Unsafe by Design:

Banned and Hazardous Chemicals in Plastic Consumer Products in Kenya

May 2026

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Disclaimer:

Abbreviations

ABS	Acrylonitrile Butadiene Styrene (a common plastic)
BFRs	Brominated Flame Retardants
BPA	Bisphenol A
BTBPE	Bis(2,4,6-Tribromophenoxy)Ethane (1,2-Bis(2,4,6-Tribromo-Phenoxy)Ethane)
decaBDE	Decabromodiphenyl Ether
DBDPE	Decabromodiphenylethane
DEHP	Di(2-Ethylhexyl) Phthalate (A Common Plasticizer/Phthalate)
EEE	Electrical and Electronic Equipment (Weee = Waste Eee)
EU	European Union
GC-MS-NICI	Gas Chromatography Coupled to Mass Spectrometry with Negative Chemical Ionisation
HBCDD	Hexabromocyclododecane (Hexabromocyclododecane)
HBBz	Hexabromobenzene
IQ	Intelligence Quotient (standardised measure of cognitive ability)
LMIC	Low- and Middle-Income Countries
LCPL	Low POPs Content Levels (threshold concentrations triggering regulatory action)
nBFRs	Novel Brominated Flame Retardants
NIASs	Non-Intentionally Added Substances
OBIND	Octabromoindane (Octabromo-1,3,3-Trimethyl-1-Phenylindane)
PBDEs	Polybrominated Diphenyl Ethers
PBEB	Pentabromoethylbenzene (2,3,4,5,6-Pentabromoethylbenzene)
PBT	Pentabromotoluene (2,3,4,5,6-Pentabromotoluene)
POPs	Persistent Organic Pollutants
PP	Polypropylene
REACH	Eu Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals
RoHS	Restriction of Hazardous Substances (Directive 2011/65/EU)
SAICM	Strategic Approach to International Chemicals Management
TBBPA	Tetrabromobisphenol A (3,3’,5,5’-Tetrabromobisphenol A)
UHPLC-MS/MS	Ultra-High Performance Liquid Chromatography Interfaced With Tandem Mass Spectrometry
USA	United States of America
WEE	Waste Electrical And Electronic Equipment (e-waste)
XRF	X-Ray Fluorescence

Contents

Executive Summary

This report presents findings from chemical analysis of 55 plastic consumer products collected from the Kenyan market, including toys, infant feeding bottles, sport bottles, snack containers, microwave lids, kitchen utensils, and pencil cases. Products were tested for halogenated flame retardants, bisphenols, and heavy metals.

Banned flame retardants were found in all four black plastic products analysed, including children's toys and a kitchen utensil. Concentrations of BDE–209 and its substitutes DBDPE and BTBPE confirm that recycled e-waste plastics are entering the consumer product chain. Dechlorane Plus, listed under the Stockholm Convention in 2023, was detected in all four tested samples (three toys and one kitchen utensil), representing, to our knowledge, among the first reported detections of this compound in such consumer products globally.

BPA was found in all 27 food contact samples tested, including "BPA-free" labelled infant feeding bottles. Four sports bottles contained BPA at concentrations up to 48,764 ng/g, indicating polycarbonate as the base material. BPS, introduced as a BPA replacement, was co-detected in most samples, illustrating a textbook case of regrettable substitution.

Cadmium was found in a children's pencil case at 766 mg/kg — nearly eight times the EU regulatory limit for cadmium in plastic articles (100 mg/kg under REACH Annex XVII), which represents the most widely applied international standard for this substance in consumer products. Cadmium was also detected in a silicone teat of an infant bottle.

These findings demonstrate that Kenyan consumers, particularly children, are exposed to a toxic chemical cocktail through ordinary product use. In the absence of national chemical safety limits and systematic market surveillance, hazardous products reach consumers undetected.

The Global Plastics Treaty must address hazardous additives with binding restrictions, enforceable limits for recycled plastics, and support for monitoring capacity in low- and middle-income countries. Toxic plastics cannot be made safe by recycling them.

Introduction

The production of novel entities — synthetic chemicals, plastics, and other materials new to the biosphere — has already transgressed one of Earth's planetary boundaries. Global chemical production increased 50-fold since 1950 and is projected to triple again by 2050 compared to 2010 levels, with an estimated 350,000 chemicals or chemical mixtures currently on the global market (Persson, 2022). Plastics alone account for a staggering chemical complexity: recent inventories identify over 16,000 known plastic-associated chemicals, including more than 5,700 additives, 3,500 processing aids, and nearly 1,800 non-intentionally added substances (Monclús, 2025; Cropper, 2024).

Of these, more than 4,200 are classified as chemicals of concern due to their persistence, bioaccumulation potential, mobility, or toxicity (Monclús, 2025). Broader assessments of substances associated with plastics indicate that more than 3,200 out of approximately 7,000 studied chemicals exhibit one or more hazardous properties, including endocrine disruption, carcinogenicity, reproductive toxicity, and neurotoxicity (UNEP, 2023). Over 2,400 substances meet one or more of the EU's persistence, bioaccumulation, and toxicity criteria, and yet many of these remain poorly studied, inadequately regulated, or are even approved for use in food-contact materials in some jurisdictions (Wiesinger et al., 2021).

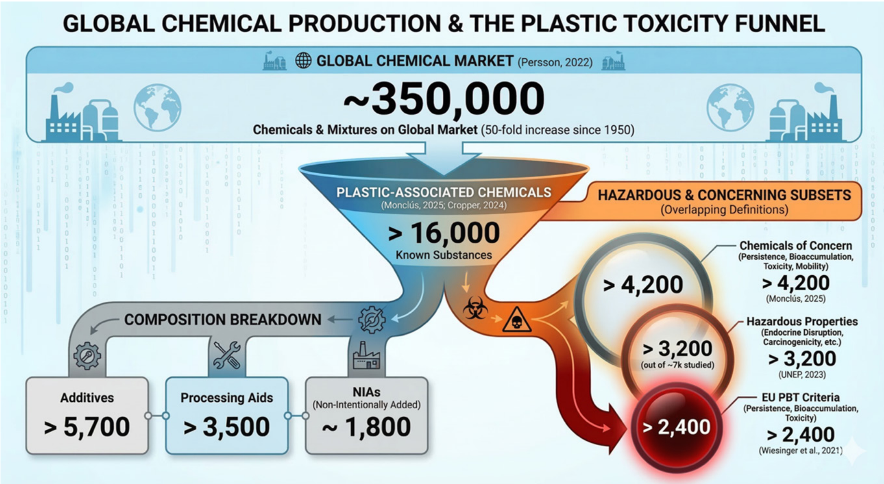


Figure 1. The plastic toxicity funnel: of ~350,000 chemicals on the global market, over 16,000 are associated with plastics, of which more than 4,200 are classified as chemicals of concern and over 2,400 meet EU criteria for persistence, bioaccumulation, and toxicity

Source : Authors

Humans are therefore exposed daily to a complex chemical cocktail using ordinary consumer products. Many chemicals are not chemically bound to the polymer matrix and can be released throughout the plastic lifecycle, resulting in continuous human and environmental exposure (Wiesinger et al., 2021). The health consequences are substantial and often only manifest over the long term, making causal attribution difficult. Three well-characterised plastic-associated chemicals alone — BPA, DEHP, and PBDEs — were linked in 2015 to 5.4 million cases of ischemic heart disease, approximately 164,000 deaths among adults aged 55–64, and the loss of 11.7 million IQ points due to prenatal PBDE exposure, with associated costs estimated at $1.5 trillion (Cropper, 2024).

Beyond general health metrics, endocrine-disrupting chemicals (EDCs) found in plastics—including BPA, phthalates, and brominated flame retardants (BFRs)—pose significant risks to women's reproductive potential. Research indicates that exposure to these widespread contaminants is linked to decreased oestradiol levels, reduced oocyte quality, and lower fertilisation and implantation rates, ultimately affecting clinical pregnancy and live birth outcomes (Karwacka et al., 2017).

PBDEs, as brominated flame retardants, are also associated with disruption of glucose metabolism, thyroid function, and cancer risk (Renzelli, 2023), while phthalates are established endocrine disruptors linked to developmental and prenatal toxicity (Santos, 2025). The global plastics system is estimated to be responsible for a cumulative burden of 83 million DALYs (disability-adjusted life years — a measure combining years of life lost to premature death and years lived with illness or disability) between 2016 and 2040, driven primarily by global warming, air pollution, and the toxic effects of plastic-associated chemicals (Deeney et al, 2026).

Children represent a particularly vulnerable population. Their smaller body size, still-developing organ systems, and behaviours such as mouthing objects result in disproportionately high exposure to toxic substances compared to adults (Santos, 2025). Plastic toys are a primary exposure route: plastics constitute approximately 90% of raw materials used in toy manufacturing today (Santos, 2025), and assessments of chemicals of concern in toy materials have identified hazard quotients of up to 387, with 31 out of 126 identified chemicals of concern showing unacceptable risk levels for children (Aurisano, 2021).

Heavy metals, phthalates, and brominated flame retardants are commonly detected, including in second-hand and recycled toys where legacy additives persist despite regulatory restrictions (Santos, 2025; Lahl & Zeschmar-Lahl, 2024). The risks do not start at birth: prenatal exposure to endocrine-disrupting chemicals has documented effects on foetal development, with implications for lifelong health outcomes (Pettoello-Mantovani et al., 2023). Environmental contamination from improper plastic disposal further compounds the problem, as heavy metals and persistent organic pollutants enter soils, water, and food chains, creating diffuse exposure pathways that are difficult to control or attribute to individual products (Santos, 2025).

Given this heightened vulnerability, food contact materials represent a critical exposure pathway deserving scrutiny. Infant bottles are of special concern as they are used from the earliest stages of life, when developmental sensitivity is greatest, and involve direct contact between plastic and heated liquids — conditions known to accelerate chemical migration. Sports bottles were included as a widely used food contact item among older children and adolescents, allowing comparison across age-relevant products and different use patterns.

It is in this context that the present study examines 55 plastic toys and other plastic consumer products sourced from the Kenyan market, testing for a range of toxic substances including heavy metals, bisphenols, and flame retardants. Many of the products on markets in the Global South are manufactured outside EU regulatory oversight, where gaps in chemical safety requirements remain significant (Santos, 2025), and where both children and adult consumers may be exposed to hazardous substances without any awareness of the risks involved.

International Context and Kenyan Commitments

International agreements establish clear obligations to protect human health and the environment from hazardous chemicals in plastics. This section examines Kenya's commitments under global conventions, compares existing regulatory approaches in high-income countries, and identifies critical gaps in national implementation.

The global community has recognised the hazards of brominated flame retardants through the Stockholm Convention on Persistent Organic Pollutants, which lists DecaBDE[1] , HBCDD, hexabromobiphenyl (HBB), and multiple PBDE congeners in Annex A for elimination. The Basel Convention regulates transboundary movement of hazardous waste, including e-waste containing these substances. Kenya is a signatory to both the Stockholm and Basel Conventions, and is thus formally obligated to prevent banned POPs (BDE-209; HBCDD; DP) from entering production, use, and import, and to control e-waste imports. None of the products in which regulated POPs were detected fall within any specific exemption permitted under the Convention.

However, Kenya's regulatory framework for chemical safety in consumer products presents significant implementation gaps:

- **Limited enforcement**: While Kenya has ratified both (Stockholm and Basel) conventions and has draft e-waste regulations in place, existing management practices remain weak and institutional settings have failed to address the problem effectively (Bimir, 2020). **As this study demonstrates, products containing banned POPs continue to reach the Kenyan market.**
- **E-waste contamination pathway:** Kenya receives substantial quantities of e-waste—approximately 50% of the computer market consists of second-hand imports from EU countries, China, and the USA—which at the end of its life, is predominantly recycled through the informal sector: operators who often have inadequate skills, are neither registered nor authorised, and operate without oversight (Bimir, 2020). **This creates direct pathways for legacy flame retardants to contaminate new consumer products.**
- **Absence of systematic monitoring:** To our knowledge, there is limited systematic surveillance for organic chemical contaminants and plasticiser additives in plastic consumer products. The present study represents an expansion of preliminary screening efforts (Jelinek et al., 2024) but highlights the need for routine regulatory testing.

This regulatory environment, combined with inadequate waste management infrastructure where only 39-45% of total waste is adequately managed (Abahussain et al., 2025), allows Kenya to function as a destination market for products and materials that face stricter controls in other jurisdictions.

1 DecaBDE (commercial decabromodiphenyl ether; predominantly BDE-209) is a brominated flame retardant that historically accounted for approximately 80% of global PBDE market demand (Stapleton et al., 2004). Commercial PBDE mixtures were produced in three main technical grades — pentaBDE (predominantly BDE-47 and -99), octaBDE (predominantly BDE-183), and decaBDE (BDE-209) — each named after the dominant degree of bromination (La Guardia et al., 2006; Stapleton et al., 2004).

