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Insights into polybrominated diphenyl ethers: occurrence, sources, and exposure health risk in selected solid waste impacted soils

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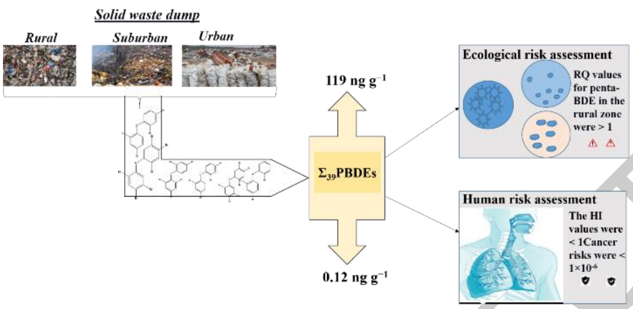
Graphical abstract



Abstract

The Coordinated management of solid waste dumps from different anthropogenic environments is important for pollution management of immediate and adjacent ecosystems. This study took three soil profile samples from three functional zones: the rural, the suburban, and the urban solid waste dumps. The samples were analyzed for the concentration, origin, and associated risks of thirty-nine Polybrominated diphenyl ethers (Σ_{39}PBDEs). Σ_{39}PBDEs demonstrated high concentrations and ranged from 0.12 to 119 ng g^{-1} dw, in the order of rural > suburban > urban, and topsoil > subsoil > bottom soil. BDE-10, −11, −13, −15, −17, −99 and −119 showed relative abundance. Penta-BDE was moderately above standard and screening levels and demonstrated high and medium ecological risk in the rural and semi-urban zones. The non-carcinogenic and cancer risks highlight onsite exposure risks. PCA evaluation depicts an abundance of persistent and toxic flame retardant additives, and cluster analysis showed PBDEs were from a common source- cancer and hazard index exposure risk depicted rural > suburban > urban zone. The results suggested the continual use of banned flame retardant additives in commercial formulations. A comparison of PBDE implied that PBDEs in the suburban and urban zones could have undergone environmental processes, and the rural zone received fresh deposition. Migration and exposure to the detected -BDEs may increase the risk to humans in these zones. The results highlighted the need to establish a standard management protocol and monitor legacy pollutants in environmental and biological samples around solid waste dump sites and similar catchments.

Keywords: PBDEs occurrence, soil pollution, onsite exposure, associated risks, solid waste

1. Introduction

Soil is a heterogeneous mixture, together with other units, acts as a sink and plays a considerable function in the distribution, fate, transport and risk of several anthropogenic pollutants. Soil pollution, erosion, overexploitation, urbanization and abuse threaten the terrestrial and aquatic ecosystems and the geochemical cycle (Chakraborty *et al.* 2016; Iwegbue *et al.* 2020; Emoyan, 2020a). Solid waste dumps are a repository for waste control in urban, suburban and rural catchments and sources of pollutants (Tesi *et al.* 2020; Emoyan *et al.* 2021ab). Several solid waste sites situated around residential and commercial catchments, sources of plastics and metal scraps for economic purposes and scavengers are prone to exposure risk. Waste dumps contain electrical, electronic, refrigerating components, plastic, metals, textile coatings, oils, upholstery and building materials. In Nigeria and some developing countries, solid waste segregation is not a regular practice and lack of proper solid waste management constitute environmental and human health challenge (Emoyan *et al.* 2008a; UNEP, 2001; Gioia *et al.* 2014). Solid waste impacted soil contains hazardous chemicals such as PBDEs in varying amounts and may contaminate immediate and surrounding ecosystems (Wang *et al.* 2016; Emoyan *et al.* 2021cd; Marin-Beltran *et al.* 2022).

Polybrominated diphenyl ethers (PBDEs) are well-known species of persistent organic pollutants (POPs). PBDEs high thermal conductivity, constant dielectric fluid, electrical

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insulation and photochemical stability properties enable its application as an additive flame retardant in coatings, households, buildings and in industrial, commercial, electronic and electrical materials (Anh *et al.* 2019). Over time, PBDE in these formulations will turn airborne disperse off the material surface and subsequent deposition on soil and water matrices. PBDEs can be released from treated products and enter the environment through partitioning to indoor dust, leaching, and volatilization recycling of waste products and landfills (Abafe and Martincigh, 2016). Environmental PBDEs are formed by-products of domestic and industrial waste, landfill, burning, industrial processes, sewage sludge, leachates, dust particles from plastics, metals, transformers, e-waste scrap dump, offices, electrical appliances repair workshops, and homes. PBDEs are ubiquitous with long-range transboundary transport (Hong *et al.* 2018; O'Brien *et al.* 2019; Emoyan *et al.* 2021c).

Pollution studies have established the concentrations and occupational risk from exposure to PBDEs in different anthropogenic impacted soils, water, and food items (Zhu *et al.* 2015; Pérez-Vázquez *et al.* 2016; Yin *et al.* 2017; Robertson *et al.* 2018; Megson *et al.* 2019; Park *et al.* 2020; Emoyan *et al.* 2021). Exposure to PBDEs contaminated food and dust particles is associated with cumulative and deleterious effects on biogeochemical health. PBDE health hazards includes neurological, birth, reproductive and developmental defects; endocrine disruption, allergies, cognitive and impaired disorder; leukemia in infants, and carcinogenic behavior (Lampa *et al.* 2018; ATSDR, 2019; Harmouche-Karaki *et al.* 2019). Consequently, in the 1970s, PBDEs as a fire retardant additive were banned. However, the prohibition and ban were absent in most developing countries including Nigeria (UNEP, 2002, 2016).

Anthropogenic activity of an area determines the chemical composition and amount of solid waste generated, and non-compliance to standards in solid waste management may lead to point and non-point source pollution. Due to lack of land space and the need in some suburban and urban environments, some waste dumps and abandoned sites may be utilized for residential, institutional, recreational, commercial, and agricultural catchments without proper soil clean-up and restoration (Emoyan *et al.* 2022b). The broad occurrence of synthetic organic compounds around residential and agricultural soils can cause human and ecological health concerns. This study determines the relative concentrations, sources, and associated exposure risks of $\sum_{39}$PBDEs in soils from selected rural, suburban and urban solid waste dump, and provides a comparative insight on Σ_{39}PBDEs pollution burden, sources, human and ecological health risks. The study represents a similar human-induced catchments and is vital for policy and decision-makers in developing models for environmental quality management.

2. Materials and methods

2.1. Description of study area and sample collection

Based on the industrial and commercial activities and population, the selected solid waste dump sites are grouped as urban, suburban and rural functional zones. The urban zone is a catchment with population density greater than 500 000, their occupation is related to secondary and tertiary sectors with high anthropogenic activities, and generating a high proportion of solid waste. The urban zone is host to several gas plants, allied companies, oil flow stations, and government agencies. The suburban is a catchment with population density less than 500 000, their occupation is related to secondary and tertiary sectors, but lack the characteristics of urban settlement, and generate less solid waste relative to the urban zone. River Ethiope used for tourism, Delta State University and some government agencies are in the suburban zone. The rural is an agro-based catchment with low population density less than 10 000, the commercial and economic activities are low relative to the suburban and urban. The rural zone lies between the suburban and urban zones.

The climatic conditions of the selected zones is of the Niger Delta region, Nigeria, Figure 1 (Ohwoghere-Asuma *et al.* 2020; Emoyan *et al.* 2020b). Twenty-seven soil samples were collected from nine solid waste dumpsites at three different depths 0-15 cm (top), 15-30 cm (sub), and 30-45 cm (bottom soil) using a soil auger. The geographical coordinates of the nine dumpsites are RA1 (5.73207 N 5°43'55.464'' 6.13992 E 6°8'23.724''), RA2 (5.73394 N 5°44'2.202'' 6.1425 E 6°8'33.012''), RA3 (5.73394N 5°44'2.196'' 6.1425 E 6°8'33.006), SA4 (5.79904 N 5°47'56.55'' 6.10837 E 6°6'30.144''), and SA5 (5.79906 N 5°47'56.622'' 6.10772 E 6°6'27.774''). Others are SA6 (5.80041N 5°48'1.476'' 6.10816 E 6°6'29.364''), UA7 (5.4835N 5°29'0.594'' 6.01909 E 6°1'8.736''), UA8 (5.48792 N 5°29'16.512'' 6.02096 E 6°1'15.45'') and UA9 (5.48772 N 5°29'15.792'' 6.02236 E 6°1'20.478''). The samples were collected into foil paper, labeled, and transported to the laboratory in a cooler of ice. The samples were air-dried, sieved with a 2 mm mesh and kept in the refrigerator at a temperature of 4°C before analysis.

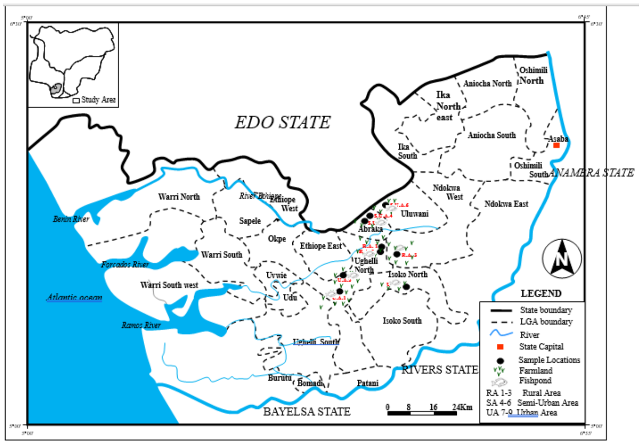

Figure 1. Map of the study area showing selected sample sites from the rural, suburban and urban zones. (Adapted in part from Emoyan *et al.* 2020b.

2.2. Reagents and equipments

The reagents used were HPLC-grade. The conductivity-pH meter is Lie-ci PXSJ-216F, lie-ci, Shanghai, China made. The Rotary vacuum evaporator was purchased from Buchi, Switzerland, and HPLC-grade n-hexane and acetone, alumina (100–300 mesh), silica gel and anhydrous sodium sulphate are Merck, Darmstadt made. Thirty-nine PBDE congeners 1, 2, 3, 7, 8, 10, 11, 12, 13, 15, 17, 25, 28, 30, 32, 33, 35, 37, 47, 49, 66, 71, 75, 77, 85, 99, 100, 116, 118, 119, 126, 137, 153, 154, 155, 166, 181, 183, and BDE-209 are Isotope Laboratories Inc, Cambridge, MA, USA made. The Agilent 7890A gas chromatograph and Agilent 5975c mass selective detector are Palo Alto, CA, USA made.

2.2.1. Determination of selected soil physicochemical properties

The electrical conductivity (EC), pH, and total organic carbon (TOC) were determined using conductivity meter, pH meter in soil to water suspension (1:2) and the dichromate-based wet oxidation digestion as described by Emoyan *et al.* (2021b).

2.3. PBDEs extraction clean up and analysis

The extraction of PBDEs was carried out using the USEPA method 3540C as describe by Iwegbue *et al.* (2019), Chen etal. (2020) and Emoyan *et al.* (2021b). A mass of 5.0 g of dried soil was spiked with a mixed standard solution of isotopic labeled PBDEs congeners and Soxhlet extracted with 150 mL of acetone/dichloromethane/*n*-hexane mixture (1:1:1 v/v) in a 65 °C water bath for 18 hrs. A gram of activated Cu granules and 3 g of anhydrous Na_2SO_4 was added to remove sulfur and water respectively. Using a rotary evaporator, the extract was evaporated to 2 mL and subjected to clean-up in a multilayer alumina-silica gel bottom-top packed column with 4 g of neutral silica gel (5% deactivated), 2 g of neutral alumina (6% deactivated) and 5 g of anhydrous Na_2SO_4. A 40 mL aliquot of *n*-hexane/dichloromethane mixture (3:1 v/v) was used to elute PBDEs from the column and the eluate was concentrated to approximately 2 mL under a stream of nitrogen gas. An Agilent 7890A gas chromatograph coupled to an Agilent 5975c mass selective detector was used for the separation, detection and quantification of the PBDEs.

