data.

Adopt Safer Waste Management Technologies

- Scale up **non-incineration methods** (e.g., autoclaving, microwave treatment).
- Assess the performance of **existing microwave technologies** for potential expansion.

Enhance Food Safety & Testing Capacity

- Establish **routine monitoring** of food for POPs, especially from sites near waste dumpsites and incinerators
- Set **clear regulatory limits** for POPs in food.
- Areas that may be **sources of POP contamination** (e.g., dumpsites or waste incinerator ash storage sites) **should be fenced off** to prevent exposure of chickens and other animals.

***Photo 13**: Microwave used for decontamination of medical waste in Kenya. Photo CEJAD, archive.*

Improve Waste Disposal & Site Remediation

- Ensure **safe disposal of toxic incinerator ash**.
- **Remediate contaminated areas** and fence off affected sites to prevent livestock and human exposure .

Increase Public Awareness & Community Action

- Launch **public education campaigns** on POPs risks.
- Empower **community monitoring** to track illegal waste burning.

Secure Policy & Financial Support

- Integrate **safer waste management into national policy** and seek funding from **donors and public-private partnerships**.
- Establish a **multi-stakeholder task force** to oversee implementation.

Photo 14: *Autoclave used for medical waste treatment in Ghana. Photo: Priscilla Mawuena Adjeidu/UNDP Ghana. Source: (UNDP, 2019)*

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