FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 14, June, 2026, pp 353 – 360
DOI: https://doi.org/10.33003/fjs-2026-1014-5673

Polybrominated Diphenyl Ethers in Dust from the Vicinity of Power Generation Plants in Nigeria: Distribution, Risks Assessment and Source Apportionment

*[1,2]Juliet N. Tesi, [1]Iwekumo E. Agbozu, [1]Oghenekohwiroro Edjere, [2]Oghenenyerhovwo E. Ididama, and [2]Godswill O. Tesi

[1]Department of Environmental Management and Toxicology, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria.
[2]Department of Chemistry, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria.

*Corresponding authors' email: tesi.godswill@fupre.edu.ng

ABSTRACT

Polybrominated diphenyl ethers (PBDEs) constitute a class of widespread environmental contaminants that pose significant health risks. Therefore, this study investigated the distribution, risks and sources of PBDEs in dusts from power generation plants in Nigeria. A total of 24 dust samples were collected from four power plants. Samples were collected for six months covering both wet and dry seasons. Dusts were extracted for PBDEs following the United State Environmental Protection Agency Method 3550C using a 1:1 mixture of dichloromethane and n-hexane. Thereafter, the extracts were cleaned-up and analyzed for PBDEs using a gas chromatograph-mass spectrometer. The results indicated that the mean concentrations of ∑39 PBDEs in the dusts ranged from 17.5 to 54.6 ng g^{-1} for wet season and 55.4 to 157 ng g^{-1} for dry season. There were significant spatio-temporal variations in the concentrations of PBDEs in the dust. The PBDEs have higher concentrations during the dry season than the wet season. The hazard index and total cancer risk values indicated that there is neither adverse non-carcinogenic risk nor carcinogenic risk from exposure to PBDEs in these dusts. Source apportionment indicated that the PBDEs in the dusts were from the use of deca- and penta-BDE commercial formulations used for dielectric insulating fluids for transformers, capacitors, cable insulators etc. It is hereby recommended that the Federal Ministry of Environment should establish environmental policy and enforceable regulatory frameworks for the control of PBDEs in order to minimize the levels environmental PBDEs and the risk to human and ecosystems.

Received: 03 Aug. 2026
Accepted: 20 Aug. 2026
Published: 27 Aug. 2026

Keywords: PBDEs, Dust, Power plants, Flame retardants, Risk assessment

INTRODUCTION

Polybrominated diphenyl ethers (PBDEs) constitute a class of widespread environmental contaminants that pose significant health risks. These compounds are industrially produced chemicals that have been utilized since the 1970s as flame retardants in plastics, textiles, furniture, and electric and electronic devices (Nakajima *et al*., 2022, Bramwell *et al*., 2016). Three major commercial formulations of PBDEs have been manufactured: Penta-BDE comprising of PBDEs 47, 99, 100 and 153, Octa-BDE comprising primarily PBDEs 153, 183, 197, 207, and 196 and Deca-BDE is made up of PBDE 209. The Penta-BDE mixtures has been widely utilized in polyurethane foam for mattresses, furniture, and upholstery as well as electronic equipment, including fax machine, computers, and televisions, while octa-BDE have added to thermoplastic resins, particularly acrylonitrile butadiene styrene (ABS) plastics and deca-BDE is incorporated into high-impact polystyrene (HIPS) used in production of casings for electrical and electronic equipment, as well as in clothing fabric, building materials, and polypropylene drapery (Jin *et al*., 2022). PBDEs possess molecular structures and physicochemical properties that closely resemble those of other persistent organic pollutants (POPs), including polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins, and polychlorinated dibenzofurans (PCDD/Fs). They can readily leach from polymeric material in which they are incorporated into the environment during manufacturing, use, and disposal because they are not chemically bound to the polymer matrix through covalent bond (Iwegbue *et al*., 2025, Gevao *et al*., 2011). As POPs, PBDEs are highly resistant to degradation and can persist in various environmental matrices, including air, dust, water, soil, and sediments (Yang *et al*., 2025, Ohoro *et al*., 2021, Han *et al*., 2016). They also have a strong tendency to bioaccumulate in living organisms, including humans. Numerous studies have demonstrated that exposure to PBDEs is associated with adverse effects on the endocrine system, neurodevelopment, reproductive health, and immune function (Gomes *et al*., 2024, Lin *et al*., 2024). Owing to these environmental and health concerns, PBDEs have been designated as priority-controlled substances under the Stockholm Convention on POPs, leading to stringent regulations and restrictions on their production and use in several major jurisdictions, including the European Union, China, and United State (Yang *et al*., 2025). Despite regulatory prohibition, human exposure to these compounds remains ongoing, attributable to their persistent nature and their continued occurrence in older consumer goods still in circulation (Iwegbue *et al*., 2025, Wu *et al*., 2021).