2.4. Quality control and assurance protocols

Sample collection, handling, storage, extraction and quantification were treated to standard procedures. All equipment and glassware were thoroughly washed twice with distilled water and dried in electric oven at 105 °C before each use, and the standard temperature programming was in sequence. The GC-MS syringe was washed twice with hexane and acetone before and after sample injection. External calibration was done with five-point PBDEs standards set by serial dilution of the standard stock solution between 10 and 100 µg/L. The spiked recovery sample was obtained by spiking blank samples with 2 µL of 20 µg/mL of PBDEs standard. The methods blanks, matrix spiked samples, and surrogate ^{13}C12-labelled PBDEs were used. The field and laboratory blanks were extracted and analyzed similarly as the samples, and PBDE-congeners were not found in the method blanks. The percentage recoveries of the surrogate $^{13}C_{12}$-isotopic PBDEs and spiked samples ranged from 79 to 96.3% and 86.2 to 105% respectively (RSD ≤ 10). These values were within the standard limits of 50% to 150% (APHA, 2005). The limits of detection and quantification of PBDEs ranged from 0.13 to 0.58 and 0.13 to 0.58 ng g^{-1} respectively, and the r^2 values ranged from 0.9992 to 0.9995.

2.5. Ecological risk assessment of PBDEs in soil

The ecological risks of PBDEs were assessed using the hazard quotient. The risk quotients (RQ) were obtained as a ratio of the measured PBDEs concentrations in the samples to the guideline values equation 1 (Chokwe *et al.* 2019).

$$RQ = \frac{Measured\ concentration\ of\ the\ PBDEs\ in\ the\ soil}{Guideline\ values} \quad (1)$$

The Federal Sediment Quality Guidelines (FSeQGs) derived from the results of toxicological studies on organisms was used (Environment Canada, 2013). The FSeQGs for tri-BDE, tetra-BDE, penta-BDE, hexa-BDE, octa-BDE and deca-BDE are 44, 39, 0.4, 440, 5600, and 19 ng g^{-1}. RQs values 0.01 ≤ RQ ≤ 0.1 indicate low risk, 0.1 ≤ RQ ≤1 indicate medium risk, and > 1 indicate high risk.

2.5.1. Assessment of human health risk of PBDEs

The human health risks of PBDEs in the samples were assessed using the hazard index (HI) and total cancer risk respectively via the dermal, ingestion, and inhalation pathways, equations 2-10, USEPA (2020).

2.6. For non-cancer risk,

$$Hazard\ Index\left(HI\right) = \sum HQ = HQ_{ing} + HQ_{inh} + HQ_{dermal} \quad (2)$$

$$HQ = \frac{CDI_{nc}}{RfD} \quad (3)$$

$$CDI_{ing-nc} = \frac{C_{soil} \times IngR \times EF \times ED}{BW \times AT_{nc}} \times 10^{-6} \quad (4)$$

$$CDI_{inh-nc} = \frac{C_{soil} \times InhR \times EF \times ET \times ED}{PEF \times 24 \times AT_{nc}} \quad (5)$$

$$CDI_{dermal-nc} = \frac{C_{soil} \times SA \times AF \times ABS_d \times EF \times ED}{BW \times AT_{nc}} \times 10^{-6} \quad (6)$$

2.7. For cancer risk

$$Total\ Cancer\ Risk = Risk_{ing} + Risk_{inh} + Risk_{dermal} \quad (7)$$

$$Risk_{ing} = \frac{C_{soil} \times IngR \times EF \times ED \times CF \times SFO}{BW \times AT} \quad (8)$$

$$Risk_{inh} = \frac{C_{soil} \times EF \times ED \times IUR}{PEF \times 24 \times AT} \quad (9)$$

$$Risk_{dermal} = \frac{C_{soil} \times SA \times AF \times ABS \times EF \times ED \times CF \times GIABS \times SFO}{BW \times AT} \quad (10)$$

Where CDI_{ing}, CDI_{inh} and CDI_{Derm} are chronic daily intake for ingestion, inhalation and dermal contact respectively; $Risk_{ing}$, $Risk_{inh}$ and $Risk_{Derm}$ are risk for ingestion, inhalation and dermal contact respectively. HQ is hazard quotient, IngR is the ingestion rate, EF is exposure frequency, ED is exposure duration, BW is body weight, AT_{nc} is averaging time for non-carcinogens, AT_{ca} is averaging time for carcinogens, C_{soil} is PBDEs concentration in soil, RfD is oral reference dose, ET is exposure ne, inhR is inhalation rate, IUR is inhalation unit risk, SA is surface area of the body, AF is soil to skin adherence factor, ABS is absorption factor, PEF is Soil to air particulate ession factor, SFO is oral slope factors, CF is conveion factor, GIABS is gastrointestinal absorption factor. The definitions of terms and values of variables are presented in the Supplementry Materials Table SM1

2.8. Statistical analysis

Principle component analysis (PCA) and analysis of variance (ANOVA) were used to determine the sources of PBDEs and significant difference in Σ_{39}PBDEs concentrations in soil profiles. Linear regression evaluated the effect of soil depths on the values TOC, EC, pH, and PBDEs. All statistical evaluations were by the Statistical Package for the Social Science (SPSS) version 22.

3. Results and discussion

3.1. Physicochemical properties of soils

The results of some soil physicochemical properties are presented in Table 1. The average pH, EC, and TOC values ranged from 5.9 to 6.5, 72 to 78 µs/cm, and 0.35 to 0.89 (%). The results show that 82% of samples were acidic, suggesting high decomposition of organic matter producing protons in the dumpsites (Meng *et al.* 2018; Molamahmood *et al.* 2020). Particle size is related to TOC, and fine grain particles have a larger surface area, hence adsorption of a high amount of organic matter (Lambert, 1967; Jun *et al.* 2017). Due to high Kow and low solubility, the observed soil pH and TOC could be favorable for adsorption, retention, reduce mobility and leaching of HMW-PBDEs from the topsoil, and less susceptible to environmental processes at the rural zone. As a predominantly agricultural settlement, plant uptake of PBDEs in the rural zone would be high relative to the suburban and urban zones. In this study, the pH, EC, and TOC values were variable, probably reflecting the difference in soil biochemical reactions, mechanical disturbances, volume and nature of waste and frequency of deposal (Cheng *et al.* 2014; Olisah *et al.* 2020). The pH, EC, and TOC values obtained were comparable to other studies previously reported for some Niger Delta soils (Emoyan *et al.* 2018; Iwegbue *et al.* 2020).

3.2. Concentration and occurrence of PBDEs

The statistical summary of Σ_{39}PBDEs concentrations of thirty-nine PBDEs determined in the rural, suburban, and urban zones (dry weight) is presented in Table 2 and the Supplementary Materials Table SM2a-c. The concentrations of Σ_{39}PBDEs ranged from 5.80 (27.26 ± 32.26) to 119 ng g^{-1} (58.27 ± 55.72), 0.12 (2.63 ± 4.15) to 62.82 ng g^{-1} (21.17 ± 36.08), and 0.46 to 62.62 ng g^{-1} (21.19 ± 35.88) in the rural suburban and urban zones respectively. Sites RA3, RA1, SA4, and UA8 recorded high Σ_{39}PBDEs concentrations. Σ39PBDEs concentrations showed no statistical difference within sample sites ($p > 0.05$). The median values ranged from 0.36 to 46.29 ng g^{-1}, site RA3 recording the highest value. This study indicates a significant concentration of Σ_{39}PBDEs in the rural (61%) zone compared to the suburban (20%) and urban (19%) zones, Figure 2. In this study, Σ_{39}PBDEs mean concentrations in the topsoil (57%) was higher compared to the subsoil (30%) and bottom soil (13%). The r^2 values of TOC (0.1239), EC (0.1523), pH (0.2402), and PBDEs (0.1290) explained 12.4%, 15.2%, 24.0%, and 12.9% variations in the dependent variables. The r^2 values show that TOC ($p > 0.05$), EC ($p < 0.05$), pH ($p < 0.05$) and PBDEs ($p > 0.05$), suggest that soil depth significantly affected EC and pH values but had no significant effects on TOC and PBDEs values, Table 1.

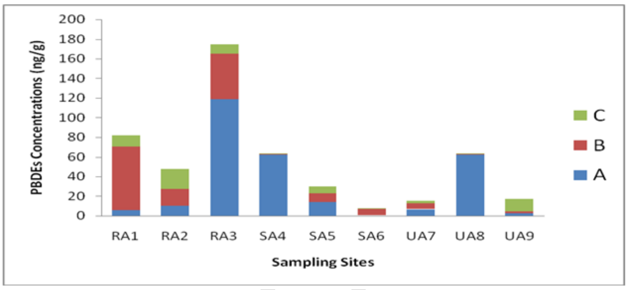

Figure 2. Compositional pattern of Σ_{39}PBDEs concentrations in soil depths with topsoil > subsoil > bottom soil. Where: A = topsoil, B = subsoil, and C = bottom soil

Scavenging and dismantling scraps in solid waste sites to recover valuable items could release hazardous pollutants such as PBDEs to immediate and surrounding soils (Wäger *et al.* 2011; Chancerel *et al.* 2011; Emoyan *et al.* 2021f). Σ_{39}PBDEs concentrations were variable, probably reflecting variations in input, accumulation and removal of Σ_{39}PBDEs, soil biochemical reactions and mechanical disturbances, median values, coefficient of variation, and congener's characteristics. In addition, the variation in concentrations is attributed to the effect of the dry season in sample collection, soil retention capacity, volume and nature of waste, and fresh deposition (Turner and Hefzi, 2010; Cheng *et al.* 2014; Radziemska and Fronczyk, 2015; Olisah *et al.* 2020; Emoyan *et al.* 2020a; 2021d). Σ_{39}PBDEs concentrations suggest continual use of banned flame retardant additives in thermoplastics, textiles, furniture, electronics, and upholstery and building materials visible in the solid waste sites during the sampling campaign. Site RA3 recorded pronounced Σ_{39}PBDEs mean and median concentrations; this suggests that the rural zone received waste rich in flame retardant additives from adjacent urban and suburban industrial and commercial clusters (UNEP, 1989; Liche *et al.* 2015). Due to Σ_{39}PBDEs pollution load, sites RA3, RA1, SA4 and UA8 act as a reservoir, contaminate surrounding terrestrial and aquatic ecosystems of River Ethiope beaches used for tourism, and River Umalokun and Abraka used for local fishing, as well as numerous farmlands surrounding these sites (Breg *et al.* 2008; Suzuki *et al.* 2009; Deng *et al.* 2014; Liua *et al.* 2017; Vogt *et al.* 2018; Vitali*et al.* 2021; Emoyan *et al.* 2018; Bai *et al.* 2018; Li and Achal, 2020; Marín-Beltrán *et al.* 2022).

Due to constant release, accumulation, persistence, and metabolites properties, the observed Σ39PBDEs concentrations may enhance occupational and food exposure risk if these sites are used for agricultural, commercial and other anthropogenic purposes. However, this could be a function of concentrations, routes, and duration of exposure (Berg *et al.* 1995; Brevik, 1996; Chen *et al.* 2017; Iwegbue *et al.* 2018; Emoyan *et al.* 2022b). In addition to hydrolysis, infiltration, leaching, diffuse and direct migration, water chemistry and water-rock interaction, observed soil physicochemical properties could impact transport and mobility of detected Σ_{39}PBDEs from top to deep soils, and subsequent contamination of immediate and surrounding soil, surface, and groundwater resources in wet season (Gioia *et al.* 2014; Cetin *et al.* 2019; Qian *et al.* 2020; Chen *et al.* 2020; Emoyan *et al.* 2021d).

3.3. PBDEs compositional pattern

The congeners and homologues compositional patterns of Σ_{39}PBDEs are presented in Table 2 and Figure 3. The congener's concentrations show that BDE-13, -17 and -119, BDE-85, -99 and -119, BDE-25, -118 and -119 had 46, 32, and 45% composition of Σ_{39}PBDEs at RA1, RA2, and RA3 respectively. The congener's concentrations at sample sites RA4, RA5, and RA6 show that BDE-10, -11, and -15, BDE-11, -15, and -137, BDE-10, -11, and -15 had 72, 38, and 79% composition of Σ39PBDEs respectively. In addition, congener's concentrations show that BDE-15, 17, and -99, BDE-30, 71, and -77, BDE-8, -13, and -15 had 31, 52, and 47% composition of Σ39PBDEs at sites RA7, RA8, and RA9 respectively. BDE-10, -11, -13, -15, -17, -99, and -119 were abundant compared to other congeners. The detection frequency of persistent and toxic BDE-47, -100, -99, and -154 were 67, 89, 89, and 89% respectively, suggesting soils from the solid waste sites have been exposed to mobile PBDE congeners (Mwakalapa *et al.* 2018). The relative occurrence of LMW and HMW congeners (BDE -8, -10, -11, -13, -15, -17, -25, -30, -38, -47, -71, -77 -85, -99, -100, -188 -119, and -137) suggests seeding of both LMW and HMW-BDE in formulations of materials found in the dumpsites. In addition, upon exposure they exert increased inter-compartmental, mobility and toxic effects in living tissues and high accumulation in terrestrial and aquatic organisms (Söderström *et al.*, 2004; Tagliaferri *et al.* 2010; Chen *et al.* 2011: Mhadhbi *et al.* 2012; Luo *et al.* 2019; Li and Achal, 2020). However, higher BDE -166, -181, -183 and -209 congeners were not detected. This could be adduced to product-debromination arising from the United Nations Stockholm Convention ban, and microbial and/or photodegradation of HMW-BDEs to LMW-BDEs.