Regulatory Comparison: The European Union Framework

The European Union provides the most comprehensive available reference framework for chemical safety in consumer products, though its applicability to the Kenyan context has important limitations. Despite decades of regulatory development, the EU's substance-by-substance approach has proven insufficient to prevent regrettable substitution — banned BFRs are routinely replaced by structural analogues with similar hazard profiles, and 53% of substances of potential concern in toys remain unregulated (Wiesinger et al., 2021). The European Chemicals Agency's move toward group-based restrictions for brominated flame retardants, initiated in 2023, represents a belated acknowledgement of this failure.

For Kenya and other low- and middle-income countries developing chemical safety frameworks, replicating a gradual substance-by-substance trajectory would be neither effective nor efficient; a group-based approach from the outset is preferable (Wiesinger et al., 2021). International cooperation through mechanisms such as the Global Framework on Chemicals remains essential for harmonising standards globally.

Materials and Methods

Samples were selected across multiple product categories to represent realistic consumer exposure pathways, consistent with approaches used in previous studies on chemical additives in consumer plastics (Hahladakis et al., 2018). A total of 55 samples of plastic products were collected and analysed from nine categories: pencil cases (n = 7), sunglasses (n = 2), sport bottles (n = 9), COFFEE cups (n = 2), infant bottles (n = 10), toys (n = 8), kitchen utensils (n = 7), microwave lids (n = 2), and snack containers (n = 8).

Plastic products were collected from the Kenyan market and assigned unique sample identifiers following the convention KE-[product category]-[sequential number], with the prefix KE denoting the country of origin (Kenya). The sampling covered nine product categories selected on the basis of potential chemical exposure relevance.

Black plastic items (toys and kitchen utensils) were specifically targeted within their respective categories given the known association between black plastic colouration and the presence of recycled e-waste-derived plastics containing flame retardants.

Where a single product consisted of multiple physically distinct components — such as a container and its lid — each part was assigned a separate sample identifier and analysed independently (for XRF). Not all samples were subjected to the full analytical panel; subsets were selected for specific analyses (bisphenols, brominated flame retardants) based on product category and anticipated contamination profile, as detailed in the respective analytical sections below.

Analyses

All 55 products were first screened using a handheld X-ray fluorescence analyser (NITON XL3t 800 XRF, Thermo Scientific) to determine total bromine and heavy metal content. Elevated bromine and antimony (Sb) content indicates that plastic may contain brominated flame retardants (Petreas et al., 2016). This XRF screening approach has been successfully applied in previous studies to identify contaminated recycled plastic products (Behnisch et al., 2023; Petrlik et al., 2023). All concentrations are reported in mg/kg.

Based on the XRF screening results, 31 samples were subsequently selected for detailed chemical analysis at the Department of Food Analysis and Nutrition, University of Chemistry and Technology based in Prague, Czech Republic. Groups of PBDEs, HBCDD, nBFRs[2], TBBPA, DP and bisphenols were analysed in the following products:

- **4 samples of black plastics** (kitchen utensils and toys) were analysed for brominated flame retardants including polybrominated diphenyl ethers (PBDEs), novel brominated flame retardants (BTBPE, DBDPE, HBBz, OBIND, PBEB, PBT), DP, hexabromocyclododecane (HBCDD), and tetrabromobisphenol A (TBBPA),

2 nBFRs - for nBFRs in this study we considered BTBPE, DBDPE, HBBz, OBIND, PBEB and PBT.

- **27 samples of transparent and colored plastics** (microwave lids, snack containers, sport and infant bottles, COFFEE cups) were analysed for bisphenol compounds.

The analytical methods used are explained in previous studies (Lankova et al. 2015; Petrlik, et al., 2023). All concentrations are reported in ng/g.

PBDE congeners and GC-amenable novel brominated flame retardants (BTBPE, DBDPE, Dechlorane Plus isomers, HBBz, OBIND, PBEB, and PBT) were determined by gas chromatography coupled to mass spectrometry with negative ion chemical ionisation (GC-MS-NICI). Hexabromocyclododecane diastereomers (α-, β-, and γ-HBCDD) and tetrabromobisphenol A (TBBPA) were analysed by ultra-high performance liquid chromatography coupled to tandem mass spectrometry with electrospray ionisation in negative mode (UHPLC-MS/MS-ESI$^-$). Both instrumental methods followed Lankova et al. (2015), with isotopically labelled internal standards used for quantification and recovery control ($^{13}C_{12}$-PBDE 209, $^{13}C_{12}$-TBBPA, $^{13}C_{12}$-α/β/γ-HBCDD, PBDE-37 and PBDE-77).

Bisphenols (BPA, BPB, BPC, BPE, BPF, BPP, BPS, BPZ, BPAF, BPAP) were extracted three times using a methanol:ethyl acetate mixture (1:1, v/v) with 30-minute ultrasonication and analysed by UHPLC-MS/MS (ESI-).

Quality Assurance and Quality Control Procedural blanks and isotopically-labelled internal standards were used throughout the analytical procedure to control for contamination and compensate for matrix effects. Limits of detection were 0.5–5.0 ng/g for brominated flame retardants and 0.05–0.50 ng/g for bisphenols (expanded uncertainty k = 2, ~95% coverage probability).

All analyses were performed at the Department of Food Chemistry and Analysis, University of Chemistry and Technology in Prague, Czech Republic, an accredited laboratory employing established analytical protocols for persistent organic pollutants (Kalachova et al., 2013; Lankova et al., 2015).

Results

Results of the analysis of consumer products from the Kenyan market are presented by compound group below.

PBDEs

Sixteen PBDE congeners were analysed, covering a range of bromination degrees from tri- to decabromodiphenyl ether: BDE-28, -47, -49, -66, -85, -99, -100, -153, -154, -183, -196, -197, -203, -206, -207, and -209. PBDEs were detected in all four black plastic samples tested.

The congener pattern was dominated by BDE-209, which accounted for the vast majority of total PBDE concentrations across all samples, ranging from 15,745 ng/g (KE-kitchen-black-01) to 43,788 ng/g (KE-toy-black-06-arrow). Sum PBDE concentrations ranged from 17,198 to 47,869 ng/g, see Figure 2.

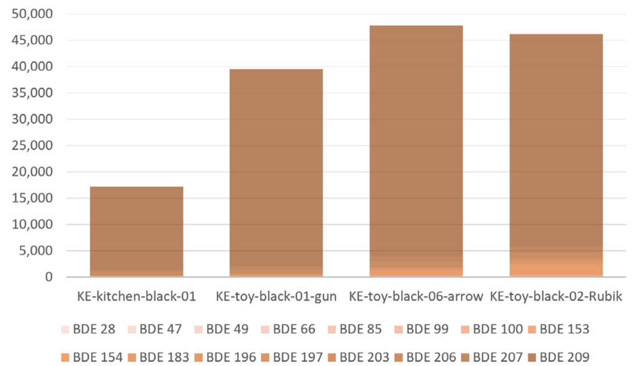


Figure 2. Concentrations of polybrominated diphenyl ethers (PBDEs) including BDE-209 in four black plastic consumer products from the Kenyan market (ng/g dry weight)

BDE-209 was the dominant congener in all samples. Lower-brominated congeners, including BDE-183, -196, -197, -203, -206, and -207, were detected at minor fractions in toy samples, indicative of partial debromination.

In Figure 3, BDE-209 was excluded. Among lower-brominated congeners, BDE-183 was the most prominent, reaching 1,854 ng/g in the Rubik's cube sample (KE-toy-black-02-Rubik), followed by BDE-206, -207, -196, -197 and -153. BDE-47 and -99 were detected at low but quantifiable levels in all samples. BDE-28, -66, -85, -100, and -154 were not detected in any sample.

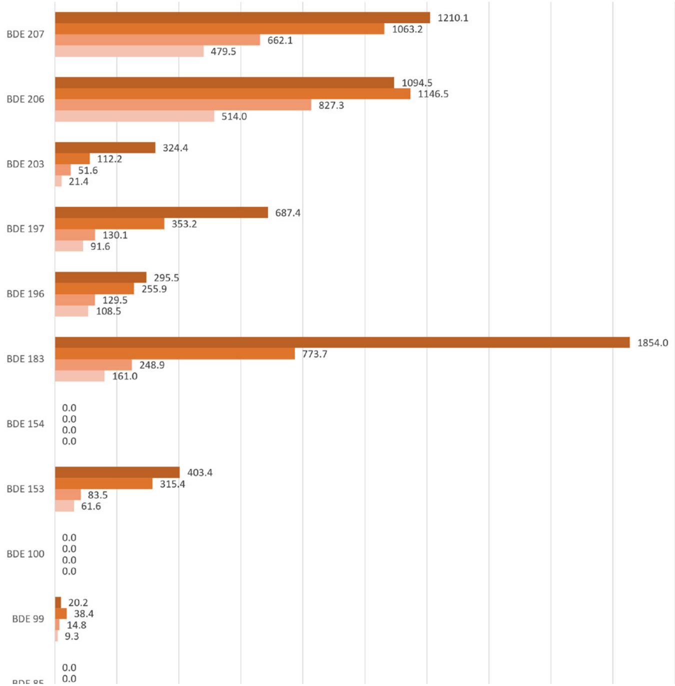


Figure 3. PBDE (excluding BDE-209) congener profiles in four black plastic consumer products from the Kenyan market (ng/g). The congener pattern is dominated by highly brominated homologues (BDE-183, -206, -207), consistent with DecaBDE technical mixture and partial debromination products. BDE-154, -100, -85, -66, -49, and -28 were not detected in any sample

nBFRs

In this study, nBFRs included BTBPE, DBDPE, HBBz, OBIND, PBEB and PBT. This should be taken into account, as the composition of ∑nBFRs may differ among studies, which can affect the comparability of results. BTBPE and DBDPE are presented in a separate figure due to their higher concentrations compared to the other nBFRs.

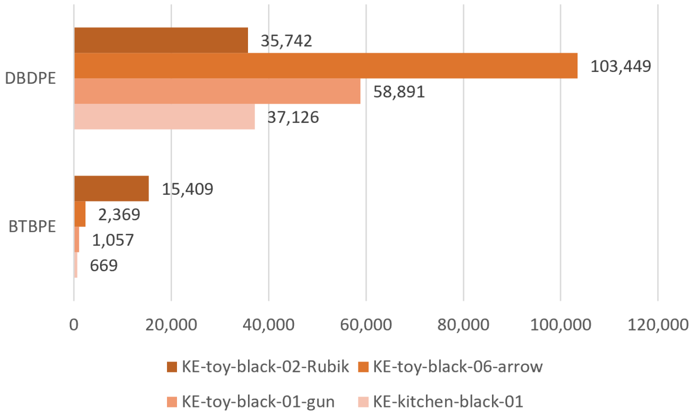


Figure 4. DBDPE and BTBPE concentrations in four black plastic consumer products from the Kenyan market (ng/g). DBDPE dominates in all samples, exceeding BTBPE by one to two orders of magnitude, consistent with its role as the primary commercial replacement for DecaBDE

BTBPE and DBDPE were detected in all four samples at notably high concentrations. Decabromodiphenylethane (DBDPE) was the dominant compound, with concentrations ranging from 35,742 ng/g (KE-kitchen-black-01) to 103,449 ng/g (KE-toy-black-06-arrow). Bis(2,4,6-tribromophenoxy)ethane (BTBPE) was detected at 669–15,409 ng/g, with the highest concentration again in the Rubik's cube sample.

Other novel brominated flame retardants were detected (except PBEB below LOQ in all cases) across all four samples. Hexabromobenzene (HBBz) was detected in all samples at 7.93–32.4 ng/g, and octabromo-1,3,3-trimethyl-1-phenylindane (OBIND) at 54.3–216 ng/g. Pentabromotoluene (PBT) was quantified at low levels (4.44–18.1 ng/g) in all samples.

The total sum of novel BFRs (BTBPE + DBDPE + HBBz + OBIND + PBT) ranged from 37,873 to 106,027 ng/g, exceeding total PBDE concentrations in all four samples.

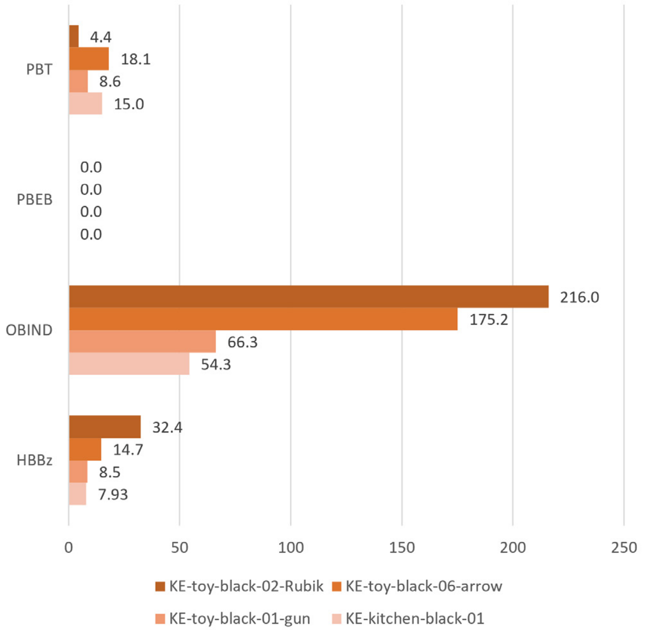


Figure 5. Concentrations of PBT, PBEB, OBIND and HBBz in four black plastic consumer products from the Kenyan market (ng/g). PBEB was not detected in any sample

Dechlorane plus

Dechlorane Plus (DP), reported as the sum of anti-DP and syn-DP isomers, was detected across all four samples at 269–911 ng/g, with the arrow toy (KE-toy-black-06-arrow) showing the highest total DP concentration—approaching the forthcoming EU POPs Regulation limit of 1 mg/kg (1,000 ng/g) for unintentional trace contamination, applicable after a 30-month transition period (from April 2028). The anti-isomer dominated in all samples (see Annex I with all results), which is consistent with the typical isomeric composition of the commercial DP mixture and has been reported previously in plastic consumer products (Behnisch et al., 2023).