Globally, the release of contaminants into the environment has been driven primarily by anthropogenic activities, including traffic and transportation systems, petroleum refining, industrial manufacturing and services, power generation plants, and gas flaring, among others. Of these processes, power generation plants have been identified as the foremost contributor to global environment pollution (Okedere *et al*., 2021). In Nigeria, power generation from thermal plants has relied almost exclusively on the combustion of the country's abundant natural gas reserves (Adesanmi *et al*., 2019., Igbokwe *et al*., 2015). The consumption of this resource, along with the resultant emissions into the environment causes contaminants including PBDEs to adhere to dust particles, which accumulate on surfaces of items and diffuse into various environmental compartments (Adesanmi *et al*., 2019).

Dust serves as a complex mixture of small particles that collects and holds both synthetic and naturally occurring contaminants (Iwegbue *et al*., 2025). Power generation plants release dust containing PBDEs which people (workers, nearby communities) are exposed to through multiple pathways such as ingestion, inhalation and dermal contacts. This exposure raises significant health concerns, particularly because these chemical compounds are toxic and individuals (workers) spend considerable time in such vicinity. Research across the United States and other nations, such as Nigeria, has consistently identified elevated concentrations of PBDEs in household dust, particularly in residential environments (Iwegbue *et al*., 2025, Emebu *et al*., 2024, Araujo *et al*., 2024, Choi *et al*., 2023, Qui, *et al*., 2023, Zandona *et al*., 2022, Ohoro *et al*., 2021, Adeyi *et al*., 2020, Oloruntoba *et al*., 2019, Iwegbue *et al*., 2019). This finding is significant because it demonstrated that dust inhalation represents the primary pathway through which people are exposed to PBDEs. According to Ohoro *et al*. (2021), dust contact may account for a substantial portion of approximately 82% of people's total daily exposure to these harmful chemicals. Most studies on PBDEs in dust have focused on environments such as electronic waste (e-waste) recycling sites, electronic repair workshops, schools/offices, and household settings, both globally and in Nigeria. However, there is a paucity of information on the occurrence of PBDEs in dust from the vicinity of power generation plants. Existing studies conducted around power generation facilities have primarily investigated metals (e.g. Luqman *et al*., 2024, Kumari *et al*., 2023, Zhang *et al*., 2020, Idowu *et al*., 2020, Adeyi and Torto, 2014), PCBs (e.g. Li *et al*., 2023, Aganbi *et al*., 2019; Folarin *et al*., 2018; Gedik and Imamoglu, 2011) and polycyclic aromatic hydrocarbons (PAHs) (Zou *et al*., 2021; Yan, 2020; Gune *et al*., 2019; Sushkova *et al*., 2019) and with little or no attention given to PBDEs contamination. This knowledge gap underscores the need for the present study, which aimed to investigates the spatiotemporal distribution, assess potential risks and source apportionment of PBDEs in dust collected from the vicinity of power generation plants in Nigeria.

MATERIALS AND METHODS

Description of Study Area

The study area comprised Benin, Calabar, Sapele and Gbarain power plants located in Edo, Cross River, Delta and Bayelsa States respectively in south-south, Nigeria (Figure 1). The information regarding the study area is shown in Table 1. Other information on the study area such as climatic conditions etc have been previously documented (Tesi *et al*., 2025; Tesi *et al*., 2022; Tesi *et al*., 2020a, b; Iwegbue *et al*., 2021).