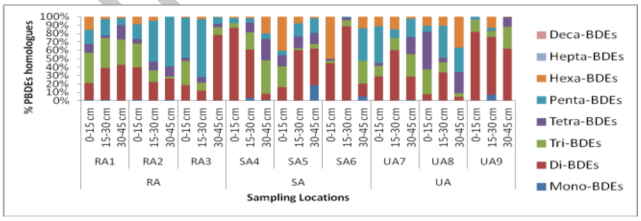

Figure 3. Percentage composition of BDEs homologue showing di-BDEs > penta-BDEs > tri-BDEs > tetra-BDEs > hexa-BDEs > mono-BDEs from the rural, suburban and urban zones.

The mono-, di- and tri-BDEs constituted 0.0 to 18.4, 4.9 to 87.9, and 2.4 to 39.5% of ∑39PBDEs concentrations respectively. The tetra-, penta-, and hexa-BDEs constituted 0.0 to 44.7, 0.0 to 68, and 0.0 to 50.3% of $\sum_{39}$PBDEs concentrations respectively. However, hepta- and deca-BDEs were not detected. The homologues pattern followed the order: penta-BDEs > di-BDEs > tri-BDEs > tetra-BDEs > mono-BDEs > hexa-BDEs for the rural zone; di-BDEs > tri-BDEs > hexa-BDEs > penta-BDEs > tetra-BDEs > mono-BDEs for the suburban zone and tetra-BDEs > tri-BDEs > di-BDEs > penta-BDEs > hexa-BDEs > mono-BDEs for the urban zone. The Federal Environmental Quality Guideline (FEQG) and Environment Canada established values for residential and industrial soils for tri, tetra, penta, and hexa -BDEs are 44, 39, 0.4, and 440 ng g^{-1} respectively (EPA, 2017; Chokwe *et al.* 2019). The tri- and tetra-, hexa -BDEs concentrations were below the FEQG standards and USEPA screening levels, while the penta-BDEs concentrations were above the FEQG standards and USEPA screening levels in 44% of the samples. The concentrations of tri- and tetra -BDEs were significant at sites RA1, RA3 and UA8.

3.4. Risk Quotients (RQs) of PBDEs

As presented in the Supplementry Material Table SM3, the RQs values of tri-, tetra-, penta- and hexa-BDEs in the rural, suburban, and urban zones ranged from 0.0 to 13.517, 0.0 to 0.614, and 0.0 to 1.440 respectively. The RQ values of tri-, tetra-, penta- and hexa-BDEs were < 0.1, indicating low ecological risk. However, RQ values for penta-BDE in the rural zone were > 1, indicating high ecological risk, while the RQ values for penta-BDE in the suburban and urban zones ranged from 0.1 to 1.0, suggesting medium ecological risk.

3.5. Comparison of PBDEs concentrations with those reported in other studies

In this study, BDE-47, -99, -153, and $\sum_{39}$PBDEs concentrations were compared to others studies reported for anthropogenic impacted soils, Table 3. BDE-47, -99 and -153 concentrations were higher than the results reported from agricultural, E-waste storage facilities, and organic farm soils from urban and rural catchments in Birmingham, UK, China, Hong Kong, Shanghai China, Manaus, Brazil, and Bratislava, Slovakia and Mainz, Germany (Harrad and Hunter, 2006; 2010; Thorenz *et al.* 2010; Man *et al.* 2011). Tombesi *et al.* (2017) reported Σ_{10}PBDEs concentration range of 0.04 to 10.7 ng g^{-1} dw in nine soils from Bahía Blanca city and the surrounding region (Southwest of Buenos Aires Province, Argentina). Sun *et al.* (2015) reported Σ_{42}PBDE concentrations range from 0.02 to 0.25 ng g^{-1} d.w from surface soils near the Changwengluozha Glacier of Central Tibetan Plateau, China. Dong *et al.* (2014) reported $\sum_{14}$PBDEs concentrations range from 2.96 to 200 ng g^{-1} (mean of 65.2 ng g^{-1}) in farmland soils from Taizhou, China. Luo *et al.* (2009) reported total PBDE concentrations range from 191 to 9156 ng g^{-1} dw and from 2.9 to 207 ng g^{-1} d.w in road soils and farmland soils respectively from e-waste recycling catchments in Southern China. Sun *et al.* (2016) reported Σ_{13}PBDE mean conentrations range from < 1.0 to 382 ng g^{-1} d.w from agricultural soils (approximately 45,800 km) in the Yangtze River Delta, China. Jiang *et al.* (2010) reported $\sum_{29}$PBDE concentrations range from 0.02 to 3.8 ng g^{-1} d.w (mean 0.74 ng g^{-1} d.w from surface soil at the urban areas of Shanghai, China. Chen *et al.* (2020) reported $\sum_{8}$PBDEs mean concentrations range from 1.71 to 64.9 ng g^{-1} d.w, 0.72 to 4.08 ng g^{-1} d.w. and 0.6 to 3.76 ng

g^{-1} d.w. in the functional industrial, agricultural and grassland zones, respectively from Inner Mongolia, northern China. Jiang *et al.* (2012) reported $\sum_{44}$PBDEs mean concentrations range from 0.13 to 1.23 ng g^{-1} d.w (mean 0.43 ng g^{-1} d.w) of surface soil collected from the agricultural region of Shanghai, China. $\sum_{39}$PBDEs results from this study can be considered higher and/or similar when compared with other studies reported. This variation is likely associated with anthropogenic activities in the catchments (Supplementry Material Table SM4).

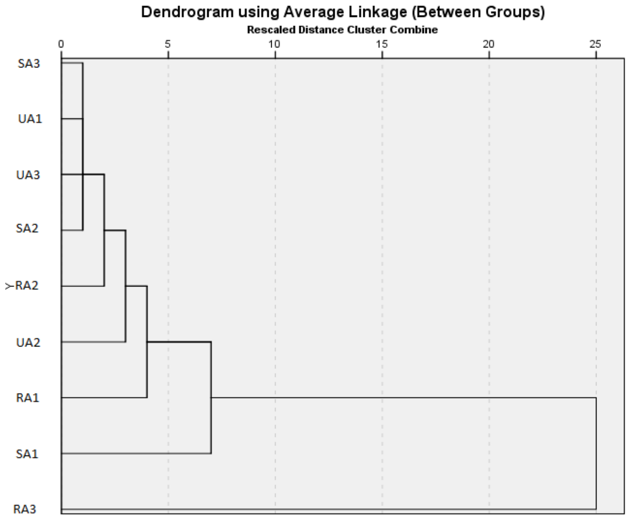

Figure 4. The dendrogram showing SA3, UA1 and SA2, UA3, RA2 cluster formation, UA2, RA1, and SA1 formed linkage, and RA3 as outlier

3.6. Non-carcinogenic and carcinogenic risk

The non-cancer and cancer risks were determined using the hazard index and total cancer risk models, Figure 4, and the Supplementry Material Table SM5 and SM6. The rationale for human health risk evaluation is exposure, hence reported for the topsoil. The HQ values through ingestion, dermal and inhalation exposure routes followed the order: HQIng > HQdermal > HQInh for infants and adults in the rural, suburban and urban zones. The HI values for infants and adults for BDE-47, -99, -153 and $\sum_{39}$PBDEs ranged from 1.92×10^{-3} to 2.79×10^{-1} and 2.54×10^{-4} to 3.94×10^{-2}. The hazard index values for infants' exposure were higher than for adults' exposure; this was related to exposure duration and smaller bodyweight of infants to soil particles at play hours. The HI values were < 1, suggesting no adverse non-carcinogenic risks to soil exposure (US EPA, 2020; Deng *et al.* 2014). The HI ingestion, dermal and inhalation exposure risk were in the order of RiskIng > Riskderm > RiskInh. Cancer risks in the rural, suburban and urban zones ranged from 1.23×10^{-8} to 4.08×10^{-6} and 1.14×10^{-9} to 3.78×10^{-7} for the infants and adults respectively, Figure 5 and the Supplementry Material SM7. Cancer exposure risk for adults' exposure was higher than infants' exposure, suggesting a long exposure duration for adults.

Cancer risks were < 1×10^{-6} indicating no carcinogenic risk soil exposure (US EPA, 2020). Total cancer and HI exposure risk depict the order rural > suburban > urban zone. Though the values of the cancer risk of Σ_{39}PBDEs and the noncancer risk of BDE-47, 99, 153 and Σ_{39}PBDEs-laden topsoil are within safe threshold, these values highlight the potential for onsite occupational exposure risk depending on the concentrations, duration and routes of exposure (Chen *et al.*, 2017) (Supplementry Material SM8).

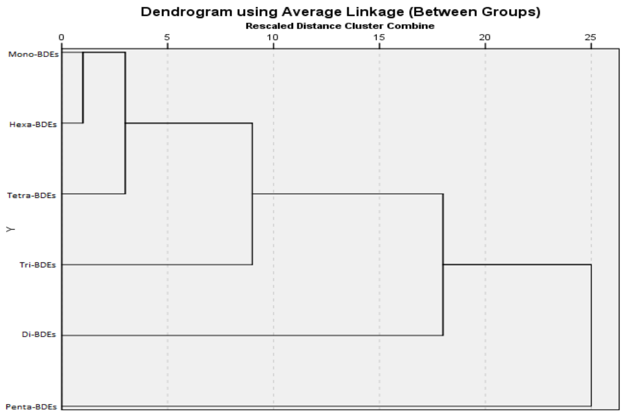

Figure 5. BDEs homologue dendrogram showing three clusters with a linkage at hexa-, tetra and tri –BDEs with penta-BDEs as independent entropy member.

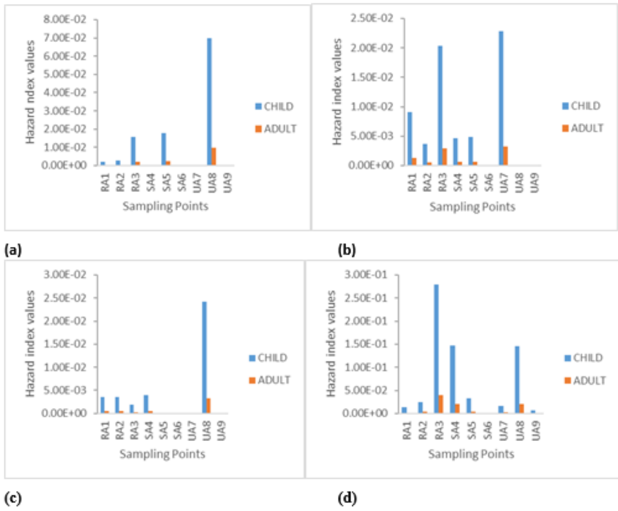

Figure 6. Hazard index of values for (a) BDE-47, (b) BDE-99, (c) BDE-153, and (d) Σ39PBDEs with infants' exposure greater than for adults' exposure.

3.7. Cluster analysis

Cluster analysis was applied to determine the relationship and homogeneity of Σ39PBDEs concentrations and sample sites, Figures 6 and 7. The dendrogram shows that SA3, UA1 and SA2, UA3, RA2, formed an independent cluster. UA2, RA1 and SA1 formed linkage clusters with RA3 as an outlier. The clusters formed to show that PBDEs in the rural zone could be related to solid waste from the suburban and urban zones. Similarly, the homologue dendrogram shows that three clusters were formed with a linkage at hexa-, tetra and tri –BDEs with penta-BDEs as independent *entropy members.* The cluster formation of sample sites and PBDEs homologue suggest that PBDEs originated from a common source

3.8. Principal component analysis (PCA)

The PCA of PBDEs concentrations in the rural, suburban and urban zones soils are presented in Table 4. The PCA for PBDEs were resolved into three components representing 66.284%, 39.924% and 56.345% in the rural, suburban and urban zones respectively. In the rural zone, components 1 and 2 had high positive loading values for tri-, tetra-and penta-BDEs and mono-, di-, tri- hexa-PBDEs respectively. In the suburban zone, components 1, 2, and 3 had positive loading values for di-, tri-and penta-BDEs, tri-, tetra-, hexa-BDEs and mono-BDEs respectively. In the urban zone, components 1, 2, and 3 accounted for high loading for tri-, tetra-, penta, and hexa-BDE, di-BDEs, and mono-BDEs. The high loading of mono-, di-, tri- tetra- penta- hexa-PBDEs depicts the presence of flame retardant additives in thermoplastics, textiles, furniture, electronics, power capacitors, upholstery, building materials, paints, hydraulic fluids, dielectric fluids, cable-wires, and circuit boards as sources of PBDEs in soils from solid waste dump in the rural, suburban, and urban zone (Xing *et al.* 2009; Barakat *et al.* 2013; Yadav *et al.*. 2017; Emoyan *et al.* 2021e).