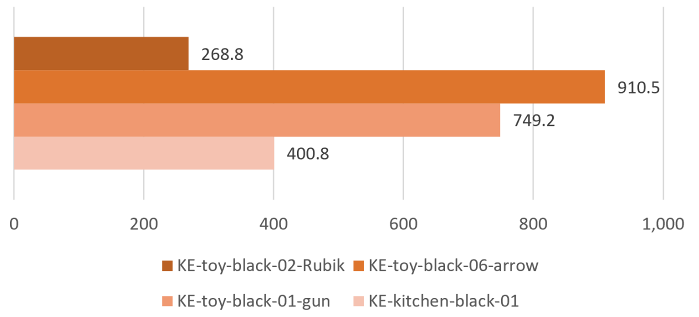
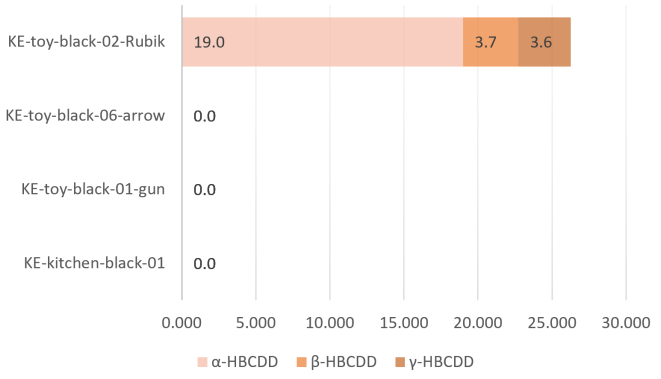


Figure 6. Concentration of Dechlorane Plus (sum of syn- and anti-DP) across four tested samples

HBCDD and TBBPA

HBCDD and TBBPA showed different detection patterns across the four samples. All three HBCDD diastereomers (α-, β-, and γ-) were below the LOQ (2.5 ng/g) in three samples, while the Rubik's cube (KE-toy-black-02-Rubik) contained quantifiable levels of all three isomers, with α-HBCDD dominating at 19.0 ng/g, followed by β-HBCDD (3.73 ng/g) and γ-HBCDD (3.56 ng/g), giving a total HBCDD concentration of 26.3 ng/g. The predominance of the α-isomer is consistent with environmental transformation patterns, where γ-HBCDD (the dominant isomer in technical mixtures) is selectively metabolised to the α-form.

TBBPA was detected in all four samples at considerably higher concentrations than HBCDD, ranging from 851 ng/g (KE-kitchen-black-01) to 32,927 ng/g (KE-toy-black-02-Rubik).



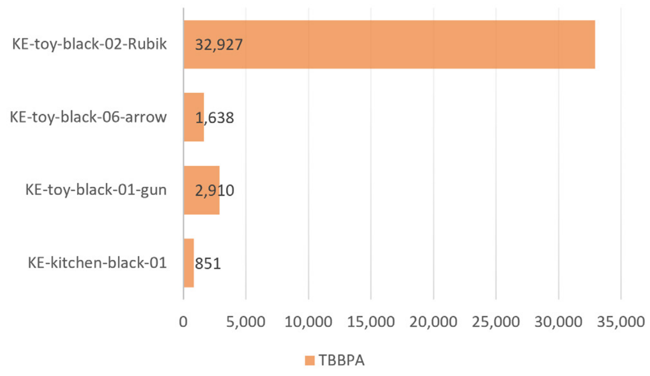


Figure 7 and 8. HBCDD isomer profiles (α-, β-, γ-HBCDD) in four black plastic consumer products from the Kenyan market (ng/g) on the right side. TBBPA concentrations in four black plastic consumer products from the Kenyan market (ng/g). The Rubik's cube (KE-toy-black-02-Rubik) shows markedly elevated TBBPA (32,927 ng/g), exceeding the other three samples by one order of magnitude

Bisphenols

Bisphenols were analysed in 27 of the 55 samples[3] collected for this study, selected to represent product categories with the highest potential for chemical migration into food and beverages: microwave lids (n=2), parts of snack containers or snack containers and a COFFEE cup (n=7; n=1), sport bottles (n=9), and infant feeding bottles (n=9). Of the ten bisphenol congeners included in the analytical panel (BPA, BPB, BPC, BPE, BPF, BPP, BPS, BPZ, BPAF, BPAP), only BPA, BPS, and BPF were detected above their respective LOQs. BPA was found in all 27 samples, BPS in 22 of 27 samples, and BPF in a single sample (KE-bottle-sport-04). All remaining congeners were below the LOQ in all samples.

Infant bottles represent the most sensitive group of consumer products tested. Nevertheless, BPA was detected in all nine infant feeding bottles at concentrations ranging from 3.9 ng/g (KE-bottle-infant-05) to 19.1 ng/g (KE-bottle-infant-01). Notably, four of the infant bottles (KE-bottle-infant-01, -02, -09, and -10) were marketed as "BPA-free," yet all four contained detectable BPA at concentrations ranging from 6.2 ng/g to 19.1 ng/g, including the highest value recorded in this product category. BPS was detected in all but two samples at concentrations between 0.177 ng/g and 0.764 ng/g; two samples were below the LOQ. All other bisphenols (BPB, BPC, BPE, BPF, BPP, BPZ, BPAF, BPAP) were below their respective LOQs in all infant bottle samples.

3 One snack container (KE-container-snack-03) was sampled twice — as the container body and the lid—yielding 28 analytical results from 27 products.

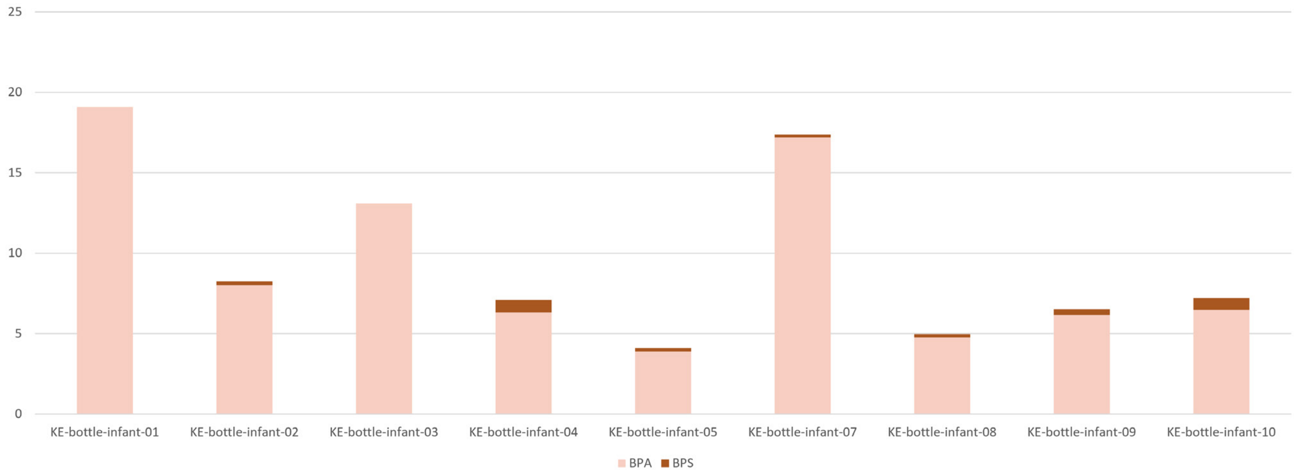


Figure 9. Bisphenol concentrations above the limit of quantification (LOQ) in infant feeding bottles from the Kenyan market (ng/g). BPA was the dominant compound detected across all nine samples. BPS was detected at low levels in several samples. All other congeners were below the limit of quantification

Highest concentrations of bisphenols were found in the sport bottles category. BPA was detected in all nine sport bottles, with concentrations spanning more than four orders of magnitude, from 3.4 ng/g (KE-bottle-sport-03) to 48,764 ng/g (KE-bottle-sport-04). Four bottles showed markedly elevated BPA concentrations: KE-bottle-sport-04 (48,764 ng/g), KE-bottle-sport-05 (20,227 ng/g), KE-bottle-sport-08 (13,812 ng/g), and KE-bottle-sport-09 (15,087 ng/g), while the remaining five bottles ranged from 3.4 to 877 ng/g. BPF was detected in a single sample (KE-bottle-sport-04) at 1.29 ng/g, co-occurring with the highest BPA concentration. BPS was detected in eight of nine bottles at concentrations between 0.373 and 10.4 ng/g. All other bisphenols were below their respective LOQs.

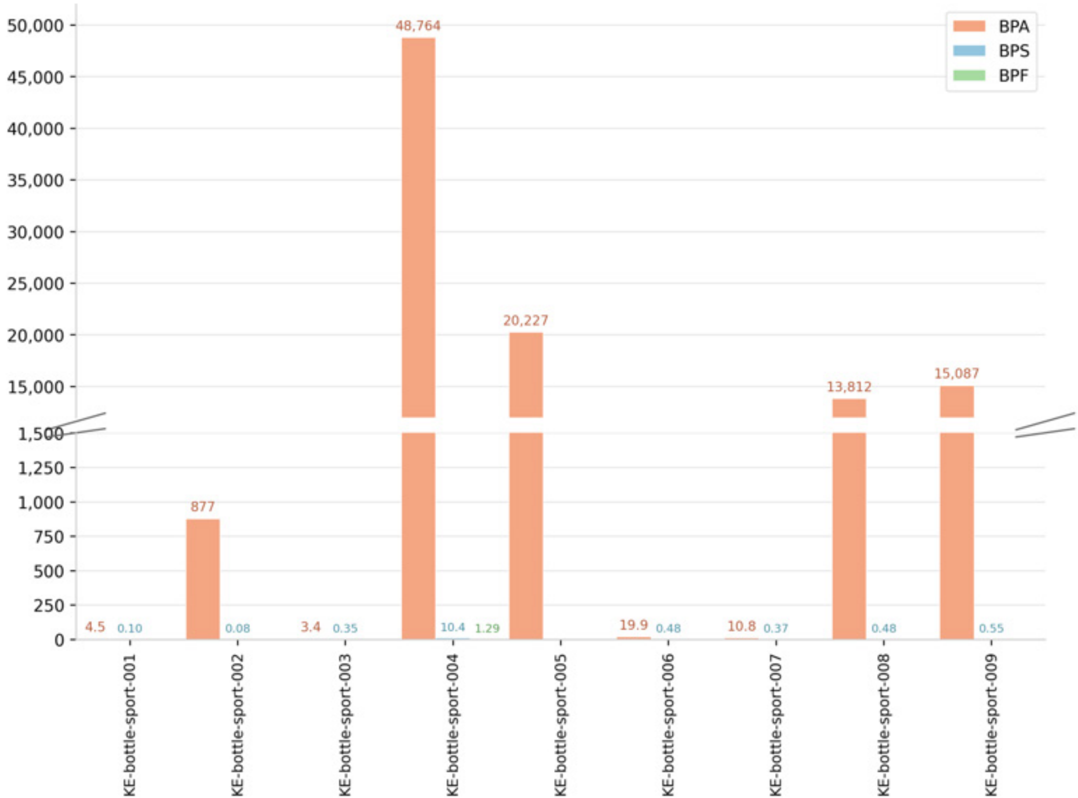


Figure 10. Bisphenol concentrations above the limit of quantification (LOQ) in sport bottles from the Kenyan market (ng/g). Note the truncated y-axis at 1,500 ng/g; five samples (KE-bottle-sport-04, -05, -08, -09) contained BPA at concentrations of 13,812–48,764 ng/g, far exceeding the displayed range. BPS was detected in eight of nine samples as a minor contributor