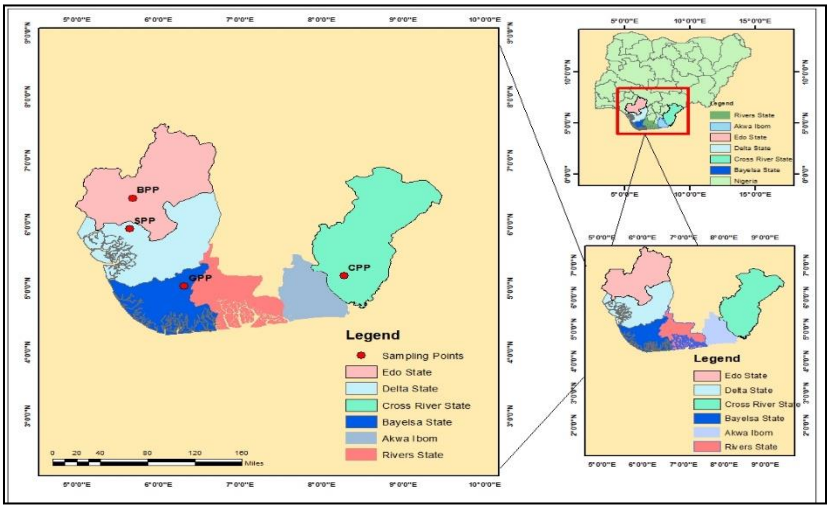

Figure 1: Map of study area

Table 1: Information Regarding the Sampled Power Generation Plants

POWER PLANTS	COORDINATES	LOCATION	TYPE	CAPACITY	STATUS	YEAR OF COMPLETION
Calabar Power Plant (CPP)	5º11´21´´ N 8º16´25´´ E	Calabar, Cross River State	Simple cycle gas turbine	561MW	Operational	2014
Benin (Ihovbor) Power Plant (BPP)	6º24´20´´ N 5º41´00´´ E	Benin City, Edo State	Simple cycle gas turbine	450MW	Operational	2013
Sapele Power Plant (BPP)	5º55´40´´ N 5º38´41´´ E	Sapele, Delta State	Simple cycle gas turbine	450MW	Operational	2012
Gbarain (GPP) Power Plant	5º1´52´´ N 6º18´5´´ E	Koroama-Yenagoa Bayelsa State	Simple cycle gas turbine	254MW	Operational	2017

Reagents

High purity dichloromethane, n-hexane, a PBDE standard mixture of 39 congeners (BDE-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 209), alumina and silica gel were purchased from Isotope Laboratories Inc., (Cambridge, MA, USA).

Sample Collection

Dust samples were collected with a brush and a stainless steel dust pan. At each power plant, composite sampling was adopted. That is, dust samples were collected from different points and pooled together to form a composite sample. Dust samples were collected for a period of six (6) months i.e. August to October, 2024 for wet season and January to March, 2025 for dry season. Thus, a total of 24 dust samples were collected. Dust samples were kept in amber glass bottles. Samples were labeled properly, kept in ice chest and transported to the laboratory. Dust samples were sieved through < 63um sieve before storing in the refrigerator until analysis.

Extraction, Cleanup and Quantification of PBDEs

The PBDEs in the dusts were extracted by ultrasonication (EPA Method 3550C) using n-hexane/dichloromethane (DCM) (1:1 v/v) at 30 °C for 30 minutes and filtered. The extraction was repeated twice. Thereafter the extracts were combined and reduced to 1 mL by using a rotary evaporator. Then sodium sulphate was added to the extract to remove traces of water and then cleaned in a column of alumina (Al_2O_3) and silica gel (SiO_2). The PBDEs was washed down from the column with 40 mL of DCM. The solution was concentrated to approximately 2 mL, and kept in a vial until analysis. The PBDEs in the extracts were quantified by means of a gas chromatograph equipped with mass spectrometry (HP 6890 Palo Alto, C A, USA).

Quality Assurance and Quality Control

All the reagents used were of analytical grade. The effectiveness of the analytical procedure for extraction of the PBDEs was evaluated by employing method blanks and recovery studies. None of the 39 PBDEs congeners investigated were found in the method blanks (n=3). The percentage recoveries of PBDEs congeners from the spike matrix were in the range of 87.3 to 92.8 %. The external calibration approach was used to quantify the PBDE levels in each sample. The concentrations of the blank samples that result in a signal over noise ratio of three and ten, respectively, were used to calculate the limits of detection (LODs) and quantification (LOQs). The LODs ranged from 0.01 to 1.0 ng g^{-1} while the LOQs ranged from 0.03 to 3.0 ng g^{-1}. The r^2 of the calibration curves obtained from the plot of peak areas against known PBDEs concentrations varied from 0.9996 to 0.9999.