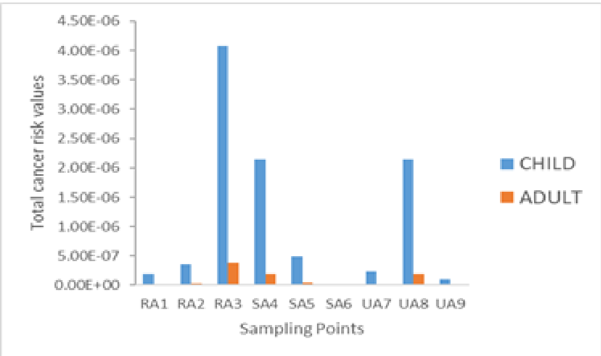

Figure 7. Total cancer risk values of ∑39PBDEs for infants and adults in topsoil. The exposure risk for adults' was greater than for infant's exposure.

4. Conclusions and recommendations

- Thirty-nine PBDEs were investigated and Σ_{39}PBDEs concentrations showed high variability, and sites RA3, RA1, SA4, and UA8 recorded significant concentrations.
- This study indicates highest concentrations of Σ_{39}PBDEs in the rural zone and the topsoil. BDE-10, -11, -13, -15, -17, -99 and -119 were the most detected.
- The tri- and tetra -BDEs concentrations were considerable at sites RA1, RA3, and UA8. Penta-BDEs concentrations were above the FEQG standards and USEPA screening levels in most samples and RQ values for penta-BDE in the rural and suburban zones indicate high and medium ecological risk.
- The non-carcinogenic and cancer risk values depict the potential for onsite exposure risk.
- The hazard index values for infants' exposure were greater than for adults' exposure; this is attributed to exposure duration and smaller body load of infants to soil and/or dust particles at play hours.
- The exposure risk for infants was considerably less than for adults' exposure, suggesting a longer exposure duration for adults.
- Total cancer and hazard index exposure risk is in the order rural > suburban > urban zone. Cluster and PCA evaluations depict that the presence of mono-, di-, tri- tetra- penta- and hexa-PBDEs flame retardant additives used in commercial formulations originated from a common source.
- Our results show that soils from the solid waste sites were polluted, and could act as a reservoir for the detected –BDEs, migrate to contaminate nearby and adjacent aquatic resources and farmlands, this could increase the risk to humans.
- The considerable amount of Σ_{39}PBDEs in the samples suggests continual use of banned flame retardant additives.
- The results highlight the need to establish a standard solid waste management protocol and monitoring of PBDEs and other priory pollutants in environmental and biological samples in similar catchments.

Declarations

Availability of data and materials

All data generated for this study are included in this article and its supplementary materials files

Competing Interest

The authors have no conflict of interest, hence none decleard.

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Author contributions

This sudy was conceptualization and design by Onoriode O. Emoyan. The collection, preparation, and analysis of samples for the determination of PBDEs were done by Onojake Lawson, Godswill O. Tesi, and Eze W. Odali. The compilation and statistical analysis of PBDEs results were done by Onoriode O.Emoyan Godswill O. Tesi, Chijioke Olisah. The first draft of the manuscript was written by Onoriode O. Emoyan, Chijioke Olisah, and Godswill O. Tesi, and Chukwujindu M.A Iwegbue. All authors commented on the previous versions of the manuscript and the review and editing of the final manuscript was by Onoriode O. Emoyan Godswill O. Tesi, and Chijioke Olisah. All authors read and approved the final manuscript.

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Table 1. Soil physicochemical properties from the rural, suburban and urban zones

	RA1			RA2			RA3			SA4			SA5			SA6			UA7			UA8			UA9		
Depth (cm)	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
TOC (%)	0.29	1.36	0.06	0.64	0.09	0.26	0.29	0.12	0.03	0.35	0.2	0.58	1.22	0.23	0.09	0.58	1.57	0.06	0.87	0.58	0.96	0.7	0.44	0.12	1.94	2.29	0.09
EC (µs/cm)	73	54	67	106	74	52	91	124	65	62	61	53	108	83	105	92	44	42	63	80	97	118	77	41	61	76	54
pH	6.8	7.2	5.3	7.8	7.3	6.2	5.6	6.9	5.8	6.7	6.3	4.8	5.4	6.2	5.8	7.4	4.9	5.6	6.9	6.2	6.7	7.5	5.8	5.2	6.3	5.9	6.4

Table 2. Summary of multiple regression of the effect of soil depth on TOC, EC, and pH (Sig. Level = 0.05%)

Parameters	**TOC (%)**	**EC (µs/cm)**	**pH**	**PBDEs**
R-squared	0.1239	0.1523	0.2402	0.1290
Standard Error	0.1368	5.189	0.1699	6.331
F-ratio (1, 25)	3.54	4.49	7.90	3.70
F-Prob.	0.0717	0.0441	0.0095	0.0657

Table 3. Summary Statistics of $\sum_{39}$PBDEs concentration (ng g^{-1} d.w.) in the rural, suburban and urban zones (n=3)

	RA1			RA2			RA3			SA4			SA5			SA6			UA7			UA8			UA9		
	MEAN	**MEDIAN**	**MAX**	**MEAN**	**MEDIAN**	**MAX**	**MEAN**	**MEDIAN**	**MAX**	**MEAN**	**MEDIAN**	**MAX**	**MEAN**	**MEDIAN**	**MAX**	**MEAN**	**MEDIAN**	**MAX**	**MEAN**	**MEDIAN**	**MAX**	**MEAN**	**MEDIAN**	**MAX**	**MEAN**	**MEDIAN**	**MAX**
BDE-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-2	0.15	ND	0.46	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.21	0.01	0.62	0.01	ND	0.02	0.003	0.00	0.01	ND	ND	ND	0.03	0.00	0.08
BDE-3	0.09	0.04	0.23	0.08	0.07	0.17	0.04	0.02	0.09	ND	ND	ND	0.24	0.01	0.72	0.01	0.01	0.02	0.01	0.01	0.03	ND	ND	ND	0.01	0.01	0.02
BDE-7	0.07	0.06	0.15	0.47	0.33	1.08	1.87	1.14	4.43	0.003	ND	0.01	0.77	0.33	1.99	0.02	0.00	0.05	0.06	0.00	0.18	0.003	0.00	0.01	0.23	0.01	0.67
BDE-8	0.14	0.07	0.29	0.19	0.10	0.45	0.24	0.07	0.62	ND	ND	ND	0.13	0.02	0.38	0.003	0.00	0.01	0.05	0.00	0.15	0.34	0.00	1.03	0.62	0.13	1.72
BDE-10	1.09	0.76	1.97	0.83	0.82	1.07	1.55	1.50	2.78	7.35	0.03	22.03	0.21	0.00	0.63	0.89	0.03	2.63	0.26	0.03	0.75	0.01	0.00	0.02	0.21	0.00	0.64
BDE-11	0.42	0.36	0.76	0.62	0.75	1.04	1.06	0.84	2.34	4.72	0.04	14.12	1.13	1.52	1.88	0.98	0.06	2.86	0.39	0.17	1.01	1.25	0.09	3.66	0.44	0.19	1.13
BDE-12	0.67	0.82	1.13	0.94	1.15	1.55	0.38	0.36	0.49	1.04	0.00	3.11	0.32	0.41	0.54	0.04	0.01	0.10	0.29	0.12	0.75	0.02	0.00	0.05	0.19	0.20	0.34
BDE-13	6.55	2.24	17.40	0.95	0.90	1.84	2.68	1.30	5.46	1.96	0.04	5.84	0.13	0.00	0.40	0.12	0.02	0.33	0.43	0.34	0.96	ND	ND	ND	0.79	0.35	2.02
BDE-15	1.27	0.74	2.79	0.30	0.30	0.40	3.93	2.10	8.97	3.21	0.02	9.60	0.80	0.45	1.68	0.20	0.04	0.55	0.58	0.15	1.58	ND	ND	ND	1.30	0.58	3.33
BDE-17	2.66	0.52	7.10	0.52	0.41	1.04	1.80	1.69	3.56	0.01	0.00	0.02	0.08	0.00	0.25	0.05	0.00	0.15	0.49	0.72	0.74	0.72	0.03	2.13	0.16	0.16	0.31

BDE-25	0.79	0.28	1.89	0.16	0.10	0.37	5.48	0.35	16.10	0.01	0.00	0.03	ND	ND	ND	0.01	0.01	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-28	1.25	0.73	2.77	0.11	0.05	0.29	1.07	0.13	3.09	ND	ND	ND	0.03	0.00	0.09	ND	ND	ND	0.17	0.14	0.36	0.003	0.00	0.01	0.02	0.00	0.05
BDE-30	1.14	0.65	2.33	0.53	0.31	1.12	1.07	0.19	2.92	ND	ND	ND	0.10	0.00	0.29	ND	ND	ND	0.09	0.00	0.26	3.97	0.00	11.90	0.003	0.00	0.01
BDE-32	1.22	0.28	3.24	0.13	0.12	0.27	0.90	0.20	2.51	0.09	0.01	0.25	0.66	0.00	1.98	0.003	0.00	0.01	0.07	0.06	0.14	0.003	0.00	0.01	0.01	0.00	0.02
BDE-33	0.54	0.46	0.97	0.16	0.15	0.34	1.59	1.78	2.93	ND	ND	ND	ND	ND	ND	0.04	0.00	0.12	ND	ND	ND	0.003	0.00	0.01	1.02	0.00	3.05
BDE-35	0.16	0.13	0.33	0.08	0.06	0.15	0.98	0.04	2.90	0.05	ND	0.14	0.04	0.00	0.12	0.04	0.01	0.11	ND	ND	ND	0.59	0.01	1.75	ND	ND	ND
BDE-37	1.71	0.76	4.14	0.26	0.21	0.56	0.39	0.50	0.68	1.06	0.01	3.18	0.47	0.23	1.19	0.06	0.00	0.17	0.003	0.00	0.01	0.94	0.00	2.82	0.09	0.03	0.25
BDE-47	0.11	0.11	0.13	0.14	0.18	0.24	0.36	0.14	0.95	ND	ND	ND	0.36	0.00	1.08	ND	ND	ND	ND	ND	ND	1.42	0.00	4.26	0.49	0.00	1.46
BDE-49	0.06	0.01	0.18	0.08	0.06	0.15	1.14	1.08	2.30	ND	ND	ND	0.03	0.00	0.08	0.003	0.00	0.01	0.10	0.06	0.25	0.31	0.00	0.94	ND	ND	ND
BDE-66	0.04	0.03	0.08	0.02	0.01	0.04	0.39	0.38	0.79	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.14	0.10	0.33	ND	ND	ND
BDE-71	0.61	0.32	1.46	0.36	0.24	0.83	0.39	0.01	1.16	ND	ND	ND	0.64	0.86	1.06	0.06	0.01	0.18	0.15	0.00	0.45	5.13	0.00	15.39	ND	ND	ND
BDE-75	0.05	0.03	0.09	0.01	0.00	0.02	0.04	0.02	0.09	0.03	0.00	0.10	0.02	0.01	0.04	ND	ND	ND	ND	ND	ND	0.38	0.02	1.10	ND	ND	ND
BDE-77	0.67	0.16	1.77	1.01	0.6	2.36	0.18	0.23	0.31	0.01	0.01	0.02	0.32	0.00	0.95	0.01	0.00	0.04	ND	ND	ND	1.98	0.00	5.95	ND	ND	ND
BDE-85	0.13	0.15	0.15	2.02	0.49	5.39	5.07	0.75	14.36	0.34	0.01	1.00	0.22	0.00	0.67	0.01	0.01	0.02	0.33	0.41	0.46	0.01	0.00	0.02	0.003	0.00	0.01
BDE-99	0.90	0.56	1.82	1.07	1.45	1.54	0.52	0.29	1.24	0.10	0.00	0.29	0.55	0.55	0.80	0.003	0.00	0.01	0.50	0.12	1.39	0.003	0.00	0.01	ND	ND	ND
BDE-100	0.15	0.02	0.41	0.85	0.89	1.60	1.70	1.68	3.40	0.00	0.00	0.01	0.11	0.07	0.26	ND	ND	ND	0.09	0.02	0.25	0.09	0.12	0.14	0.03	0.00	0.09
BDE-116	0.01	0.00	0.04	0.06	0.04	0.14	0.09	0.02	0.25	ND	ND	ND	0.00	0.00	0.01	0.01	0.00	0.02	0.14	0.00	0.42	ND	ND	ND	0.003	0.00	0.01
BDE-118	0.16	0.14	0.25	1.49	1.65	2.67	10.67	6.83	24.91	0.10	0.01	0.28	ND	ND	ND	ND	ND	ND	0.07	0.00	0.20	ND	ND	ND	0.01	0.00	0.02
BDE-119	3.27	0.14	9.57	1.57	1.66	2.98	11.38	6.89	26.95	0.63	0.00	1.89	0.09	0.02	0.24	0.02	0.00	0.05	0.21	0.24	0.38	1.52	0.03	4.53	ND	ND	ND
BDE-126	0.11	0.09	0.16	0.32	0.15	0.82	0.28	0.00	0.84	ND	ND	ND	0.14	0.00	0.41	0.003	0.00	0.01	0.04	0.00	0.11	ND	ND	ND	ND	ND	ND