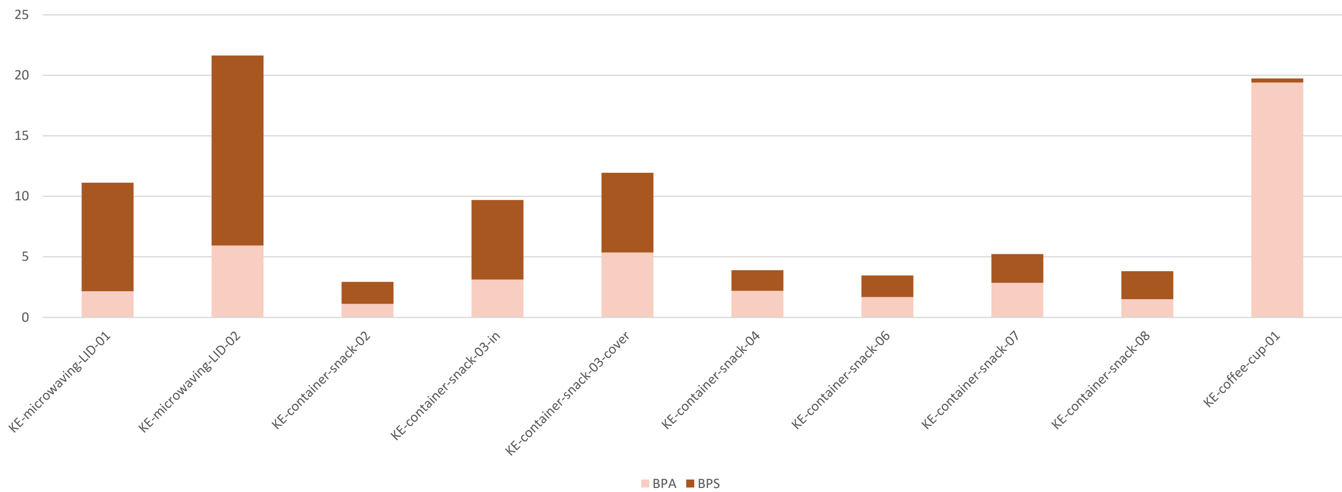


Figure 11. Bisphenol concentrations above the limit of quantification (LOQ) in snack containers, microwave lids, and a COFFEE cup from the Kenyan market (ng/g). BPA and BPS were the only detected congeners. BPS contributions are particularly prominent in the two microwave lids (leftmost bars)

In addition to infant and sport bottles, BPA was detected in all the remaining samples at concentrations ranging from 1.12 ng/g (KE-container-snack-02) to 19.4 ng/g (KE-COFFEE-cup-01). BPS was also detected in all (nine containers and one cup) samples, ranging from 0.334 ng/g (KE-COFFEE-cup-01) to 15.7 ng/g (KE-microwaving-LID-02), with the highest concentrations recorded in the two microwave lids (8.96 and 15.7 ng/g). All other bisphenols were below their respective LOQs.

Heavy metals

XRF screening showed pronounced differences in elemental concentrations among product categories, with children's toys exhibiting the highest levels of potentially hazardous elements. Table 1 presents selected items that displayed elevated concentrations. The most prominent finding was an exceptionally high cadmium (Cd) concentration of 766 mg/kg detected in a children's stationery item. Elevated concentrations of lead (Pb), zinc (Zn), and iron (Fe) were frequently observed across the analysed samples, reaching maximum values of 82.7 mg/kg, 1344 mg/kg, and 4213 mg/kg, respectively.

Table 1: Concentration of heavy metals in selected samples (ppm=mg/kg)

Category/part	Sample	Cr	Ba	Ti	Cl	Sb	Sn	Cd	Pb	Br	Zn	Cu	Ni	Fe
Kitchenware	KE-KITCHEN-black-01	< LOD	1898.99	1401.70	< LOD	79.12	< LOD	< LOD	59.26	181.90	192.51	57.69	< LOD	519.35
Kitchenware	KE-KITCHEN-black-03	185.51	221.03	2490.65	< LOD	<LOD*	< LOD	< LOD	< LOD	28.60	34.31	< LOD	< LOD	< LOD
Infant bottle/ dummy	KE-BOTTLE-infant-04	< LOD	< LOD	< LOD	< LOD	22.77	< LOD	18.88	< LOD	< LOD	185.54	< LOD	< LOD	< LOD
Sunglasses/Glass	KE-SUNGLASS-02	< LOD	1303.64	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	9.09	< LOD	< LOD	< LOD	< LOD
MICROWAVE lid	KE-MICROWAVE-lid-03	< LOD	2080.93	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	13.75	< LOD	42.08	< LOD	< LOD
Children toy/rubik cube	KE-TOY-black-02	< LOD	< LOD	3793.42	< LOD	182.23	< LOD	<LOD*	19.89	548.01	1344.15	<LOD*	< LOD	4212.59
Children toy/bottom	KE-TOY-black-05	< LOD	248.55	< LOD	< LOD	< LOD	< LOD	< LOD	35.47	68.85	151.46	54.48	< LOD	464.33
Children toy/gun	KE-TOY-black-06	< LOD	1274.1	1927.87	< LOD	< LOD	< LOD	< LOD	52.61	157.31	363.56	<LOD*	< LOD	618.74
Children toy/arrows		< LOD	3077.32	< LOD	< LOD	107.09	< LOD	< LOD	82.73	247.56	208.07	<LOD*	< LOD	716.32
Pencil case	KE-PENCIL-case-03	< LOD	443.59	< LOD	360000	< LOD	237.29	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Pencil case/ transparent	KE-PENCIL-case-05	< LOD	< LOD	< LOD	< LOD	219.7	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	22.85	< LOD
Pencil case	KE-PENCIL-case-07	< LOD	1258.52	< LOD	< LOD	< LOD	< LOD	766.48	< LOD	9.40	229.42	<LOD*	< LOD	< LOD
Snack container/lid	KE-CONTAINER-snack-06	< LOD	1264.60	4628.51	< LOD	< LOD	< LOD	< LOD	< LOD	13.11	87.53	< LOD	< LOD	< LOD

*For elements showing inconsistent results across repeated measurements (<LOD vs quantifiable values), the concentration is reported as LOD to ensure conservative data interpretation.

**In some cases, multiple measurements were taken on one sample due to material differences; the tested part is indicated in the first column.

Discussion

PBDEs

PBDEs were detected in all four samples, with ΣPBDEs ranging from 17,198 to 47,869 ng/g (17.2–47.9 mg/kg). BDE-209 was the dominant congener across all samples, accounting for 87–95% of total PBDEs, with concentrations ranging from 15,745 ng/g (KE-kitchen-black-01) to 43,788 ng/g (KE-toy-black-06-arrow). Alongside BDE-209, elevated concentrations of higher brominated congeners including BDE-206, BDE-207, BDE-183, and BDE-197 were observed across all samples, a pattern indicative of partial debromination of DecaBDE during thermal processing or UV exposure, as well as co-contamination from OctaBDE and NonaBDE[4] technical mixtures.

When compared to the broader African and Middle Eastern dataset (Table 2), ΣPBDE concentrations in this study (17.2–47.9 mg/kg) fall within the mid-range, exceeding the minimum values reported for Gabon (0.54 mg/kg) and Syria (3.9 mg/kg), while remaining well below the maxima recorded in Jordan (390 mg/kg), Morocco (315 mg/kg), and Tanzania (332 mg/kg). The concentrations are consistent with the previously reported range for Kenyan consumer products (0.2–279 mg/kg; Petrlik et al., 2023), suggesting no marked increase in PBDE burden in the current sample set, though the limited sample size (n=4) precludes broader conclusions.

In comparison with other published datasets for plastic toys, PBDE concentrations in this study are broadly comparable to those reported for hard plastic toys from South China, where median ΣPBDEs reached 53,000 ng/g (53 mg/kg; Chen et al., 2009), and within the range reported for toys from Belgium, where BDE-209 maxima reached 143 mg/kg (Ionas et al., 2014). They are, however, considerably higher than those found in consumer products from Nigeria, where ΣPBDEs reached up to 23.5 mg/kg and BDE-183 alone reached 14.1 µg/g in a purse handle (Olisah et al., 2024).

Table 2. Comparison of ΣPBDEs concentrations in ppm (mg/kg) in black plastic consumer products from Kenya and selected African and Middle Eastern countries. Source: Petrlik et al., 2023

Country	n	ΣPBDEs	Country	n	ΣPBDEs
Burkina Faso	5	19–111	Kenya	18	0.2–279
Cameroon	5	50–210	Morocco	7	37–315
Egypt	7	17–267	Syria	4	3.9–194
Ethiopia	4	35–149	Tanzania	11	50–332
Gabon	8	0.54–209	Tunisia	10	11–308
Jordan	4	30–390	UK (Fatunsin et al., 2020)	23	NC
Kenya (this study)	4	17.2–47.9			

Sources: Fatunsin et al., 2020; Petrlik et al., 2023; this study. Note: The nBFR panel in this study includes BTBPE, DBDPE, HBBz, OBIND, PBEB, and PBT. NC – not calculated

4 Nona-BDEs are bromodiphenyl ether congeners carrying nine bromine atoms on the diphenyl ether backbone, representing one degree of bromination below deca-BDE (BDE-209). The most commonly occurring nona-BDE congeners are BDE-206, BDE-207, and BDE-208, differing in the positional arrangement of the nine bromine substituents.

Photo 1.: Toy gun with arrows (KE-toy-black-06-arrow) from the Kenyan market. This sample showed the highest total flame retardant burden of all analysed products, with total BFR concentrations reaching 188 mg/kg, dominated by DBDPE and BDE-209

Similar contamination patterns dominated by BDE-209 have been reported in recycled plastic consumer products from Japan, where analysis of 109 items revealed ΣPBDEs ranging across several orders of magnitude, with 34 samples exceeding 1,000 mg/kg and PBDE components predominantly attributed to the technical c-DecaBDE mixture (Kajiwara et al., 2022); the concentrations observed in the present study are comparable to the lowest tier of that dataset. Likewise, a UK-based study by Fatunsin et al. (2020) detected PBDEs in all 23 samples of new and second-hand children's toys, again identifying BDE-209 as the dominant congener with concentrations reaching up to 2,500 mg/kg.

The dominance of BDE-209 and the co-occurrence of higher brominated congeners across all four samples points to recycled plastics originating from waste electrical and electronic equipment (WEEE) as the primary contamination source. This chemical signature is characteristic of legacy ABS plastics from electronic equipment treated with DecaBDE, which subsequently enter recycling streams and are incorporated into new consumer products, including toys (Guzzonato et al., 2017; Ionas et al., 2014). Guzzonato et al. (2017) found that 45% of Br-positive toy and food contact samples exceeded regulatory PBDE limits, with ABS identified as the dominant polymer in non-compliant samples. Fatunsin et al. (2020) attributed similar congener profiles in UK toys to the recycling of BFR-treated electronic plastics, leading to the unintentional contamination of articles not required to be flame-retarded. This explanation is particularly plausible for the Kenyan samples, given the country's well-documented role as a recipient of imported second-hand electronics and plastic waste.

All ΣPBDE concentrations in this study fall below the EU POPs regulation limits applicable to PBDEs in articles (500 mg/kg = 500 000 ng/g). However, since three of the samples were children's toys (a gun, an arrow game, and a Rubik's cube), this represents a direct exposure pathway through dermal contact and potential mouthing behaviour. Ultimately, the detection of regulated POPs in the Kenyan market reflects a systemic global failure to prevent WEEE-derived contaminants from re-entering the consumer product stream. As highlighted in a recent scoping review (Mlelwa & Rother, 2025), widespread PBDE contamination in children's products stems from inadequate regulation of recycled plastics within circular economy frameworks, allowing hazardous legacy chemicals to re-circulate into the most sensitive product categories.

Novel brominated flame retardants

Novel brominated flame retardants (nBFRs) were introduced largely as replacements for regulated PBDEs, yet several raise comparable environmental and health concerns. DBDPE was developed as a structural analogue of DecaBDE, while BTBPE serves as a replacement for OctaBDE. Despite their positioning as safer alternatives, both BTBPE and HBBz have been flagged for bioaccumulation potential, and BTBPE mixtures have been found to contain or promote the formation of brominated dioxins during plastic processing (Petrlik et al., 2023). For most nBFRs, toxicological and environmental data remain insufficient for meaningful risk assessment (Petrlik et al., 2023), making their widespread use in consumer products a concern of regrettable substitution.

DBDPE and BTBPE were the dominant nBFRs detected in all four samples in this study, with total nBFR concentrations ranging from 37.9 to 106.9 mg/kg. Notably, nBFR concentrations exceeded total PBDE concentrations in all samples, suggesting a substantial shift in flame retardant composition. When placed in the context of comparative African and Middle Eastern datasets, the lower range of nBFR concentrations observed in this study is markedly higher than those previously reported for Kenyan consumer products (0.3–412 mg/kg; Petrlik et al., 2023), though the previous dataset exhibited considerably greater variability across a larger sample set (n=18). Across the broader regional dataset, Jordan recorded the highest nBFR maximum (689 mg/kg), followed by Morocco (434 mg/kg) and Tunisia (325 mg/kg), while the lowest nBFR levels were observed in Gabon and Syria. The total BFR burden in this study (56–188 mg/kg) falls within the mid-range of the comparative dataset, below peak values recorded in Jordan (57–1180 mg/kg), Morocco (98–897 mg/kg), and Tunisia (30–608 mg/kg), but comparable to or exceeding several Sub-Saharan African countries including Burkina Faso, Ethiopia, and Tanzania. The elevated nBFR concentrations relative to PBDEs observed across most countries in the dataset, including in this study, likely reflect the continued and growing use of these compounds as substitutes for regulated PBDEs, consistent with broader trends documented across multiple environmental matrices (Xiong, 2019; UNEP, 2023).