Statistical Analysis

The statistical analysis of data was done using the IBM-SPSS software (version 27). The Kruskal Wallis and Mann-Whitney U tests were used to determine if there were significant spatio-temporal variations in the concentrations of PBDEs in the dusts. The relationship between PBDEs homologues was established by means of Pearson's correlation coefficient. Principal component analysis (PCA) was utilized for source identification of PBDEs in the dusts.

Human Risk Assessment

The non-carcinogenic risk of PBDEs in the dust was evaluated using the hazard index (HI) while the carcinogenic risk was evaluated using the total cancer risk (TCR) via the three exposure pathways of ingestion, inhalation, and dermal contact. Equations (1) through (4) were used to determine the HI, while equations (5) through (8) were used to determine the overall cancer risks (USEPA, 2009).

$$\text{Hazard index (HI)} = \text{HQ(Hazard Quotient)}_{\text{Ingestion}} + \text{HQ}_{\text{Inhalation}} + \text{HQ}_{\text{Dermal contact}} \quad (1)$$

$$\text{HQ}_{\text{Ingestion}} = [\frac{C \times IngR \times EF \times ED}{BW \times AT_{nc}} \times 10^{-6}] / RfDo \quad (2)$$

$$\text{HQ}_{\text{Inhalation}} = \frac{C \times Inh \times EF \times ED \times RFDi}{PEF \times ATnc} \quad (3)$$

$$\text{HQ}_{\text{Dermal contact}} = \frac{C \times SA \times AF \times ABS \times EF \times ED}{BW \times AT_{nc}} \times 10^{-6}] / (RfDo \times GIABS) \quad (4)$$

$$\text{Total cancer risk} = \text{Risk}_{\text{Ing}} + \text{Risk}_{\text{Inh}} + \text{Risk}_{\text{Dermal}} \quad (5)$$

$$\text{Risk}_{\text{Ingestion}} = \frac{C \times IngR \times EF \times ED \times CF \times SFO}{BW \times ATca} \quad (6)$$

$$\text{Risk}_{\text{Inhalation}} = \frac{C \times Inh \times EF \times ED \times IUR}{PEF \times ATca} \quad (7)$$

$$\text{Risk}_{\text{Dermal contact}} = \frac{C \times SA \times AF \times ABS \times EF \times ED \times CF \times SFO \times GIABS}{BW \times ATca} \quad (8)$$

The definitions of terms and values of variables used for evaluating the human health risk are given elsewhere (Iwegbue et al., 2025; Emoyan et al., 2022). In general, TCR values larger than 1.0 x 10^{-6} imply carcinogenic risk, but HI values greater than 1 suggest adverse non-carcinogenic risk (USEPA, 2022).

RESULTS AND DISCUSSION

PBDEs Concentrations in the Dust

The concentrations of the PBDEs in the dusts from the power generation plants are shown in Tables 2 and 3 for wet and dry seasons respectively. The mean concentrations of total PBDEs in the dusts ranged from 17.5 to 54.6 ng g^{-1} for wet season and 55.4 to 157 ng g^{-1} for dry season. There were significant spatiotemporal variations ($p < 0.05$) in the PBDEs concentrations in the dust. The spatial variations are related to dust dispersion rate, pavement types and frequency of pavement cleaning (Ossai *et al*., 2021; Khanal *et al*., 2018). The mean total PBDEs concentrations were in the order of CPP > SPP > BPP > GPP for wet season and SPP > GPP > BPP > CPP for dry season. The highest concentration of total PBDEs was found in March 2025 except for CPP which has the highest concentration in September 2024 (Figure 1). Dry season PBDE levels in the dust were higher than wet season levels. The higher levels of PBDEs during the dry season may be due to a lack of dilution and reduced transport.