BDE-137	0.22	0.24	0.34	0.24	0.35	0.38	0.68	0.71	1.31	0.20	0.00	0.60	1.91	0.00	5.73	0.003	0.00	0.01	0.09	0.00	0.27	0.003	0.00	0.01	0.04	0.02	0.09
BDE-153	0.67	0.55	1.37	0.30	0.35	0.54	0.13	0.09	0.29	0.20	0.00	0.61	0.25	0.08	0.66	ND	ND	ND	0.05	0.06	0.10	1.24	0.02	3.69	ND	ND	ND
BDE-154	0.07	0.05	0.16	0.02	0.02	0.05	0.05	0.01	0.14	0.04	0.03	0.09	0.01	0.00	0.03	ND	ND	ND	0.11	0.00	0.33	0.06	0.01	0.18	ND	ND	ND
BDE-155	0.08	0.09	0.11	0.02	0.01	0.05	0.19	0.05	0.52	ND	ND	ND	ND	ND	ND	0.06	0.00	0.18	0.31	0.18	0.76	1.05	0.01	3.13	0.06	0.00	0.17
BDE-166	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-181	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-183	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-209	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
∑39 PBDE	27.26	11.63	64.36	15.93	17.13	20.30	58.27	46.29	119.00	21.17	0.43	62.84	9.98	8.46	14.15	2.63	0.36	7.42	5.08	5.97	6.77	21.19	0.49	62.62	5.73	2.75	13.01
Mono-BDEs	0.25	0.04	0.70	0.08	0.07	0.17	0.04	0.02	0.09	0.00	0.00	0.01	0.46	0.03	1.35	0.02	0.01	0.04	0.02	0.03	0.03	ND	ND	ND	0.04	0.01	0.10
Di-BDEs	10.21	4.97	24.48	4.31	4.02	5.16	11.72	7.45	22.13	18.29	0.14	54.71	3.50	3.20	5.09	2.23	0.16	6.52	2.06	1.94	3.55	1.62	0.15	4.69	3.77	2.25	8.08
Tri-BDEs	9.47	3.53	22.77	1.96	2.45	2.95	13.30	4.35	34.70	1.22	0.17	3.43	1.38	0.41	3.51	0.20	0.03	0.55	0.81	0.86	0.88	6.22	0.05	18.60	1.29	0.40	3.37
Tetra-BDEs	1.55	1.97	2.09	1.61	1.73	2.50	2.50	3.11	3.97	0.05	0.03	0.11	1.36	1.17	1.95	0.08	0.01	0.23	0.25	0.25	0.51	9.37	0.12	27.98	0.49	0.00	1.46
Penta-BDEs	4.74	0.96	12.33	7.38	8.36	11.98	29.71	31.8	56.61	1.17	0.03	3.46	1.11	1.30	1.30	0.04	0.05	0.08	1.37	0.62	2.96	1.61	0.17	4.53	0.05	0.04	0.09
Hexa-BDEs	1.04	0.92	1.98	0.58	0.84	0.91	1.06	1.44	1.67	0.44	0.09	1.24	2.17	0.66	5.73	0.07	0.02	0.18	0.57	0.76	0.88	2.35	0.18	6.82	0.09	0.09	0.19
Hepta-BDEs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Deca - BDEs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 4. Comparison of Σ_{39}PBDEs concentrations (ng g^{-1}) in this study with others reported in literature

6.5	Site activity	No. of Samples	No. of PBDEs congeners	BDE-47	BDE-99	BDE-119	BDE-153	Total BDEs	Reference
Nigeria	Solid waste dump site	27	39	ND-4.26	ND-1.82	ND-26.95	ND-3.67	0.12-119	This study
Nigeria	Plastic and metal scrap site	18	39	ND-12.5	ND-0.10	ND-0.03	ND-0.33	1.85-302	Emoyan *et al.* (2021)
Bahia Blanca, Argentina	Urban	9	10	-	-	-	-	0.04-10.7	Tombesi *et al.* (2017)
Tibetan Plateau, China	Surface soil	-	42	0.68-900	0.52-1425	0.51-126	3.0-3072	0.02-0.25	Sun *et al.* (2015)
Taizhou, China	Farmland soil	_	14	-	-	-	-	2.96-200	Dong *et al.* (2014)
Southern, China	Road/farmland soil	-	-	-	-	-	-	191-9156	Luo *et al.* (2009)
Yangtze River,, China	Agricultural soils	-	13	-	-	-	-	<1.0-382	Sun *et al.* (2016)
Shanghai, China	Urban surface soil	-	29	-	-	-	-	0.02-3.8	Jiang *et al.* (2010)
Shanghai, China,	Surface soil	-	44	-	-	-	-	0.13-1.23	Jiang *et al.* (2012)
Shanghai, China,	Industrial soils	-	8	-	-	-	-	1.71-64.9	Chem *et al.* (2020)
Shanghai, China,	Agricultural soils	-	8	-	-	-	-	0.72-4.08	Chem *et al.* (2020)
Northern, China	Grassland soils	-	8	-	-	-	-	0.6-3.76	Chem *et al.* (2020)
Hong Kong, China	Organic farm	5	22	1.62	0	0	0	23.5	Man *et al.* (2011)
Hong Kong, China	Agricultural	5	22	1.77	0.71	0.90	2.24	27.5	Man *et al.* (2011)
Hong Kong, China	E-waste storage site	5	22	5.67	4.99	2.06	0	50.5	Man *et al.* (2011)
Hong Kong, China	Open burning site	5	22	12.9	9.3	14.8	55.2	28,111	Man *et al.* (2011)
Hong Kong, China	E-waste dismantling site	5	22	384	236	117	1542	6875	Man *et al.* (2011)
Hong Kong, China	E-waste open burning site	5	22	2287	1410	799	5806	32,337	Man *et al.* (2011)
Birmingham, UK	Urban		6	0.10-0.91	0.12-1.71	0.04-0.41	-	0.40-3.89	Harrad and Hunter (2006)
Birmingham, UK	Rural		6	0.03-0.07	0.09-0.131	0.01-0.03	-	0.07-0.29	Harrad and Hunter (2006)
Mainz, Germany	Urban		8	0.49	0.091	0.29	0.76	1.043	Thorenz *et al.* (2010)
Manaus, Brazil	Urban		8	ND	0.071	0.33	0.50	0.434	Thorenz *et al.* (2010)
Bratislavia, Slovakia	Urban		8	0.065	0.034	0.016	ND	0.161	Thorenz *et al.* (2010)

Table SM1. Values of variables for estimation of human health risk

Parameters	Unit	Definition	Values		References
			Infant	Adult	
Csoil	ng/g	PBDEs concentration in soil			
ABS	-	Dermal absorption factor	0.1	0.1	USEPA, 2011
AF	mg/cm^2	Soil to skin adherences factor	0.2	0.07	USEPA, 2011
BW	Kg	Average body weight	15	60	USEPA, 2001
ED	Year	Exposure duration	6	30	USEPA, 2001

EF	d/yr	Exposure frequency	350	350	
ET	h/d	Exposure time	8	8	USEPA, 1987
IngR	mg/d	Soil ingestion rate for receptor	200	100	USDOE, 2011
SA	cm^2/event	Skin surface area	2800	5700	USDOE, 2011
ATnc	d	Averaging time for non-carcinogenic	ED x 365		USDOE, 2011
ATca	d	Averaging time for carcinogenic	LT x 365		USDOE, 2011
LT	Year	Lifetime	55 years		WHO, 2018
PEF	m^3/kg	Soil to air particulate emission factor	1.36×10^9		USDOE, 2011
CF	kg mg^{-1}	Conversion factor	1×10^{-6}		USDOE (2011)
IUR	mg m^{-3}	Inhalation unit risk	7.0×10^{-4}		USDOE (2011)
SFO	mg/kg/d	Oral slope factor	7.0×10^{-4}		USDOE (2011)

Table SM 2a. Summary Statistics of $\sum_{39}$PBDEs concentrations (ng g^{-1} d.w.) in soils from the Rural Zone

	RA1						RA2						RA3					
	MEAN	**SD**	**MEDIAN**	**MIN**	**MAX**	**CV (%)**	**MEAN**	**SD**	**MEDIAN**	**MIN**	**MAX**	**CV (%)**	**MEAN**	**SD**	**MEDIAN**	**MIN**	**MAX**	**CV (%)**
BDE-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-2	0.15	0.27	ND	ND	0.46	173	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-3	0.09	0.12	0.04	0.01	0.23	128	0.08	0.08	0.07	0.01	0.17	97	0.04	0.05	0.02	ND	0.09	129
BDE-7	0.07	0.07	0.06	0.01	0.15	97	0.47	0.55	0.33	ND	1.08	118	1.87	2.28	1.14	0.05	4.43	122
BDE-8	0.14	0.13	0.07	0.05	0.29	97	0.19	0.23	0.10	0.02	0.45	120	0.24	0.33	0.07	0.03	0.62	137
BDE-10	1.09	0.77	0.76	0.54	1.97	71	0.83	0.23	0.82	0.61	1.07	28	1.55	1.21	1.50	0.37	2.78	78
BDE-11	0.42	0.32	0.36	0.13	0.76	77	0.62	0.50	0.75	0.07	1.04	80	1.06	1.19	0.84	ND	2.34	112
BDE-12	0.67	0.55	0.82	0.07	1.13	81	0.94	0.74	1.15	0.11	1.55	79	0.38	0.10	0.36	0.29	0.49	27
BDE-13	6.55	9.46	2.24	0.02	17.40	144	0.95	0.87	0.90	0.11	1.84	91	2.68	2.41	1.30	1.28	5.46	90
BDE-15	1.27	1.33	0.74	0.29	2.79	105	0.30	0.10	0.30	0.21	0.40	31	3.93	4.42	2.10	0.72	8.97	112
BDE-17	2.66	3.85	0.52	0.36	7.10	145	0.52	0.47	0.41	0.11	1.04	91	1.80	1.70	1.69	0.16	3.56	94
BDE-25	0.79	0.95	0.28	0.21	1.89	120	0.16	0.19	0.10	ND	0.37	122	5.48	9.20	0.35	ND	16.10	168
BDE-28	1.25	1.33	0.73	0.26	2.77	106	0.11	0.16	0.05	ND	0.29	137	1.07	1.75	0.13	ND	3.09	163
BDE-30	1.14	1.04	0.65	0.44	2.33	91	0.53	0.52	0.31	0.16	1.12	97	1.07	1.60	0.19	0.10	2.92	150
BDE-32	1.22	1.75	0.28	0.14	3.24	144	0.13	0.14	0.12	ND	0.27	104	0.90	1.40	0.20	ND	2.51	154
BDE-33	0.54	0.40	0.46	0.18	0.97	75	0.16	0.17	0.15	ND	0.34	104	1.59	1.44	1.78	0.07	2.93	90
BDE-35	0.16	0.16	0.13	0.02	0.33	98	0.08	0.06	0.06	0.04	0.15	70	0.98	1.66	0.04	ND	2.90	170
BDE-37	1.71	2.12	0.76	0.23	4.14	124	0.26	0.28	0.21	ND	0.56	110	0.39	0.35	0.50	ND	0.68	90
BDE-47	0.11	0.02	0.11	0.10	0.13	13	0.14	0.12	0.18	ND	0.24	89	0.36	0.51	0.14	ND	0.95	141
BDE-49	0.06	0.10	0.01	ND	0.18	160	0.08	0.06	0.06	0.04	0.15	70	1.14	1.13	1.08	0.04	2.30	99
BDE-66	0.04	0.04	0.03	0.01	0.08	90	0.02	0.02	0.01	ND	0.04	125	0.39	0.40	0.38	ND	0.79	101
BDE-71	0.61	0.75	0.32	0.05	1.46	123	0.36	0.43	0.24	ND	0.83	120	0.39	0.67	0.01	ND	1.16	171
BDE-75	0.05	0.04	0.03	0.02	0.09	81	0.01	0.01	0.00	ND	0.02	173	0.04	0.05	0.02	ND	0.09	129
BDE-77	0.67	0.95	0.16	0.09	1.77	141	1.01	1.20	0.6	0.06	2.36	119	0.18	0.16	0.23	ND	0.31	89