Dechlorane Plus

Dechlorane Plus (DP) was detected in all four samples, with total DP concentrations ranging from 268.8 ng/g (KE-toy-black-02-Rubik) to 910.5 ng/g (KE-toy-black-06-arrow). Both isomers were present in all samples, with anti-DP consistently dominant, accounting for 74–78% of total DP, consistent with the composition of commercial DP mixtures. A direct comparison with published data on DP in consumer products is not possible, as peer-reviewed studies reporting DP concentrations in toys, kitchen utensils, or other plastic consumer goods are essentially absent from the literature. While DP has been detected in environmental matrices associated with e-waste recycling, e. g. in Asia (Dvorská, 2023), the transfer of DP into finished consumer products via recycled Waste Electrical and Electronic Equipment (WEEE) plastics has not been systematically studied. This represents a significant monitoring gap, particularly given DP's recent listing under Stockholm Convention Annex A (2023) for global elimination and its known use as a flame retardant in the ABS and PP plastics commonly found in e-waste. The detection of DP across all four samples in this study suggests that consumer product monitoring programs should routinely include DP alongside brominated flame retardants, as the recycling pathways that carry PBDEs into black plastic consumer goods are likely to carry DP as well.

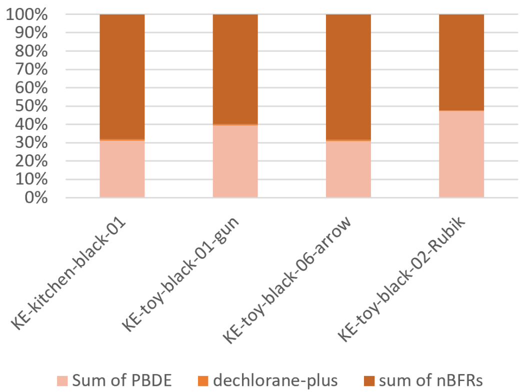


Figure 12. Relative contribution of flame retardant groups to total flame retardant burden in four black plastic consumer products from the Kenyan market (% of sum)

Novel brominated flame retardants (nBFRs: DBDPE, BTBPE, OBIND, PBT, PBEB, HBBz) dominate in all four samples, with similar relative contribution in KE-kitchen-black-01 and KE-toy-black-06-arrow, and the lowest in KE-toy-black-02-Rubik. PBDEs constitute a substantial fraction in all samples. Dechlorane Plus (a chlorinated, non-brominated flame retardant) is present as a minor but consistent component across all four products.

HBCDD

Hexabromocyclododecane (HBCDD) is a non-aromatic additive brominated flame retardant used primarily in expanded and extruded polystyrene foam for thermal insulation, as well as in textiles and electronics. As an additive flame retardant, HBCDD is not chemically bound to the polymer matrix and is therefore prone to leaching into the environment. The three most studied diastereomers are α-, β-, and γ-HBCDD, with γ-HBCDD dominating in technical mixtures, while α-HBCDD predominates in biological samples following environmental transformation. HBCDD was listed under Annex A of the Stockholm Convention in 2013 for global elimination due to its persistence, bioaccumulation, and toxicity (Mlelwa & Rother, 2025; Marques & Cairrao, 2023).

HBCDD was detected only in the Rubik's cube sample (KE-toy-black-02-Rubik) at a total concentration of 26.3 ng/g (0.0263 mg/kg), well below the EU POPs regulation limit of 1,000 mg/kg for HBCDD in articles (Chaine, 2021). The α-isomer dominated, consistent with environmental and biological transformation patterns favouring α-HBCDD accumulation. While concentrations in this study are low compared to those reported in UK toys by Fatunsin et al. (2020), where HBCDD ranged widely from 139 to 840 mg/kg across samples, suggesting considerable variability depending on product type and recycled material source, the detection of a Stockholm Convention-listed POP in a children's toy nonetheless confirms the presence of legacy flame retardants in recycled plastic consumer products on the Kenyan market, highlighting the role of recycling as a pathway for continued human exposure to regulated substances.

Table 3. Comparison of HBCDD concentrations in ppm (mg/kg) in black plastic consumer products from Kenya and selected African and Middle Eastern countries. Source: Petrlik et al., 2023, this study

Country	n	HBCDD	Country	n	HBCDD
Burkina Faso	5	<LOQ–0.3	Kenya	18	<LOQ–1.1
Cameroon	5	<LOQ–1.5	Morocco	7	<LOQ–3.1
Egypt	7	<LOQ–12.5	Syria	4	0.004–0.2
Ethiopia	4	<LOQ–2.5	Tanzania	11	<LOQ–1.8
Gabon	8	<LOQ–4.7	Tunisia	10	<LOQ–49
Jordan	4	<LOQ–1.2	UK (Fatunsin et al., 2020)	23	<LOQ-840
Kenya (this study)	4	<LOQ–0.027			

Sources: Fatunsin et al., 2020; Petrlik et al., 2023; this study.

TBBPA

Tetrabromobisphenol A (TBBPA) is the most widely produced brominated flame retardant globally (Osimitz & Droege, 2025). Unlike additive flame retardants such as PBDEs and HBCDD, TBBPA is primarily used as a reactive flame retardant — chemically bound to the polymer matrix, particularly in printed circuit boards — but is also used additively in plastic housings of electronic equipment, from which it may leach in small amounts (UNEP, 2023). Its widespread use in electronics makes recycled e-waste plastic a primary contamination pathway for consumer products

TBBPA was detected in all four samples at concentrations ranging from 851 ng/g (0.851 mg/kg; KE-kitchen-black-01) to 32,927 ng/g (32.9 mg/kg; KE-toy-black-02-Rubik), making it the dominant compound by mass in the Rubik's cube sample. These concentrations are substantially higher than those reported for a Kenyan toy car in Behnisch et al. (2023) (0.477 mg/kg) and fall within the upper range of values reported for Kenyan consumer products in Petrlik et al. (2023)(0.5–980 mg/kg). Within the broader Behnisch et al. (2023) dataset, TBBPA concentrations in Rubik's-like cubes ranged from 0.897 mg/kg (Indonesia) to 368 mg/kg (Russia), with the Kenyan Rubik's cube in this study (32.9 mg/kg) falling within the mid-range, consistent with the high variability in TBBPA content observed across this product type globally. When placed in the context of the broader African and Middle Eastern comparative dataset (Table 4), Kenya recorded the highest maximum TBBPA concentration across all countries included, with the previous Kenyan dataset reaching 980 mg/kg – exceeding Ethiopia (243 mg/kg), Jordan (186 mg/kg), and Morocco (196 mg/kg).

TBBPA concentrations in this study (0.85–32.9 mg/kg) fall within the lower portion of that Kenyan range, likely reflecting the small and compositionally specific sample set (n=4) rather than an overall decrease in TBBPA use. The detection of TBBPA in a black plastic kitchen utensil is consistent with broader findings of BFR contamination in kitchen products made from recycled plastics (Lahl & Zeschmar-Lahl, 2024), and its presence in toys confirms pathways of children's exposure documented in previous studies (Fatunsin et al., 2020; Chaine, 2021).

Although the TBBPA concentration in the Rubik's cube sample was the highest detected (32,927 ng/g, or approximately 33 mg/kg), it remains significantly below the 1,000 mg/kg (0.1%) threshold allowed for CMR impurities in toys under the Toy Safety

Directive and well under the 2,500 mg/kg (0.25%) threshold for hazardous waste classification under Regulation (EU) 2017/997.

Table 4. Comparison of TBBPA concentrations in ppm (mg/kg) in black plastic consumer products from Kenya and selected African and Middle Eastern countries. Source: Petrlik et al., 2023, this study

Country	n	TBBPA	Country	n	TBBPA
Burkina Faso	5	1.0–14	Kenya	18	0.5–980
Cameroon	5	19–113	Morocco	7	10–196
Egypt	7	0.4–84	Syria	4	0.2–64
Ethiopia	4	1.2–243	Tanzania	11	30–91
Gabon	8	0.4–89	Tunisia	10	3.5–151
Jordan	4	7.3–186	UK (Fatunsin et al., 2020)	23	<LOQ-3100
Kenya (this study)	4	0.85–32.9			

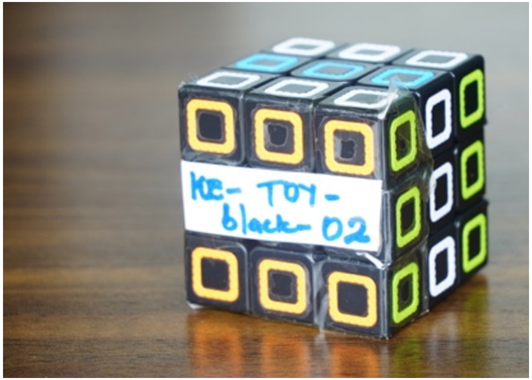


Photo 2. Rubik's cube (KE-toy-black-02-Rubik) from the Kenyan market

This sample contained the highest TBBPA concentration in this study (32,927 ng/g) and was the only sample in which HBCDD was detected.

Bisphenols

BPA was detected in all 27 food contact samples, confirming its continued widespread presence in plastic consumer products on the Kenyan market despite growing international regulatory attention. Concentrations varied markedly across product categories and individual samples, spanning more than four orders of magnitude from 2.940 ng/g to 48,776 ng/g (for the sum of bisphenols). The most striking findings were recorded in four sport bottles (KE-bottle-sport-04, -05, -08, -09), where BPA concentrations ranged from 13,812 to 48,764 ng/g, indicating that these products were manufactured from or contain significant quantities of BPA-based polycarbonate. The co-detection of BPF in KE-bottle-sport-04 (1.29 ng/g) – the sample with the highest BPA concentration – may reflect the use of mixed or transitional polymer formulations. BPS was detected in 25 of 27 samples and was particularly prominent in food containers intended for microwave use (8.96–15.7 ng/g), a pattern consistent with BPS's known use as a BPA replacement in heat-resistant applications.

Photo 3. Green-purple-blue sport bottle (KE-bottle-sport-04) from the Kenyan market, containing BPA at 48,764 ng/g — the highest concentration recorded in this study and indicative of polycarbonate construction

The co-occurrence of BPA and BPS across product categories is noteworthy from a regrettable substitution perspective. BPS has been introduced as a BPA alternative following regulatory pressure on BPA, yet accumulating evidence indicates it exhibits comparable endocrine-disrupting properties, including estrogen receptor binding, thyroid hormone disruption, and persistence in the environment (Ojo et al., 2025; Persson et al., 2022). The simultaneous detection of both compounds in the majority of samples suggests that Kenyan markets receive products from multiple production streams – some still containing BPA, others nominally BPA-free but substituted with BPS – without meaningful regulatory oversight to ensure either is absent.

The universal detection of BPA in Kenyan food-contact samples is particularly concerning for women. BPA and its substitutes (like BPS) have a documented ability to bind to estrogen receptors. In human studies, high concentrations of bisphenols are associated with decreased antral follicle counts and impaired embryo quality, highlighting a direct threat to female fertility within the Kenyan consumer market (Karwacka et al., 2017; Piazza & Urbanetz, 2019)

BPA concentrations in infant feeding bottles (3.9–19.1 ng/g) were among the lowest recorded in this study, yet their detection in products specifically intended for the youngest and most vulnerable age group warrants concern. A systematic review by Ucheana et al. (2024) confirmed that BPA research in Africa remains highly limited, with consumer goods being among the least studied matrices despite maximum concentrations reported up to 3,590,000 ng/g in some African cosmetic and consumer product samples.

BPA and BPS were the only bisphenol congeners detected across the food-contact samples. This pattern is consistent with broader findings in plastic consumer products; Souza et al. (2022), for instance, identified the same two congeners as predominant among ten bisphenol analytes screened in Brazilian plastic toys.

Bisphenols in food contact materials in the EU

In the EU, Bisphenol A (BPA) is banned in polycarbonate baby bottles under Directive 2011/8/EU. Both BPA and BPS are listed as authorised substances for use in plastic food contact materials under Regulation (EU) No 10/2011 (Annex I, FCM No 151 and 154, respectively). The regulatory status of other bisphenol analogues, including BPF, continues to evolve; these substances are not currently included in the European Union [NM2.1]list of authorised substances under Regulation (EU) No 10/2011

Photo 4. Infant feeding bottle KE-bottle-infant-01 (bottom right, green lid) from the Kenyan market, containing detectable BPA at 19.1 ng/g. Products in this category are intended for children under one year of age

Photo 5. Microwave lids KE-microwaving-LID-01 and -02, showing the highest BPS concentrations in this product group (8.96–15.7 ng/g

Heavy metals

The elemental screening of consumer goods from the Kenyan market revealed the presence of several potentially hazardous elements, with cadmium (Cd) showing a markedly elevated concentration in one sample.