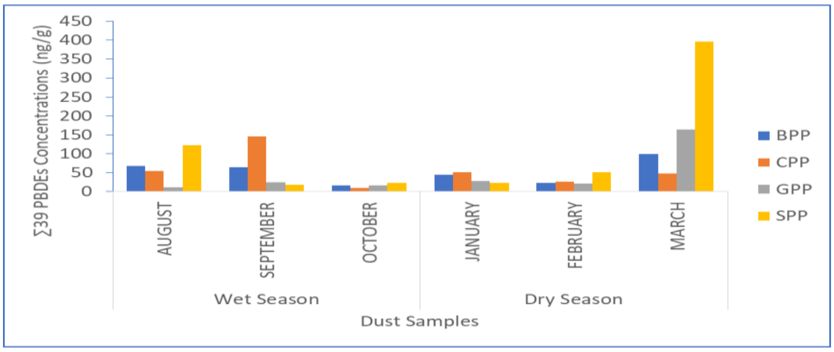

Figure 1: Monthly variations of PBDEs in the dust

The concentrations of PBDEs obtained in this study were similar to those reported for urban outdoor dusts in Nigeria, China and Vietnam irrespective of the number of PBDEs determined and the number of dust samples analyzed. In Nigeria, Iwegbue *et al*. (2025) reported a concentration range of 0.54 -60.4 ng g^{-1} in urban dust of Port-Harcourt, Nigeria. In China, Wu *et al*. (2021) and Wu *et al*. (2015) reported a range of 53.5-213 ng g^{-1} and 6.71-342 ng g^{-1} respectively while Yu *et al*. (2012) reported a range of 8.7-3116 ng g^{-1}. Moreover, Anh *et al*. (2018) reported a range of 0.91-56 ng g^{-1} in outdoor dust from Vietnam.

PBDEs Occurrence Pattern in the Dust

The occurrence pattern of PBDEs in the dusts from the PGPs are displayed in Figure 2. The occurrence pattern of PBDEs homologues in the dust followed the order of penta-BDE > tri-BDE > hexa-BDE > tetra-BDE > hepta-BDE > di-BDE > deca-BDE > mono-BDE for wet season and penta-BDE > hexa-BDE > tri-BDE > di-BDE > tetra-BDE > hepta-BDE > deca-BDE > mono-BDE for dry season.