BDE-85	0.13	0.04	0.15	0.08	0.15	32	2.02	2.92	0.49	0.18	5.39	145	5.07	8.05	0.75	0.11	14.36	159
BDE-99	0.90	0.81	0.56	0.31	1.82	90	1.07	0.74	1.45	0.22	1.54	69	0.52	0.64	0.29	0.03	1.24	122
BDE-100	0.15	0.23	0.02	0.02	0.41	150	0.85	0.78	0.89	0.05	1.60	92	1.70	1.70	1.68	0.01	3.40	100
BDE-116	0.01	0.02	0.00	ND	0.04	173	0.06	0.07	0.04	0.01	0.14	107	0.09	0.14	0.02	ND	0.25	154
BDE-118	0.16	0.08	0.14	0.10	0.25	48	1.49	1.27	1.65	0.15	2.67	85	10.67	12.76	6.83	0.28	24.91	120
BDE-119	3.27	5.45	0.14	0.11	9.57	167	1.57	1.46	1.66	0.07	2.98	93	11.38	13.88	6.89	0.29	26.95	122
BDE-126	0.11	0.04	0.09	0.09	0.16	36	0.32	0.44	0.15	ND	0.82	135	0.28	0.48	0.00	ND	0.84	173
BDE-137	0.22	0.13	0.24	0.09	0.34	56	0.24	0.21	0.35	ND	0.38	87	0.68	0.64	0.71	0.03	1.31	94
BDE-153	0.67	0.64	0.55	0.10	1.37	96	0.30	0.27	0.35	ND	0.54	92	0.13	0.14	0.09	0.02	0.29	105
BDE-154	0.07	0.08	0.05	0.01	0.16	106	0.02	0.03	0.02	ND	0.05	108	0.05	0.08	0.01	ND	0.14	156
BDE-155	0.08	0.04	0.09	0.03	0.11	54	0.02	0.03	0.01	ND	0.05	132	0.19	0.29	0.05	ND	0.52	151
BDE-166	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-181	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-183	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-209	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
∑39 PBDE	27.26	32.26	11.63	5.80	64.36	118	15.93	5.07	17.13	10.37	20.30	32	58.27	55.72	46.29	9.51	119.00	96
Mono-BDEs	0.25	0.39	0.04	0.01	0.70	156	0.08	0.08	0.07	0.01	0.17	97	0.04	0.05	0.02	0.00	0.09	129
Di-BDEs	10.21	12.51	4.97	1.17	24.48	123	4.31	0.75	4.02	3.74	5.16	17	11.72	9.07	7.45	5.57	22.13	77
Tri-BDEs	9.47	11.54	3.53	2.11	22.77	122	1.96	1.30	2.45	0.49	2.95	66	13.30	18.62	4.35	0.85	34.70	140
Tetra-BDEs	1.55	0.83	1.97	0.59	2.09	54	1.61	0.96	1.73	0.60	2.50	59	2.50	1.85	3.11	0.42	3.97	74
Penta-BDEs	4.74	6.57	0.96	0.93	12.33	139	7.38	5.15	8.36	1.81	11.98	70	29.71	28.00	31.8	0.72	56.61	94
Hexa-BDEs	1.04	0.88	0.92	0.23	1.98	84	0.58	0.51	0.84	ND	0.91	87	1.06	0.87	1.44	0.07	1.67	82
Hepta-BDEs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Deca-BDEs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table SM 2b: Summary Statistics of $\sum_{39}$PBDEs concentrations (ng g^{-1} d.w.) in soils from the Suburban Zone

	SA4						SA5						SA6					
	MEAN	**SD**	**MEDIAN**	**MIN**	**MAX**	**CV (%)**	**MEAN**	**SD**	**MEDIAN**	**MIN**	**MAX**	**CV (%)**	**MEAN**	**SD**	**MEDIAN**	**MIN**	**MAX**	**CV (%)**
BDE-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-2	ND	ND	ND	ND	ND	ND	0.21	0.36	0.01	ND	0.62	169	0.01	0.01	ND	ND	0.02	173
BDE-3	ND	ND	ND	ND	ND	ND	0.24	0.41	0.01	ND	0.72	170	0.01	0.01	0.01	ND	0.02	100
BDE-7	0.003	0.01	ND	ND	0.01	173	0.77	1.07	0.33	ND	1.99	138	0.02	0.03	0.00	ND	0.05	173
BDE-8	ND	ND	ND	ND	ND	ND	0.13	0.21	0.02	ND	0.38	160	0.003	0.01	0.00	ND	0.01	173
BDE-10	7.35	12.71	0.03	ND	22.03	173	0.21	0.36	0.00	ND	0.63	173	0.89	1.51	0.03	ND	2.63	170
BDE-11	4.72	8.14	0.04	ND	14.12	172	1.13	1.00	1.52	ND	1.88	88	0.98	1.63	0.06	0.01	2.86	167
BDE-12	1.04	1.80	0.00	ND	3.11	173	0.32	0.28	0.41	ND	0.54	89	0.04	0.06	0.01	ND	0.10	150
BDE-13	1.96	3.36	0.04	0.01	5.84	171	0.13	0.23	0.00	ND	0.40	173	0.12	0.19	0.02	ND	0.33	159
BDE-15	3.21	5.53	0.02	0.02	9.60	172	0.80	0.77	0.45	0.27	1.68	96	0.20	0.30	0.04	0.01	0.55	152
BDE-17	0.01	0.01	0.00	ND	0.02	173	0.08	0.14	0.00	ND	0.25	173	0.05	0.09	0.00	ND	0.15	173

BDE-25	0.01	0.02	0.00	ND	0.03	173	ND	ND	ND	ND	ND	ND	0.01	0.01	0.01	ND	0.01	87
BDE-28	ND	ND	ND	ND	ND	ND	0.03	0.05	0.00	ND	0.09	173	ND	ND	ND	ND	ND	ND
BDE-30	ND	ND	ND	ND	ND	ND	0.10	0.17	0.00	ND	0.29	173	ND	ND	ND	ND	ND	ND
BDE-32	0.09	0.14	0.01	ND	0.25	163	0.66	1.14	0.00	ND	1.98	173	0.003	0.01	0.00	ND	0.01	173
BDE-33	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.04	0.07	0.00	ND	0.12	173
BDE-35	0.05	0.08	ND	ND	0.14	173	0.04	0.07	0.00	ND	0.12	173	0.04	0.06	0.01	ND	0.11	152
BDE-37	1.06	1.83	0.01	ND	3.18	172	0.47	0.63	0.23	ND	1.19	133	0.06	0.10	0.00	ND	0.17	173
BDE-47	ND	ND	ND	ND	ND	ND	0.36	0.62	0.00	ND	1.08	173	ND	ND	ND	ND	ND	ND
BDE-49	ND	ND	ND	ND	ND	ND	0.03	0.05	0.00	ND	0.08	173	0.003	0.01	0.00	ND	0.01	173
BDE-66	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-71	ND	ND	ND	ND	ND	ND	0.64	0.56	0.86	ND	1.06	88	0.06	0.10	0.01	ND	0.18	160
BDE-75	0.03	0.06	0.00	ND	0.10	173	0.02	0.02	0.01	ND	0.04	125	ND	ND	ND	ND	ND	ND
BDE-77	0.01	0.01	0.01	ND	0.02	100	0.32	0.55	0.00	ND	0.95	173	0.01	0.02	0.00	ND	0.04	173
BDE-85	0.34	0.57	0.01	0.01	1.00	168	0.22	0.39	0.00	ND	0.67	173	0.01	0.01	0.01	ND	0.02	100
BDE-99	0.10	0.17	0.00	ND	0.29	173	0.55	0.25	0.55	0.30	0.80	45	0.003	0.01	0.00	ND	0.01	173
BDE-100	0.00	0.01	0.00	ND	0.01	173	0.11	0.13	0.07	ND	0.26	122	ND	ND	ND	ND	ND	ND
BDE-116	ND	ND	ND	ND	ND	ND	0.00	0.01	0.00	ND	0.01	173	0.01	0.01	0.00	ND	0.02	173
BDE-118	0.10	0.16	0.01	ND	0.28	164	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-119	0.63	1.09	0.00	ND	1.89	173	0.09	0.13	0.02	ND	0.24	154	0.02	0.03	0.00	ND	0.05	173
BDE-126	ND	ND	ND	ND	ND	ND	0.14	0.24	0.00	ND	0.41	173	0.003	0.01	0.00	ND	0.01	173
BDE-137	0.20	0.35	0.00	ND	0.60	173	1.91	3.31	0.00	ND	5.73	173	0.003	0.01	0.00	ND	0.01	173
BDE-153	0.20	0.35	0.00	ND	0.61	173	0.25	0.36	0.08	ND	0.66	146	ND	ND	ND	ND	ND	ND
BDE-154	0.04	0.05	0.03	ND	0.09	115	0.01	0.02	0.00	ND	0.03	173	ND	ND	ND	ND	ND	ND
BDE-155	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.06	0.10	0.00	ND	0.18	173
BDE-166	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-181	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-183	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-209	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
∑39 PBDE	21.17	36.08	0.43	0.25	62.84	170	9.98	3.66	8.46	7.32	14.15	37	2.63	4.15	0.36	0.12	7.42	157
Mono-BDEs	0.00	0.01	0.00	ND	0.01	173	0.46	0.77	0.03	ND	1.35	168	0.02	0.02	0.01	ND	0.04	125
Di-BDEs	18.29	31.54	0.14	0.03	54.71	172	3.50	1.46	3.20	2.21	5.09	42	2.23	3.71	0.16	0.02	6.52	166
Tri-BDEs	1.22	1.92	0.17	0.05	3.43	158	1.38	1.84	0.41	0.23	3.51	133	0.20	0.31	0.03	0.01	0.55	156
Tetra-BDEs	0.05	0.06	0.03	ND	0.11	122	1.36	0.53	1.17	0.95	1.95	39	0.08	0.13	0.01	ND	0.23	163
Penta-BDEs	1.17	1.99	0.03	0.01	3.46	170	1.11	0.32	1.30	0.74	1.30	29	0.04	0.04	0.05	ND	0.08	93
Hexa-BDEs	0.44	0.69	0.09	ND	1.24	156	2.17	3.09	0.66	0.12	5.73	143	0.07	0.10	0.02	ND	0.18	148
Hepta-BDEs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Deca-BDEs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table SM 2c: Summary Statistics of $\sum_{39}$PBDEs concentrations (ng g^{-1} d.w.) in soils from the Urban Zone