Photo 6. Green children's pencil case (KE-PENCIL-case-07) found to contain cadmium at 766 mg/kg, exceeding the REACH limit for cadmium in plastic articles (100 mg/kg)

The highest Cd level (766 mg/kg) was detected in a children's pencil case (KE-PENCIL-case-07), while Cd concentrations in the remaining samples were substantially lower. This value lies within the range reported in an XRF survey of plastic toys from Sri Lanka, where Cd concentrations reached up to 1140.73 mg/kg. Lead (Pb) was detected in several toy samples at moderately elevated concentrations (up to 82.7 mg/kg), which are notably lower than those reported in the Sri Lankan study (Ratnakumar et al., 2017). Although these values represent total Pb content measured by XRF, such concentrations may indicate a potential risk of exceeding the migration limits established by the Toy Safety Directive (2009/48/EC), which sets limits of 13.5 mg/kg for dry materials and 3.4 mg/kg for liquid or sticky materials.

Photo 7. Infant feeding bottle dummy/teat component (KE-bottle-infant-04) from the Kenyan market

Cadmium was detected at 18.9 mg/kg in this component, which comes into direct oral contact with infants.

The presence of bromine (Br) and antimony (Sb) in several toy samples represents a relevant warning signal, as antimony is commonly used as a synergist in brominated flame retardants and may indicate the use of recycled plastics from e-waste streams (Chaine et al., 2022). The co-occurrence of high chlorine (Cl) and detectable tin (Sn) concentration in sample KE-PENCIL-case-03 suggests a PVC-based material, where organotin compounds are typically used as stabilisers (Hahladakis et al., 2018).

It is important to emphasise that XRF screening cannot be directly compared with migration limits set by the Toy Safety Directive (2009/48/EC). XRF measures total elemental content, while compliance is based on migration testing (EN 71-3); however, elevated XRF values may indicate an increased risk and justify further targeted testing.

Sample	Cr	Ba	Ti	Sb	Sn	Cd	Pb	Br	Zn	Cu	Ni	Fe
KE-KITCHEN-black-01	< LOD	1,899	1,402	79.1	< LOD	< LOD	59.3	182	193	57.7	< LOD	519
KE-KITCHEN-black-03	186	221	2,491	< LOD*	< LOD	< LOD	< LOD	28.6	34.3	< LOD	< LOD	< LOD
KE-BOTTLE-infant-04	< LOD	< LOD	< LOD	22.8	< LOD	18.9	< LOD	< LOD	186	< LOD	< LOD	< LOD
KE-SUNGLASS-02	< LOD	1,304	< LOD	< LOD	< LOD	< LOD	< LOD	9.1	< LOD	< LOD	< LOD	< LOD
KE-MICROWAVE-lid-03	< LOD	2,081	< LOD	< LOD	< LOD	< LOD	< LOD	13.8	< LOD	42.1	< LOD	< LOD
KE-TOY-black-02	< LOD	< LOD	3,793	182	< LOD	< LOD*	19.9	548	1,344	< LOD*	< LOD	4,213
KE-TOY-black-05	< LOD	249	< LOD	< LOD	< LOD	< LOD	35.5	68.8	151	54.5	< LOD	464
KE-TOY-black-06a	< LOD	1,274	1,928	< LOD	< LOD	< LOD	52.6	157	364	< LOD*	< LOD	619
KE-TOY-black-06b	< LOD	3,077	< LOD	107	< LOD	< LOD	82.7	248	208	< LOD*	< LOD	716
KE-PENCIL-case-03	< LOD	444	< LOD	< LOD	237	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
KE-PENCIL-case-05	< LOD	< LOD	< LOD	220	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	22.9	< LOD
KE-PENCIL-case-07	< LOD	1,259	< LOD	< LOD	< LOD	766	< LOD	9.4	229	< LOD*	< LOD	< LOD
KE-CONTAINER-snack-06	< LOD	1,265	4,629	< LOD	< LOD	< LOD	< LOD	13.1	87.5	< LOD	< LOD	< LOD

Low 0 — 4,629 ppm High

< LOD = below limit of detection. < LOD* = below LOD but near detection threshold. Values in ppm (mg/kg).

Figure 13. Elemental composition of selected consumer products from the Kenyan market as determined by XRF screening (values in mg/kg). Color intensity reflects relative concentration on a linear scale from 0 to 4,629 mg/kg

Health Implications

Plastic consumer products may contain a range of hazardous chemical additives — including flame retardants, bisphenols, and heavy metal compounds — that are not chemically bound to the polymer matrix and can migrate through mechanical abrasion, ingestion, or contact with acidic media (Hahladakis et al., 2018; Lithner et al., 2011). These findings are of concern given the higher vulnerability of children to chemical exposure, resulting from higher intake relative to body weight, immature detoxification systems, and sensitive developmental stages.

Frequent hand-to-mouth behaviour and mouthing of toys may further increase exposure to substances present in plastic materials (Landrigan & Goldman, 2011). Brominated flame retardants have been associated with adverse neurodevelopmental outcomes and endocrine disruption (Kim et al., 2014). Bisphenols, including BPA and its substitutes, are endocrine-disrupting compounds linked to reproductive harm, thyroid disruption, metabolic dysregulation, and impaired fetal and infant brain development (Bhan et al., 2025; Kania et al., 2024; Cropper et al., 2024; Chen, 2016).

While children are highly vulnerable, women face unique health risks from plastic-associated chemicals. EDCs can interfere with the endocrine system at any life stage. Exposure is linked to the development of polycystic ovary syndrome (PCOS), endometriosis, and uterine leiomyomas (myomas) (Piazza & Urbanetz, 2019). Furthermore, prenatal exposure can disrupt fetal cellular programming, leading to trans-generational health changes that affect future generations.

Heavy metals pose greater health risks to children than to adults, with exposure linked to intellectual disability, neurocognitive and behavioural disorders, respiratory disease, cancer, and cardiovascular conditions (Al Osman et al., 2019).

Crucially, this chemical cocktail also disproportionately affects women's health, with EDCs linked to increased rates of infertility, pregnancy disorders, and hormone-dependent diseases (Karwacka et al., 2017; Piazza & Urbanetz, 2019).

What can you do?

You cannot tell from looking at a plastic product whether it contains harmful chemicals. There is no smell, no colour, no label that warns you. But there are some simple steps that can reduce your exposure and that of your children:

» Avoid heating food in plastic containers, even those labelled microwave-safe. Heat increases the migration of chemicals ,including BPA and BPS, into food. Use glass or ceramic instead.

» Do not let young children mouth or chew plastic toys, particularly older or cheaply made ones. Hand-to-mouth contact is one of the primary exposure routes for flame retardants and heavy metals in children's products.

» Avoid black plastic kitchen utensils and food containers.

- Do not buy black plastic items. Black plastic, including toys, is frequently made from recycled electronic waste and is more likely to contain brominated flame retardants.
- When possible, choose products made from glass or stainless steel for food contact and children's use.

But individual choices are not enough. The chemicals in this study were placed in these products by manufacturers, permitted by absent or unenforced regulations, and distributed through global supply chains. Protecting people from toxic plastics requires political solutions — binding international rules, mandatory testing, and enforcement — not just consumer awareness.

Policy Recommendations

1. Prevent toxic additives from entering recycled plastics and consumer products.

The study confirms that banned persistent organic pollutants (POPs), including DecaBDE, HBCDD, and their structural analogues continue to reach Kenyan consumers through recycled plastics, particularly material derived from Waste Electrical and Electronic Equipment (WEEE). This is not a Kenyan problem — it is a systemic global failure enabled by the absence of binding international rules on what chemicals may be present in plastic products and recycled materials.

The National Environment Management Authority (NEMA) should develop recycling guidelines that prohibit the recycling of plastics containing toxic chemicals into everyday consumer products, including toys and food contact materials.

The Global Plastics Treaty, currently under negotiation, offers a historic opportunity to address this gap. As a country receiving contaminated plastic waste, Kenya is well-positioned—particularly as part of the African Group of Negotiators—to demand treaty provisions that explicitly regulate hazardous chemical additives and prevent the circulation of POPs-contaminated recycled plastics. For the treaty to be meaningful, it must address the whole plastic life cycle and explicitly regulate hazardous chemical additives in plastic products. Leaving unchecked the thousands of chemicals incorporated into plastics would fail to protect human health. The treaty should provide for elimination of hazardous additives in plastic production, ensure traceability of plastic feedstocks used in recycling, and prioritise controls on substances known to persist in recycling loops, including brominated flame retardants, endocrine disruptors, and heavy-metal stabilisers. Toxic plastics cannot become safe through recycling alone.

2. Establish enforceable concentration limits for hazardous chemicals in plastic products, including recycled materials.

Effective chemical safety frameworks require clear and enforceable limits on hazardous substances in plastic articles.

Kenya Bureau of Standards should develop national standards that set the concentration limits of the identified hazardous chemicals in consumer plastic products, preventing the intentional addition, importation of products containing these chemicals and recycling of these chemicals into new products.

The Basel Convention and Global Plastic Treaty should establish low POPs content levels (LPCLs) and other non-POP concentration thresholds applicable to all plastic products, including recycled materials. The regulatory gaps have allowed for POPs-contaminated WEEE plastics to be legally recycled into new consumer products.

Particular protection should be ensured for toys, childcare products, and food-contact materials, where migration of hazardous substances such as brominated flame retardants, bisphenol A, and heavy metal stabilisers presents direct exposure risks. Existing standards such as those under the EU POPs Regulation and related chemical safety frameworks offer a good baseline upon which these limits can be aligned to enhance the protective clauses.

3. Strengthen monitoring and enforcement capacity in Kenya and other low- and middle-income countries.

The study findings highlight a major regulatory gap: limited capacity to detect hazardous chemicals in plastic products entering domestic markets. This has resulted in hazardous products reaching consumers without detection.

To prevent the importation of plastics containing toxic chemicals, the Kenya Bureau of Standards should invest in strengthening the technical capacity and analytical infrastructure for chemical detection and screening.

The treaty should include dedicated provisions for technical assistance, technology transfer, and financial support to enable effective monitoring in low- and middle-income countries. This should include access to practical screening technologies such as handheld XRF analysers for bromine and heavy metals, laboratory testing infrastructure, and training for customs and market surveillance authorities.

4. Control e-waste flows.

A proportion of the plastic contamination documented in this study originates from the recycling of e-waste.

The National Environment Management Authority should develop regulations that prevent the entry of e-waste or EEE that are nearing the end of their useful life into the country, which end up being recycled into consumer products. This requires clear and enforceable criteria for distinguishing functional second-hand electronics from non-functional equipment destined for disposal.

The Basel Convention should strengthen existing controls on transboundary movements of e-waste and plastic waste, particularly shipments falsely labelled as second-hand goods. Improved enforcement mechanisms and clearer definitions of functional second-hand electronics are needed to prevent non-functional equipment from being exported to countries lacking adequate recycling infrastructure.

The informal plastic recyclers in receiving countries must be supported in transitioning toward practices that prevent POPs-contaminated materials from re-entering the consumer product stream.

5. Support Just Transition towards safer recycling systems in informal sectors.

In many countries, including Kenya, informal recycling sectors play a critical role in waste management but often lack the capacity to identify or safely manage plastics containing hazardous additives. Workers in these sectors face direct health risks from exposure to brominated flame retardants, bisphenols, and heavy metals — substances linked to neurodevelopmental harm, endocrine disruption, and increased cancer risk.

In collaboration with NEMA, EEE assemblers, distributors, and recyclers, the Electronic Waste Producer Responsibility Organisation Kenya should implement capacity-building programs aimed at equipping informal sector workers with knowledge and skills for the safe handling, management, and recovery of e-waste contaminated plastics for recycling.

National health and environmental agencies (NEMA and the Ministry of Health) must implement targeted awareness programs for women, especially those in the informal waste sector. These programs should address the impact of EDCs on reproductive health and fertility, ensuring that safety guidelines for plastic handling account for the higher bioaccumulation risks in women due to physiological differences and the critical importance of prenatal health.

The Global Plastics Treaty should include support mechanisms to help transition recycling systems toward safer practices, including improved material sorting, removal of contaminated plastics, protective measures, and safer working conditions. Without such support, POPs-containing plastics from legacy products will continue to circulate in recycled consumer goods — and workers will continue to bear the health burden.

Conclusion

This study documents a troubling mix of hazardous chemicals in everyday plastic products sold on the Kenyan market. These include banned persistent organic pollutants, endocrine-disrupting bisphenols, and toxic heavy metals. Brominated flame retardants (commonly used in electronics), among them BDE-209 and their structural substitutes DBDPE and BTBPE, were detected in all tested black plastic products, suggesting they were made from recycled electronic waste.

Bisphenol A (BPA) was found in every food-contact sample tested, including "BPA-free" labelled infant feeding bottles, while cadmium was detected in a children's pencil case at levels exceeding European Union safety limits. Exposure to heavy metals is especially harmful to children and has been linked to intellectual disability, behavioural and developmental disorders, respiratory disease, cancer, and cardiovascular problems (Al Osman et al., 2019).

No single finding in this study is an isolated anomaly. Collectively, these findings confirm that consumers, especially children, are regularly exposed to a toxic chemical cocktail through the ordinary use of plastic products. This exposure is invisible: there is no warning label, no smell, no visible sign. In many cases, the chemicals are built into the plastic itself, often carried through recycling systems that turn discarded electronics into new consumer goods. Addressing this reality requires action at multiple levels simultaneously.