	UA7						UA8						UA9					
	MEAN	SD	MEDIAN	MIN	MAX	CV (%)	MEAN	SD	MEDIAN	MIN	MAX	CV (%)	MEAN	SD	MEDIAN	MIN	MAX	CV (%)
BDE-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-2	0.003	0.01	0.00	ND	0.01	173	ND	ND	ND	ND	ND	ND	0.03	0.05	0.00	ND	0.08	173
BDE-3	0.01	0.02	0.01	ND	0.03	115	ND	ND	ND	ND	ND	ND	0.01	0.01	0.01	ND	0.02	100
BDE-7	0.06	0.10	0.00	ND	0.18	173	0.003	0.01	0.00	ND	0.01	173	0.23	0.38	0.01	0.01	0.67	166
BDE-8	0.05	0.09	0.00	ND	0.15	173	0.34	0.59	0.00	ND	1.03	173	0.62	0.95	0.13	0.01	1.72	154
BDE-10	0.26	0.42	0.03	ND	0.75	163	0.01	0.01	0.00	ND	0.02	173	0.21	0.37	0.00	ND	0.64	173
BDE-11	0.39	0.54	0.17	ND	1.01	137	1.25	2.09	0.09	ND	3.66	167	0.44	0.61	0.19	ND	1.13	138
BDE-12	0.29	0.40	0.12	ND	0.75	139	0.02	0.03	0.00	ND	0.05	173	0.19	0.16	0.20	0.03	0.34	82
BDE-13	0.43	0.49	0.34	ND	0.96	112	ND	ND	ND	ND	ND	ND	0.79	1.08	0.35	ND	2.02	137
BDE-15	0.58	0.87	0.15	ND	1.58	151	ND	ND	ND	ND	ND	ND	1.30	1.78	0.58	ND	3.33	136
BDE-17	0.49	0.42	0.72	ND	0.74	87	0.72	1.22	0.03	ND	2.13	170	0.16	0.16	0.16	ND	0.31	99
BDE-25	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-28	0.17	0.18	0.14	ND	0.36	109	0.003	0.01	0.00	ND	0.01	173	0.02	0.03	0.00	ND	0.05	173
BDE-30	0.09	0.15	0.00	ND	0.26	173	3.97	6.87	0.00	ND	11.90	173	0.003	0.01	0.00	ND	0.01	173
BDE-32	0.07	0.07	0.06	ND	0.14	105	0.003	0.01	0.00	ND	0.01	173	0.01	0.01	0.00	ND	0.02	173
BDE-33	ND	ND	ND	ND	ND	ND	0.003	0.01	0.00	ND	0.01	173	1.02	1.76	0.00	ND	3.05	173
BDE-35	ND	ND	ND	ND	ND	ND	0.59	1.01	0.01	ND	1.75	172	ND	ND	ND	ND	ND	ND
BDE-37	0.003	0.01	0.00	ND	0.01	173	0.94	1.63	0.00	ND	2.82	173	0.09	0.14	0.03	ND	0.25	146
BDE-47	ND	ND	ND	ND	ND	ND	1.42	2.46	0.00	ND	4.26	173	0.49	0.84	0.00	ND	1.46	173
BDE-49	0.10	0.13	0.06	ND	0.25	126	0.31	0.54	0.00	ND	0.94	173	ND	ND	ND	ND	ND	ND
BDE-66	ND	ND	ND	ND	ND	ND	0.14	0.17	0.10	ND	0.33	118	ND	ND	ND	ND	ND	ND
BDE-71	0.15	0.26	0.00	ND	0.45	173	5.13	8.89	0.00	ND	15.39	173	ND	ND	ND	ND	ND	ND
BDE-75	ND	ND	ND	ND	ND	ND	0.38	0.62	0.02	0.02	1.10	164	ND	ND	ND	ND	ND	ND
BDE-77	ND	ND	ND	ND	ND	ND	1.98	3.44	0.00	ND	5.95	173	ND	ND	ND	ND	ND	ND
BDE-85	0.33	0.18	0.41	0.13	0.46	53	0.01	0.01	0.00	ND	0.02	173	0.003	0.01	0.00	ND	0.01	173
BDE-99	0.50	0.77	0.12	ND	1.39	153	0.003	0.01	0.00	ND	0.01	173	ND	ND	ND	ND	ND	ND
BDE-100	0.09	0.14	0.02	ND	0.25	154	0.09	0.08	0.12	ND	0.14	87	0.03	0.05	0.00	ND	0.09	173
BDE-116	0.14	0.24	0.00	ND	0.42	173	ND	ND	ND	ND	ND	ND	0.003	0.01	0.00	ND	0.01	173
BDE-118	0.07	0.12	0.00	ND	0.20	173	ND	ND	ND	ND	ND	ND	0.01	0.01	0.00	ND	0.02	173
BDE-119	0.21	0.19	0.24	ND	0.38	93	1.52	2.61	0.03	ND	4.53	171	ND	ND	ND	ND	ND	ND
BDE-126	0.04	0.06	0.00	ND	0.11	173	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-137	0.09	0.16	0.00	ND	0.27	173	0.003	0.01	0.00	ND	0.01	173	0.04	0.05	0.02	ND	0.09	129

BDE-153	0.05	0.05	0.06	ND	0.10	94	1.24	2.12	0.02	ND	3.69	172	ND	ND	ND	ND	ND	ND
BDE-154	0.11	0.19	0.00	ND	0.33	173	0.06	0.10	0.01	ND	0.18	160	ND	ND	ND	ND	ND	ND
BDE-155	0.31	0.40	0.18	ND	0.76	127	1.05	1.80	0.01	ND	3.13	172	0.06	0.10	0.00	ND	0.17	173
BDE-166	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-181	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-183	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BDE-209	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
∑39 PBDE	5.08	2.26	5.97	2.51	6.77	45	21.19	35.88	0.49	0.46	62.62	169	5.73	6.34	2.75	1.44	13.01	111
Mono-BDEs	0.02	0.02	0.03	ND	0.03	87	ND	ND	ND	ND	ND	ND	0.04	0.06	0.01	ND	0.10	150
Di-BDEs	2.06	1.43	1.94	0.69	3.55	70	1.62	2.66	0.15	0.02	4.69	164	3.77	3.78	2.25	0.99	8.08	100
Tri-BDEs	0.81	0.11	0.86	0.68	0.88	14	6.22	10.72	0.05	0.02	18.60	172	1.29	1.80	0.40	0.11	3.37	140
Tetra-BDEs	0.25	0.26	0.25	ND	0.51	101	9.37	16.11	0.12	0.02	27.98	172	0.49	0.84	0.00	ND	1.46	173
Penta-BDEs	1.37	1.37	0.62	0.54	2.96	100	1.61	2.53	0.17	0.14	4.53	157	0.05	0.04	0.04	0.01	0.09	87
Hexa-BDEs	0.57	0.44	0.76	0.06	0.88	78	2.35	3.87	0.18	0.05	6.82	165	0.09	0.10	0.09	ND	0.19	102
Hepta-BDEs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Deca-BDEs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table SM3: ANOVA of PBDEs in the dumpsite soil with respect to locations

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3140.96	2	1570.48	2.141155	0.13943	3.402826
Within Groups	17603.36	24	733.4734			
Total	20744.32	26				

Table SM4: PCA of PBDEs homologues in soils from the rural, suburban and urban zones

	Rural		Suburban			Urban		
	Component		Component			Component		
	1	2	1	2	3	1	2	3
MonoBDEs	-0.107	0.946	0.014	0.009	0.984	-0.112	-0.105	0.986
DiBDEs	0.472	0.833	0.987	-0.085	-0.124	0.202	0.973	-0.109
TriBDEs	0.684	0.661	0.696	0.661	-0.185	0.949	0.266	-0.114
TetraBDEs	0.910	0.139	-0.098	0.912	0.297	0.977	0.148	-0.096
PentaBDEs	0.976	0.153	0.952	0.121	0.186	0.738	0.035	-0.177
HexaBDEs	0.469	0.697	0.140	0.963	-0.183	0.963	0.124	-0.068
% Variance	66.284	21.334	39.924	36.970	19.568	56.345	21.793	21.678
Cumm Var. %	66.284	87.618	39.924	76.894	96.462	56.345	78.138	100.00

Table SM5: Risk Quotients (RQs) of tri-, tetr-, pent-, and hexa-BDEs in soils

Locations	Tri-BDEs	Tetra-BDEs	Penta-BDEs	Hexa-BDEs
Rural	0.038	0.005	6.018	0.001

	0.049	0.011	2.073	0.001
	0.019	0.004	2.247	0.000
	0.021	0.012	0.139	0.000
	0.017	0.001	10.269	0.000
	0.017	0.016	13.517	0.000
	0.009	0.000	0.601	0.000
	0.018	0.000	0.000	0.000
Sub-urban	0.001	0.003	0.476	0.002
	0.000	0.000	0.541	0.000
	0.000	0.000	0.096	0.000
	0.001	0.006	0.009	0.000
	0.006	0.000	0.081	0.000
	0.000	0.003	0.614	0.000
	0.001	0.000	0.118	0.000
	0.012	0.000	0.000	0.000
Urban	0.010	0.016	0.283	0.000
	0.000	0.004	0.422	0.001
	0.001	0.001	0.175	0.000
	0.031	0.045	0.119	0.001
	0.001	0.003	0.063	0.000
	0.008	0.017	1.440	0.000
	0.004	0.000	0.031	0.000
	0.008	0.000	0.000	0.000

Table SM6: Hazard index of BDE-47, -99, -153 and $\sum_{39}$PBDEs in soils from infant's exposure

		BDE-47				BDE-99				BDE-153				∑39 BDE			
Sites	**Depth**	**HQIng**	**HQInh**	**HQDerm**	**HI**	**HQIng**	**HQInh**	**HQDerm**	**HI**	**HQIng**	**HQInh**	**HQDerm**	**HI**	**HQIng**	**HQInh**	**HQDerm**	**HI**
RA1	0-15 cm	1.69E-03	3.72E-07	4.73E-04	2.16E-03	7.11E-03	1.57E-06	1.99E-03	9.10E-03	3.49E-03	7.70E-07	9.77E-05	3.59E-03	1.06E-02	2.34E-06	2.97E-03	1.36E-02
	15-30 cm	1.43E-03	3.16E-07	4.01E-04	1.83E-03	2.32E-02	5.13E-06	6.51E-03	2.98E-02	8.77E-03	1.93E-06	2.46E-04	9.02E-03	1.18E-01	2.59E-05	3.29E-02	1.50E-01
	30-45 cm	1.25E-03	2.76E-07	3.51E-04	1.60E-03	3.96E-03	8.74E-07	1.11E-03	5.07E-03	6.39E-04	1.41E-07	1.79E-05	6.57E-04	2.12E-02	4.68E-06	5.95E-03	2.72E-02
RA2	0-15 cm	2.28E-03	5.02E-07	6.37E-04	2.91E-03	2.84E-03	6.26E-07	7.95E-04	3.63E-03	3.46E-03	7.64E-07	9.70E-05	3.56E-03	1.89E-02	4.18E-06	5.30E-03	2.42E-02
	15-30 cm	3.02E-03	6.66E-07	8.45E-04	3.86E-03	1.86E-02	4.10E-06	5.20E-03	2.38E-02	2.25E-03	4.96E-07	6.30E-05	2.31E-03	3.13E-02	6.90E-06	8.76E-03	4.01E-02
	30-45 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.97E-02	4.35E-06	5.52E-03	2.52E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.71E-02	8.18E-06	1.04E-02	4.75E-02
RA3	0-15 cm	1.22E-02	2.69E-06	3.42E-03	1.56E-02	1.59E-02	3.50E-06	4.44E-03	2.03E-02	1.87E-03	4.12E-07	5.23E-05	1.92E-03	2.18E-01	4.80E-05	6.09E-02	2.79E-01
	15-30 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.76E-03	8.29E-07	1.05E-03	4.81E-03	5.50E-04	1.21E-07	1.54E-05	5.65E-04	8.46E-02	1.87E-05	2.37E-02	1.08E-01
	30-45 cm	1.76E-03	3.89E-07	4.94E-04	2.26E-03	3.84E-04	8.46E-08	1.07E-04	4.91E-04	1.41E-04	3.10E-08	3.94E-06	1.45E-04	1.74E-02	3.83E-06	4.86E-03	2.22E-02
SA4	0-15 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.66E-03	8.07E-07	1.02E-03	4.68E-03	3.87E-03	8.55E-07	1.08E-04	3.98E-03	1.15E-01	2.53E-05	3.21E-02	1.47E-01
	15-30 cm	5.11E-05	1.13E-08	1.43E-05	6.55E-05	2.56E-05	5.64E-09	7.16E-06	3.27E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.49E-04	9.91E-08	1.26E-04	5.75E-04
	30-45 cm	2.56E-05	5.64E-09	7.16E-06	3.27E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.85E-04	1.73E-07	2.20E-04	1.01E-03
SA5	0-15 cm	1.38E-02	3.05E-06	3.87E-03	1.77E-02	3.81E-03	8.40E-07	1.07E-03	4.88E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.59E-02	5.70E-06	7.24E-03	3.31E-02