At the individual level, people can reduce their exposure by avoiding heating food in plastic, limiting children's contact with cheap plastic toys, and choosing glass or stainless steel for food contact use where possible. However, consumer choices alone cannot provide systemic protection. Consumers should not bear the burden of avoiding hazards that originate in manufacturing practices and weak regulation.

Stronger policy action is needed at the national and regional level. Kenya and other countries in the Global South need enforceable chemical safety standards for imported consumer products, mandatory testing at borders and markets, and regulation of informal e-waste recycling to prevent POPs-contaminated materials from re-entering consumer product streams. Regional cooperation on monitoring and enforcement would strengthen the capacity of individual countries to act.

At the global level, the ongoing negotiations for a Global Plastics Treaty offer a critical opportunity to address the chemical safety of plastics through a binding international law. A treaty that does not consider what plastics contain will fail to protect human health.

The treaty must establish restrictions on hazardous additives, close the loopholes that allow POPs-contaminated plastics to be recycled into children's products, support monitoring capacity in low- and middle-income countries, and ensure compliance through transparent reporting and enforcement mechanisms. Toxic plastics cannot be made safe by recycling them — the chemicals must be removed from the production chain altogether.

The evidence from Kenyan markets presented in this report adds to a growing global body of research showing that the plastics crisis is also a chemicals crisis. Solving it requires political will, international cooperation, and a recognition that the right to products free from toxic additives is not a privilege — it is a matter of basic human health.

Annex 1: Complete Results

Table 1: Concentrations of PBDEs in black plastic consumer products collected from the Kenyan market (ng/g)

			Sample name	KE-kitchen-black-01	KE-toy-black-01-gun	KE-toy-black-06-arrow	KE-toy-black-02-Rubik
Analyte	**CAS number**	**LOQ**	**unit**	**black plastic**	**Black plastic**	**Black plastic**	**Black plastic**
PBDE 28	41318-75-6	0.5	ng/g	<0.5	<0.5	<0.5	<0.5
PBDE 47	5436-43-1	0.5	ng/g	6.26	10.3	22.8	21.3
PBDE 49	243982-82-3	0.5	ng/g	<0.5	<0.5	<0.5	<0.5
PBDE 66	189084-61-5	0.5	ng/g	<0.5	<0.5	<0.5	<0.5
PBDE 85	182346-21-0	0.5	ng/g	<0.5	<0.5	<0.5	<0.5
PBDE 99	60348-60-9	0.5	ng/g	9.26	14.8	38.4	20.2
PBDE 100	189084-64-8	0.5	ng/g	<0.5	<0.5	<0.5	<0.5
PBDE 153	68631-49-2	0.5	ng/g	61.6	83.5	315	403
PBDE 154	207122-15-4	0.5	ng/g	<0.5	<0.5	<0.5	<0.5
PBDE 183	207122-16-5	0.5	ng/g	161	249	774	1,854
PBDE 196	446255-39-6	0.5	ng/g	108	130	256	295
PBDE 197	117964-21-3	0.5	ng/g	91.6	130	353	687
PBDE 203	337513-72-1	0.5	ng/g	21.4	51.6	112	324
PBDE 206	63387-28-0	2.5	ng/g	514	827	1,146	1,095
PBDE 207	437701-79-6	2.5	ng/g	480	662	1,063	1,210
PBDE 209	1163-19-5	2.5	ng/g	15,745	37,408	43,788	40,253
Sum of PBDEs				17,198	39,566	47,869	46,164

Table 2: Concentrations of brominated flame retardants (BFRs) in black plastic consumer products collected from the Kenyan market (ng/g)

			Sample name	KE-kitchen-black-01	KE-toy-black-01-gun	KE-toy-black-06-arrow	KE-toy-black-02-Rubik
Analyte	**CAS number**	**LOQ**	**unit**	**black plastic**	**Black plastic**	**Black plastic**	**Black plastic**
BTBPE	37853-59-1	1.0	ng/g	669	1,057	2,369	15,409
DBDPE	84852-53-9	10	ng/g	37,126	58,891	103,449	35,742
HBBz	87-82-1	0.5	ng/g	7.93	8.51	14.7	32.4
OBIND	155613-93-7	5.0	ng/g	54.3	66.3	175	216
PBEB	85-22-3	0.5	ng/g	<0.5	<0.5	<0.5	<0.5
PBT	87-83-2	0.5	ng/g	15.0	8.59	18.1	4.44
Sum of nBFRs				37872.6	60032.0	106026.6	51404.0

Table 3: Concentrations of HBCDDs in black plastic consumer products collected from the Kenyan market (ng/g)

			Sample name	KE-kitchen-black-01	KE-toy-black-01-gun	KE-toy-black-06-arrow	KE-toy-black-02-Rubik
Analyte	**CAS number**	**LOQ**	**unit**	**black plastic**	**Black plastic**	**Black plastic**	**Black plastic**
α-HBCDD	134237-50-6	2.5	ng/g	<2,5	<2,5	<2,5	19.0
β-HBCDD	134237-51-7	2.5	ng/g	<2,5	<2,5	<2,5	3.73
γ-HBCDD	134237-52-8	2.5	ng/g	<2,5	<2,5	<2,5	3.56
Sum of HBCDD				<LOQ	<LOQ	<LOQ	26.277

Table 4: Concentrations of TBBPA in black plastic consumer products collected from the Kenyan market (ng/g)

			Sample name	KE-kitchen-black-01	KE-toy-black-01-gun	KE-toy-black-06-arrow	KE-toy-black-02-Rubik
Analyte	**CAS number**	**LOQ**	**unit**	**black plastic**	**Black plastic**	**Black plastic**	**Black plastic**
TBBPA	79-94-7	10	ng/g	851	2,910	1,638	32,927

Table 5: Concentrations of dechlorane plus (DP) in black plastic consumer products collected from the Kenyan market (ng/g)

			Sample name	KE-kitchen-black-01	KE-toy-black-01-gun	KE-toy-black-06-arrow	KE-toy-black-02-Rubik
			unit	black plastic	Black plastic	Black plastic	Black plastic
Anti-DP	135821-74-8	0.5	ng/g	308	572	706	198
Syn-DP	135821-03-3	0.5	ng/g	92.7	177	205	70.6
Sum of DP				400.8	749.2	910.5	268.8

Table 6: Bisphenol concentrations (ng/g) in microwave lids, snack containers, and a COFFEEe cup collected from the Kenyan market

	KE-microwaving-LID-01	KE-microwaving-LID-02	KE-container-snack-02	KE-container-snack-03-in	KE-container-snack-03-cover	KE-container-snack-04	KE-container-snack-06	KE-container-snack-07	KE-container-snack-08	KE-COFFEEe-cup-01
BPA	2.17	5.94	1.12	3.12	5.36	2.2	1.68	2.85	1.51	19.4
BPB	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
BPC	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
BPE	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
BPF	<0,25	<0,25	<0,25	<0,25	<0,25	<0,25	<0,25	<0,25	<0,25	<0,25
BPP	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
BPS	8.96	15.7	1.82	6.57	6.59	1.7	1.78	2.38	2.3	0.334
BPZ	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
BPAF	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
BPAP	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05

Table 7: Bisphenol concentrations (ng/g) in sport bottles collected from the Kenyan market

	KE-bottle-sport-01	KE-bottle-sport-02	KE-bottle-sport-03	KE-bottle-sport-04	KE-bottle-sport-05	KE-bottle-sport-06	KE-bottle-sport-07	KE-bottle-sport-08	KE-bottle-sport-09
BPA	4.54	877	3.4	48,764	20,227	19.9	10.8	13,812	15,087
BPB	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
BPC	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
BPE	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
BPF	<0,25	<0,25	<0,25	1.29	<0,25	<0,25	<0,25	<0,25	<0,25
BPP	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
BPS	0.105	0.076	0.352	10.4	<0,05	0.485	0.373	0.485	0.546
BPZ	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
BPAF	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
BPAP	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05

Table 8: Bisphenol concentrations (ng/g) in infant feeding bottles collected from the Kenyan market

	KE-bottle-infant-01	KE-bottle-infant-02	KE-bottle-infant-03	KE-bottle-infant-04	KE-bottle-infant-05	KE-bottle-infant-07	KE-bottle-infant-08	KE-bottle-infant-09	KE-bottle-infant-10
BPA	19.1	8.01	13.1	6.33	3.9	17.2	4.76	6.16	6.48
BPB	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
BPC	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
BPE	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
BPF	<0,25	<0,25	<0,25	<0,25	<0,25	<0,25	<0,25	<0,25	<0,25
BPP	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
BPS	<0,05	0.242	<0,05	0.764	0.209	0.177	0.212	0.358	0.735
BPZ	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
BPAF	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
BPAP	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05

Annex 2: List of Samples

Infant Bottles

KE-BOTTLE-infant-01

Name: Infant bottle with green lid
Parts analysed by XRF: Bottle, dummy, screw ring, dummy cover

KE-BOTTLE-infant-02

Name: Infant bottle with light green lid
Parts analysed by XRF: Bottle, dummy, screw ring, dummy cover

KE-BOTTLE-infant-03

Name: Infant bottle with pink screw ring
Parts analysed by XRF: Bottle, dummy, screw ring

KE-BOTTLE-infant-04

Name: Infant bottle with purple lid and handles
Parts analysed by XRF: Bottle, dummy, screw ring, dummy cover

KE-BOTTLE-infant-05

Name: Infant bottle with light blue lid
Parts analysed by XRF: Bottle, dummy, screw ring, dummy cover

KE-BOTTLE-infant-06

Name: Toddler bottle with blue spout and handles
Parts analysed by XRF: Bottle, spout

KE-BOTTLE-infant-07

Name: Toddler bottle with green lid and handles
Parts analysed by XRF: Bottle, lid

KE-BOTTLE-infant-08

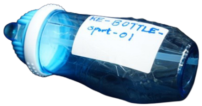
Name: Infant bottle with transparent lid and turquoise screw ring
Parts analysed by XRF: Bottle, lid

KE-BOTTLE-infant-09
Name: Toddler bottle with turquoise lid and handles
Parts analysed by XRF: Bottle, lid, spout

KE-BOTTLE-infant-10
Name: Infant bottle with grey lid and handles
Parts analysed by XRF: Bottle, dummy, screw ring, dummy cover

Port Bottles

KE-BOTTLE-sport-01
Name: Blue sports bottle with flip spout
Parts analysed by XRF: Bottle, lid



KE-BOTTLE-sport-02
Name: Black sports bottle with flip cap
Parts analysed by XRF: Bottle, lid

KE-BOTTLE-sport-03
Name: Black sports bottle with push spout.
Parts analysed by XRF: Bottle, lid

KE-BOTTLE-sport-04
Name: Green–blue sports bottle with flip lid
Parts analysed by XRF: Bottle, lid

KE-BOTTLE-sport-05
Name: Black sports bottle with flip lid
Parts analysed by XRF: Bottle, lid

KE-BOTTLE-sport-06
Name: Green sports bottle with screw cap and carry strap
Parts analysed by XRF: Bottle, lid

KE-BOTTLE-sport-07
Name: Black textured sports bottle with screw lid
Parts analysed by XRF: Bottle, lid

KE-BOTTLE-sport-08
Name: Pink children's sports bottle with flip lid
Parts analysed by XRF: Bottle, lid

KE-BOTTLE-sport-09
Name: Transparent sports bottle with white lid and blue handle
Parts analysed by XRF: Bottle, lid

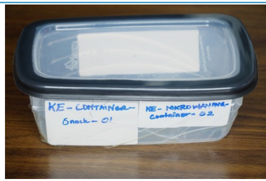
COFFEE Cups

KE-COFFEEE-cup-01
Name: Black reusable COFFEE cup with lid
Parts analysed by XRF: Cup, inside of cup, lid

KE-COFFEEE-cup-02
Name: Black reusable COFFEE cup with lid
Parts analysed by XRF: Cup, inside of cup, lid

Snack Containers

KE-SNACK-container-01
Name: Transparent container with dark lid
Parts analysed by XRF: Container, lid



KE-SNACK-container-02
Name: Blue lunch box with transparent lid and yellow clips
Parts analysed by XRF: Container, lid

KE-SNACK-container-03
Name: Small blue snack box with hinged lid
Parts analysed by XRF: Container, inside part, lid

KE-SNACK-container-04
Name: Mint lunch box with side clips
Parts analysed by XRF: Container, lid

KE-SNACK-container-05
Name: Round yellow snack container with white lid and handle
Parts analysed by XRF: Container, lid

KE-SNACK-container-05

Name: Round yellow snack container with white lid and handle
Parts analysed by XRF: Container, lid

KE-SNACK-container-07

Name: Transparent round container with green lid
Parts analysed by XRF: Container, lid

KE-SNACK-container-08

Name: Transparent container with white lid
Parts analysed by XRF: Container, lid

Kitchenware

KE-KITCHEN-snack-01

Name: Black slotted spoon with light dots
Parts analysed by XRF: Black components only

KE-KITCHEN-snack-02

Name: Black cooking spoon
Parts analysed by XRF: Black components only

KE-KITCHEN-snack-03

Name: Black masher with metal handle
Parts analysed by XRF: Black components only

KE-KITCHEN-snack-04

Name: Black slotted spoon with metal handle
Parts analysed by XRF: Black components only

KE-KITCHEN-snack-05

Name: Black skimmer with metal handle
Parts analysed by XRF: Black components only

KE-KITCHEN-snack-06

Name: Black ladle with metal handle
Parts analysed by XRF: Black components only

KE-KITCHEN-snack-07

Name: Black wok spatula
Parts analysed by XRF: Black components only

MICROWAVE Container

KE-MICROWAVE-container-01

Name: Transparent rectangular container with white lid
Parts analysed by XRF: Container, lid

KE-MICROWAVE-container-02

Name: Transparent container with dark lid
Parts analysed by XRF: Container, lid

KE-MICROWAVE-container-03

Name: Transparent rectangular container with grey lid
Parts analysed by XRF: Container, lid

MICROWAVE Lids

KE-MICROWAVE-lid-01

Name: Blue microwave cover with steam vent.
Parts analysed by XRF: Transparent plastic

KE-MICROWAVE-lid-02

Name: Blue microwave cover with handle
Parts analysed by XRF: Transparent plastic

Pencil Cases

KE-PENCIL-case-01

Name: Blue zip pencil case
Parts analysed by XRF: Dark blue material

KE-PENCIL-case-02

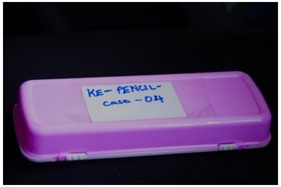
Name: Holographic zip pencil case
Parts analysed by XRF: Holographic material

KE-PENCIL-case-03

Name: Transparent zip pencil case
Parts analysed by XRF: Transparent material

KE-PENCIL-case-04

Name: White-pink plastic pencil box
Parts analysed by XRF: White plastic, pink plastic



KE-PENCIL-case-05

Name: Blue bus-shaped pencil box (three-tier design)
Parts analysed by XRF: Blue, white and transparent plastic

KE-PENCIL-case-06

Name: Blue plastic pencil box with soft top layer and cartoon print
Parts analysed by XRF: Soft top layer, hard plastic

KE-PENCIL-case-07

Name: Green plastic pencil box
Parts analysed by XRF: Green plastic

Sunglasses

KE-SUNGLASS-01

Name: Black plastic sunglasses
Parts analysed by XRF: Lenses, temples

KE-SUNGLASS-02

Name: Black plastic sunglasses
Parts analysed by XRF: Lenses, temples

Children Toys

KE-TOY-black-01

Name: Black spiderman monster truck
Parts analysed by XRF: Black plastic body

KE-TOY-black-02
Name: Rubik's Cube
Parts analysed by XRF:
Black part

KE-TOY-black-03
Name: Black and white plastic wind-up boat
Parts analysed by XRF:
Black plastic, white plastic

KE-TOY-black-04
Name: Black toy police car
Parts analysed by XRF:
Top part, bottom part

KE-TOY-black-05
Name: Racing car toy
Parts analysed by XRF:
Top part, bottom part

KE-TOY-black-06
Name: Black toy rifle (arrow gun)
Parts analysed by XRF:
Rifle, arrow

KE-TOY-black-07
Name: Black monster truck
Parts analysed by XRF:
Top part, bottom part

KE-TOY-black-08
Name: LEGO-style minifigure
Parts analysed by XRF:
Plastic head

Annex 3: Regulatory Framework Reference

This annex provides an overview of the international conventions and European Union regulations referenced throughout this report, explaining their relevance to the findings on hazardous chemicals in plastic consumer products.

International Conventions

Stockholm Convention on Persistent Organic Pollutants

The Stockholm Convention is a global treaty adopted in 2001 and that entered into force in 2004, aimed at protecting human health and the environment from persistent organic pollutants (POPs) — chemicals that remain intact in the environment for long periods, become widely distributed geographically, accumulate in fatty tissue of living organisms, and are toxic to humans and wildlife. The Convention establishes three categories of action: Annex A lists substances for elimination, Annex B lists substances for restriction, and Annex C addresses unintentional production. Substances relevant to this study include DecaBDE (listed in 2017), HBCDD (listed in 2013), and Dechlorane Plus (listed in 2023), all under Annex A for elimination. Kenya is a Party to the Stockholm Convention and is therefore obligated to prohibit and eliminate the production, use, and import of Annex A substances, including in consumer products. The detection of these substances in toys and kitchen utensils on the Kenyan market demonstrates a gap between international commitments and domestic implementation.

Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal

The Basel Convention is an international treaty adopted in 1989 and that entered into force in 1992, designed to reduce the movement of hazardous waste between nations, particularly from developed to less developed countries. The Convention regulates transboundary movements of hazardous waste and other waste, including e-waste containing brominated flame retardants. Parties are obligated to ensure that hazardous waste is managed in an environmentally sound manner, to minimise hazardous waste generation, and to prevent illegal traffic. Kenya is a Party to the Basel Convention. The findings of this study — indicating that recycled e-waste plastics containing banned POPs are entering the Kenyan consumer product stream — highlight the challenges of implementing Basel Convention obligations in countries that receive substantial quantities of second-hand electronics and e-waste from higher-income jurisdictions.

European Union Regulations and Directives

REACH Annex XVII (Regulation (EC) No 1907/2006)

REACH Annex XVII establishes restrictions on the manufacture, placing on the market, and use of certain dangerous substances.

- Entry 20 restricts organostannic compounds, including dibutyltin (DBT) and dioctyltin (DOT), in articles supplied to the general public, setting a concentration limit of 0.1% (1,000 mg/kg) by weight of tin. While the tin concentrations detected in kitchenware and school supplies in this study (up to 237.3 mg/kg) remain below this legal threshold, they serve as an indicator of tin-based stabilisers or additives circulating in common household and children's products.
- Entry 23 sets a limit of 100 mg/kg for cadmium in plastic parts of articles, applicable since 2011 with limited exemptions for specific applications. This regulation is referenced in this study as a benchmark for evaluating cadmium concentrations detected in consumer products, particularly a children's pencil case that exceeded this limit nearly eightfold (766 mg/kg).
- Entry 27 restricts nickel in articles intended to come into direct and prolonged contact with the skin, such as jewellery, watches, or garment fasteners, specifying a migration limit of 0.5 µg/cm2/week. This restriction is relevant to the study as children and students frequently handle school supplies for extended periods; the detection of nickel in a pencil case sample (22.85 mg/kg) highlights its presence in everyday items that undergo constant dermal contact.
- Entry 63 of REACH Annex XVII restricts lead in articles or accessible parts thereof that may be placed in the mouth by children, setting a limit of 0.05% (500 mg/kg) by weight. While this limit applies to total content rather than migration, it provides an additional reference point for evaluating lead concentrations in children's products. The lead concentrations detected in toy samples in this study (up to 82.7 mg/kg) fall below this threshold but nonetheless warrant attention given the cumulative nature of lead exposure and its well-documented neurotoxic effects in children.

RoHS Directive (Directive 2011/65/EU)

The Restriction of Hazardous Substances (RoHS) Directive establishes rules to limit specific hazardous materials in electrical and electronic equipment (EEE) placed on the EU market. Currently, TBBPA is not included in the list of restricted substances under Annex II of the RoHS Directive. However, under the REACH Regulation, Tetrabromobisphenol A is officially classified as a Carcinogen category 1B (this is the reason for adding it to SVHC) and Toxic for Reproduction category 1B. Scientific literature and expert opinions confirm that this brominated flame retardant is frequently detected in various consumer products, including plastic toys manufactured for children. The detection of TBBPA in items such as plastic cubes serves as evidence of its continued presence in children's products, even while it remains unregulated for specific use in electronics.

CLP Regulation (Regulation (EC) No 1272/2008)

The Classification, Labelling and Packaging Regulation establishes criteria for classifying hazardous substances in the EU. TBBPA is classified under CLP as H410 (very toxic to aquatic life with long-lasting effects). This classification is the basis for deriving concentration thresholds under Council Regulation (EU) 2017/997, which determines when waste containing H410-classified substances must be classified as hazardous.

Waste Framework Directive (Directive 2008/98/EC) and Council Regulation (EU) 2017/997

The Waste Framework Directive establishes the legal framework for waste management in the EU, including criteria for classifying waste as hazardous. Annex III of this directive was amended by Council Regulation (EU) 2017/997, which established criteria for the hazardous property HP14 "Ecotoxic." For substances classified as H410 (very toxic to aquatic life with long-lasting effects), such as TBBPA, the regulation implies a threshold of 2,500 mg/kg (0.25%) above which waste containing even a single such substance must be classified as hazardous. This threshold is cited to illustrate that materials currently circulating in consumer products would trigger hazardous waste classification at end-of-life.

EU POPs Regulation (Regulation (EU) 2019/1021)

The EU POPs Regulation implements the Stockholm Convention within the European Union, establishing prohibitions and concentration limits for persistent organic pollutants in articles, mixtures, and waste.

PBDEs: Annex I sets a limit of 500 mg/kg for the sum of tetra-, penta-, hexa-, hepta-, and decabromodiphenyl ether in articles and mixtures. All ΣPBDE concentrations in this study (17.2–47.9 mg/kg) fall below this limit.

HBCDD: Annex I sets a limit of 1,000 mg/kg for hexabromocyclododecane in articles. The HBCDD concentration detected in the Rubik's cube sample (0.027 mg/kg) is well below this threshold.

Dechlorane Plus: Following the listing of Dechlorane Plus under Stockholm Convention Annex A in 2023, the EU adopted amendments 2025/1930 to Regulation 2019/1021 establishing a limit of 1 mg/kg (1,000 ng/g) for unintentional trace contamination in articles, applicable after a 30-month transition period (from 15 April 2028). One sample in this study (KE-toy-black-06-arrow, 910.5 ng/g) approached this forthcoming limit.

Directive 2011/8/EU (BPA ban in infant feeding bottles)

This directive amended Directive 2002/72/EC to prohibit the use of bisphenol A in the manufacture of polycarbonate infant feeding bottles in the EU, effective from 1 June 2011. The directive is referenced in this study to highlight that BPA was detected in all infant feeding bottles tested from the Kenyan market (3.9–19.1 ng/g), including those labelled as "BPA-free," demonstrating that products sold outside EU jurisdiction do not comply with this protective standard.

Regulation (EU) No 10/2011 (Food Contact Materials)

This regulation establishes rules for plastic materials and articles intended to come into contact with food. Annex I provides a

Union list of authorised substances, including BPA (FCM No 151) and BPS (FCM No 154), with the latter restricted by a specific migration limit (SML) of 0.05 mg/kg. For BPA, the SML has been progressively tightened; following EFSA's 2023 re-evaluation, which established a TDI of 0.2 ng/kg bw/day, the European Commission is expected to further restrict BPA in food contact materials. The regulation is referenced to provide context for bisphenol detections in food contact materials such as sport bottles, microwave lids, and snack containers analysed in this study.

Toy Safety Directive (Directive 2009/48/EC)

The Toy Safety Directive establishes the safety requirements that toys must meet before being placed on the EU market, with a particular focus on protecting children from chemical hazards.

CMR Restrictions: Under Annex II, Part III, the directive strictly prohibits the use of substances classified as carcinogenic, mutagenic, or toxic for reproduction (CMR) of category 1A, 1B, or 2 in toys or their components. This general prohibition is directly applicable to substances analysed in this study: TBBPA is officially identified as a category 1B carcinogen, and Bisphenol A (BPA) is classified as a category 1B reproductive toxin. Such substances may only be used if they are below specific concentration limits for mixtures or if they are completely inaccessible to children during use. The detection of these compounds in plastic toys illustrates potential challenges in ensuring that children's products remain free from industrial CMR chemicals.

Migration Limits for Elements: The directive also defines specific migration limits for 19 elements to prevent toxic exposure through mouthing or ingestion. These limits vary based on the toy material:

- Lead (Pb): The migration limit is set at 13.5 mg/kg for dry materials and 160 mg/kg for scraped-off materials. While XRF measures total content, the detected lead concentrations (up to 82.7 mg/kg) indicate a risk of exceeding migration thresholds in dry or brittle materials.
- Cadmium (Cd): This element is subject to very strict migration limits of 1.9 mg/kg (dry) and 23 mg/kg (scraped-off). The total concentration of 766 mg/kg found in a pencil case is over 30 times higher than the maximum allowable migration for solid materials, signalling a significant safety concern.
- Antimony (Sb) and Barium (Ba): These elements are restricted by migration limits of 560 mg/kg and 56,000 mg/kg, respectively for scraped-off materials. The detection of antimony (up to 219.7 mg/kg) and barium (up to 3,077 mg/kg) in school supplies and toy arrows provides a benchmark for evaluating the chemical safety of recycled or contaminated plastic matrices used in these products.

Compliance with these limits is typically verified through standardised testing (EN 71-3), and the elevated total concentrations detected in this study warrant further migration-specific analysis to confirm legal compliance.

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