	15-30 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.03E-02	2.26E-06	2.87E-03	1.31E-02	4.23E-03	9.34E-07	1.18E-04	4.35E-03	1.55E-02	3.41E-06	4.33E-03	1.98E-02
	30-45 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.01E-03	1.55E-06	1.96E-03	8.97E-03	5.24E-04	1.16E-07	1.47E-05	5.39E-04	1.34E-02	2.95E-06	3.74E-03	1.71E-02
SA6	0-15 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.54E-04	1.44E-07	1.83E-04	8.37E-04
	15-30 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-04	2.26E-08	2.86E-05	1.31E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E-02	2.99E-06	3.79E-03	1.73E-02
	30-45 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.11E-05	1.13E-08	1.43E-05	6.55E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.16E-04	4.75E-08	6.03E-05	2.76E-04
UA7	0-15 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-02	3.92E-06	4.98E-03	2.28E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-02	2.73E-06	3.46E-03	1.58E-02
	15-30 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.26E-04	1.38E-07	1.75E-05	6.44E-04	1.09E-02	2.40E-06	3.05E-03	1.40E-02
	30-45 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.48E-03	3.27E-07	4.15E-04	1.90E-03	3.84E-04	8.46E-08	1.07E-05	3.94E-04	4.58E-03	1.01E-06	1.28E-03	5.86E-03
UA8	0-15 cm	5.45E-02	1.20E-05	1.53E-02	6.98E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.36E-02	5.20E-06	6.60E-04	2.42E-02	1.14E-01	2.52E-05	3.20E-02	1.46E-01
	15-30 cm	2.56E-05	5.64E-09	7.16E-06	3.27E-05	7.67E-05	1.69E-08	2.15E-05	9.82E-05	1.41E-04	3.10E-08	3.94E-06	1.45E-04	8.33E-04	1.84E-07	2.33E-04	1.07E-03
	30-45 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.56E-05	5.64E-09	7.16E-06	3.27E-05	1.28E-05	2.82E-09	3.58E-07	1.31E-05	8.99E-04	1.98E-07	2.52E-04	1.15E-03
UA9	0-15 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.03E-03	1.11E-06	1.41E-03	6.44E-03
	15-30 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.11E-05	1.13E-08	1.43E-05	6.55E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.63E-03	5.79E-07	7.35E-04	3.36E-03
	30-45 cm	1.87E-02	4.12E-06	5.23E-03	2.39E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.38E-02	5.24E-06	6.65E-03	3.04E-02

Table SM7. Hazard index of BDE-47, -99, -153 and $\sum_{39}$PBDEs in soils from adult exposure

		BDE-47				BDE-99				BDE-153				∑39 BDE			
Sites	**Depth**	**HQIng**	**HQInh**	**HQDerm**	**HI**	**HQIng**	**HQInh**	**HQDerm**	**HI**	**HQIng**	**HQInh**	**HQDerm**	**HI**	**HQIng**	**HQInh**	**HQDerm**	**HI**
RA1	0-15 cm	2.20E-04	1.55E-06	8.42E-05	3.06E-04	9.27E-04	6.53E-06	3.55E-04	1.29E-03	4.55E-04	3.21E-06	1.74E-05	4.76E-04	1.38E-03	9.74E-06	5.29E-04	1.92E-03
	15-30 cm	1.87E-04	1.32E-06	7.14E-05	2.59E-04	3.03E-03	2.14E-05	1.16E-03	4.21E-03	1.14E-03	8.06E-06	4.37E-05	1.20E-03	1.53E-02	1.08E-04	5.86E-03	2.13E-02
	30-45 cm	1.63E-04	1.15E-06	6.25E-05	2.27E-04	5.17E-04	3.64E-06	1.98E-04	7.18E-04	8.33E-05	5.88E-07	3.19E-06	8.71E-05	2.77E-03	1.95E-05	1.06E-03	3.85E-03
RA2	0-15 cm	2.97E-04	2.09E-06	1.14E-04	4.12E-04	3.70E-04	2.61E-06	1.42E-04	5.14E-04	4.52E-04	3.18E-06	1.73E-05	4.72E-04	2.47E-03	1.74E-05	9.44E-04	3.43E-03
	15-30 cm	3.93E-04	2.77E-06	1.50E-04	5.47E-04	2.42E-03	1.71E-05	9.26E-04	3.36E-03	2.93E-04	2.07E-06	1.12E-05	3.07E-04	4.08E-03	2.88E-05	1.56E-03	5.67E-03
	30-45 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.57E-03	1.81E-05	9.83E-04	3.57E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.83E-03	3.41E-05	1.85E-03	6.72E-03
RA3	0-15 cm	1.59E-03	1.12E-05	6.08E-04	2.21E-03	2.07E-03	1.46E-05	7.91E-04	2.87E-03	2.43E-04	1.72E-06	9.31E-06	2.54E-04	2.84E-02	2.00E-04	1.09E-02	3.94E-02
	15-30 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-04	3.45E-06	1.87E-04	6.81E-04	7.17E-05	5.05E-07	2.74E-06	7.49E-05	1.10E-02	7.77E-05	4.22E-03	1.53E-02
	30-45 cm	2.30E-04	1.62E-06	8.80E-05	3.20E-04	5.00E-05	3.53E-07	1.91E-05	6.95E-05	1.83E-05	1.29E-07	7.01E-07	1.92E-05	2.26E-03	1.60E-05	8.66E-04	3.15E-03
SA4	0-15 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.77E-04	3.36E-06	1.82E-04	6.62E-04	5.05E-04	3.56E-06	1.93E-05	5.28E-04	1.50E-02	1.05E-04	5.72E-03	2.08E-02

	15-30 cm	6.67E-06	4.70E-08	2.55E-06	9.26E-06	3.33E-06	2.35E-08	1.28E-06	4.63E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.86E-05	4.13E-07	2.24E-05	8.14E-05
	30-45 cm	3.33E-06	2.35E-08	1.28E-06	4.63E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-04	7.22E-07	3.92E-05	1.42E-04
SA5	0-15 cm	1.80E-03	1.27E-05	6.89E-04	2.50E-03	4.97E-04	3.50E-06	1.90E-04	6.90E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.37E-03	2.38E-05	1.29E-03	4.68E-03
	15-30 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.34E-03	9.42E-06	5.11E-04	1.86E-03	5.52E-04	3.89E-06	2.11E-05	5.77E-04	2.01E-03	1.42E-05	7.71E-04	2.80E-03
	30-45 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.13E-04	6.44E-06	3.49E-04	1.27E-03	6.83E-05	4.82E-07	2.61E-06	7.14E-05	1.74E-03	1.23E-05	6.67E-04	2.42E-03
SA6	0-15 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.52E-05	6.01E-07	3.26E-05	1.18E-04
	15-30 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.33E-05	9.40E-08	5.10E-06	1.85E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.77E-03	1.24E-05	6.76E-04	2.45E-03
	30-45 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.67E-06	4.70E-08	2.55E-06	9.26E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.81E-05	1.98E-07	1.07E-05	3.90E-05
UA7	0-15 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.32E-03	1.63E-05	8.86E-04	3.22E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.61E-03	1.14E-05	6.17E-04	2.24E-03
	15-30 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.17E-05	5.76E-07	3.12E-06	8.54E-05	1.42E-03	1.00E-05	5.44E-04	1.97E-03
	30-45 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.93E-04	1.36E-06	7.40E-05	2.69E-04	5.00E-05	3.53E-07	1.91E-06	5.23E-05	5.97E-04	4.21E-06	2.28E-04	8.30E-04
UA8	0-15 cm	7.10E-03	5.01E-05	2.72E-03	9.87E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.07E-03	2.17E-05	1.18E-04	3.21E-03	1.49E-02	1.05E-04	5.70E-03	2.07E-02
	15-30 cm	3.33E-06	2.35E-08	1.28E-06	4.63E-06	1.00E-05	7.05E-08	3.83E-06	1.39E-05	1.83E-05	1.29E-07	7.01E-07	1.92E-05	1.09E-04	7.66E-07	4.15E-05	1.51E-04
	30-45 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.33E-06	2.35E-08	1.28E-06	4.63E-06	1.67E-06	1.18E-08	6.38E-08	1.74E-06	1.17E-04	8.26E-07	4.48E-05	1.63E-04
UA9	0-15 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.55E-04	4.62E-06	2.51E-04	9.11E-04
	15-30 cm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.67E-06	4.70E-08	2.55E-06	9.26E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.42E-04	2.41E-06	1.31E-04	4.76E-04
	30-45 cm	2.43E-03	1.72E-05	9.31E-04	3.38E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-03	2.18E-05	1.19E-03	4.30E-03

Table SM8. Total Cancer Risk based on $\sum_{39}$PBDEs in the soils.

		CHILD				ADULT			
Sites	**Depth**	**RiskIng**	**RiskInh**	**RiskDerm**	**Total Cancer Risk**	**RiskIng**	**RiskInh**	**RiskDerm**	**Total Cancer Risk**
RA1	0-15 cm	5.19E-08	1.36E-09	1.45E-07	1.99E-07	3.54E-09	7.44E-10	1.41E-08	1.84E-08
	15-30 cm	5.76E-07	1.51E-08	1.61E-06	2.20E-06	3.93E-08	8.25E-09	1.57E-07	2.04E-07

	30-45 cm	1.04E-07	2.73E-09	2.91E-07	3.98E-07	7.10E-09	1.49E-09	2.83E-08	3.69E-08
RA2	0-15 cm	9.28E-08	2.44E-09	2.60E-07	3.55E-07	6.33E-09	1.33E-09	2.52E-08	3.29E-08
	15-30 cm	1.53E-07	4.03E-09	4.29E-07	5.87E-07	1.05E-08	2.20E-09	4.17E-08	5.44E-08
	30-45 cm	1.82E-07	4.77E-09	5.09E-07	6.95E-07	1.24E-08	2.60E-09	4.94E-08	6.44E-08
RA3	0-15 cm	1.07E-06	2.80E-08	2.99E-06	4.08E-06	7.27E-08	1.53E-08	2.90E-07	3.78E-07
	15-30 cm	4.14E-07	1.09E-08	1.16E-06	1.59E-06	2.82E-08	5.93E-09	1.13E-07	1.47E-07
	30-45 cm	8.51E-08	2.24E-09	2.38E-07	3.26E-07	5.80E-09	1.22E-09	2.32E-08	3.02E-08
SA4	0-15 cm	5.62E-07	1.48E-08	1.57E-06	2.15E-06	3.83E-08	8.06E-09	1.53E-07	1.99E-07
	15-30 cm	2.20E-09	5.78E-11	6.16E-09	8.42E-09	1.50E-10	3.15E-11	5.99E-10	7.81E-10
	30-45 cm	3.85E-09	1.01E-10	1.08E-08	1.47E-08	2.62E-10	5.51E-11	1.05E-09	1.36E-09
SA5	0-15 cm	1.27E-07	3.33E-09	3.55E-07	4.85E-07	8.64E-09	1.81E-09	3.45E-08	4.49E-08
	15-30 cm	7.57E-08	1.99E-09	2.12E-07	2.90E-07	5.16E-09	1.08E-09	2.06E-08	2.69E-08
	30-45 cm	6.55E-08	1.72E-09	1.83E-07	2.51E-07	4.47E-09	9.38E-10	1.78E-08	2.32E-08
SA6	0-15 cm	3.20E-09	8.41E-11	8.97E-09	1.23E-08	2.18E-10	4.59E-11	8.72E-10	1.14E-09
	15-30 cm	6.64E-08	1.74E-09	1.86E-07	2.54E-07	4.53E-09	9.51E-10	1.81E-08	2.35E-08
	30-45 cm	1.06E-09	2.77E-11	2.96E-09	4.04E-09	7.20E-11	1.51E-11	2.87E-10	3.74E-10
UA7	0-15 cm	6.06E-08	1.59E-09	1.70E-07	2.32E-07	4.13E-09	8.68E-10	1.65E-08	2.15E-08
	15-30 cm	5.34E-08	1.40E-09	1.50E-07	2.04E-07	3.64E-09	7.65E-10	1.45E-08	1.89E-08
	30-45 cm	2.24E-08	5.89E-10	6.28E-08	8.59E-08	1.53E-09	3.22E-10	6.11E-09	7.96E-09
UA8	0-15 cm	5.60E-07	1.47E-08	1.57E-06	2.14E-06	3.82E-08	8.03E-09	1.52E-07	1.99E-07
	15-30 cm	4.08E-09	1.07E-10	1.14E-08	1.56E-08	2.78E-10	5.85E-11	1.11E-09	1.45E-09
	30-45 cm	4.40E-09	1.16E-10	1.23E-08	1.68E-08	3.00E-10	6.31E-11	1.20E-09	1.56E-09
UA9	0-15 cm	2.46E-08	6.47E-10	6.90E-08	9.42E-08	1.68E-09	3.53E-10	6.70E-09	8.73E-09
	15-30 cm	1.29E-08	3.38E-10	3.60E-08	4.92E-08	8.77E-10	1.84E-10	3.50E-09	4.56E-09
	30-45 cm	1.16E-07	3.06E-09	3.26E-07	4.46E-07	7.94E-09	1.67E-09	3.17E-08	4.13E-08