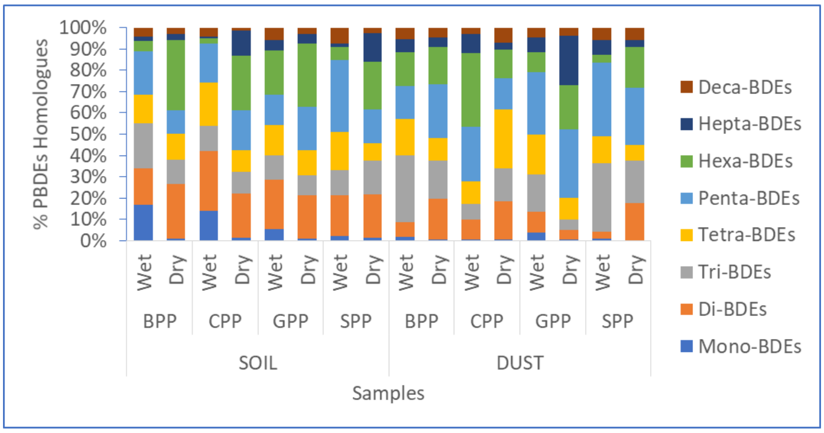

Figure 2: Homologues distribution of PBDEs in the dusts

The concentrations of the mono-BDEs (sum of BDE-1, BDE-2 and BDE-3) ranged from 0.22 to 0.84 ng g^{-1} and constituted 0.4 to 3.6% of the total PBDEs. The concentrations of the individual mono-BDE congeners were in the order of BDE-3 > BDE-2 > BDE-1. The concentrations of the di-BDEs (sum of BDE-7, BDE-8, BDE-10, BDE-11, BDE-12, BDE-13, and BDE-15) ranged from 1.77 to 26.9 ng g^{-1} and constituted 3.4 to 19.1% of the total PBDEs. The concentrations of the individual di-BDE congeners were in the order of BDE-10 > BDE-11 > BDE-15 >BDE-13 > BDE-8 > BDE-12 > BDE-7. The concentrations of the tri-BDEs (sum of BDE-17, BDE-25, BDE-28, BDE-30, BDE-32, BDE-33, BDE-35 and BDE-37) ranged from 3.0 to 31.3 ng g^{-1} and constituted 4.8 to 32.1% of the total PBDEs. The concentrations of the individual tri-BDE congeners were in the order of BDE-17 > BDE-28 > BDE-35 > BDE-25 > BDE-33 > BDE-37 > BDE-30 > BDE32. The concentrations of the tetra-BDEs (sum of BDE-47, BDE-49, BDE-66, BDE-71, BDE-75, and BDE-77) ranged from 3.29 to 19.2 ng g^{-1} and constituted 7.5 to 27.5% of the total PBDEs. The concentrations of the individual tetra-BDE congeners were in the order of BDE-77 > BDE-71 > BDE-47 >BDE-49 > BDE-75 > BDE-66. The concentrations of the penta-BDEs (sum of BDE-85, BDE-99, BDE-100, BDE-116, BDE-118, BDEs-119 and BDE-126) ranged from 5.10 to 41.7 ng g^{-1} and constituted 15.0 to 34.5% of the total PBDEs. The concentrations of the individual penta-BDE congeners were in the order of BDE-85 > BDE-100 > BDE-99 >BDE-118 > BDE-1116 > BDE-119 > BDE-126. The concentrations of the hexa-BDEs (sum of BDE-137, BDE-153, BDE-154, BDE-155, and BDE-166) ranged from 1.69 to 30.6 ng g^{-1} and constituted 3.7 to 34.6% of the total PBDEs. The concentrations of the individual hexa-BDE congeners were in the order of BDE-166 > BDE-155 > BDE-153 >BDE-137 > BDE-154. The concentrations of the hepta-BDEs (sum of BDE-181, and BDE-183) ranged from 1.21 to 16.5 ng g^{-1} and constituted 3.3 to 23.2% of the total PBDEs. The concentrations of the individual hepta-BDE congeners were in the order of BDE-183 > BDE-181. The concentrations of the deca-BDE (BDE-209) ranged from 0.77 to 8.81 ng g^{-1} and constituted 2.9 to 6.8% of the total PBDEs. On average, the penta-, hexa- and tri-BDEs were the top three dominant PBDE homologues in the dust. The lower brominated PBDEs (mono- to penta-BDEs) were dominant in both seasons (Figure 3). This might have significant environmental and health implications such as environmental degradation (debromination), increased ecological risk, and higher mobility. The concentrations of the LB-PBDEs (sum of mono- to penta-BDEs) in the dust ranged from 13.8 to 112 ng g^{-1} and constituted 52.4 to 83.5% of the total PBDEs while the concentrations of the HB-PBDEs ranged from 3.67 to 44.5 ng g^{-1} and constituted 16.4 to 47.6% of the total PBDEs.

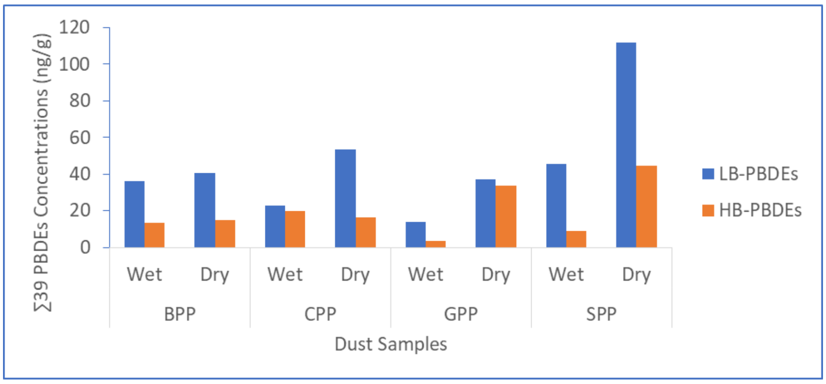

Figure 3: Lower brominated vs higher brominated PBDEs in dust

Human Health Risks of PBDEs

The computed HI for children and adults' exposure to the PBDEs in the dusts from the PGPs are shown in Table 4. The HQ values were as follows: $HQ_{Ing} > HQ_{Derm} >> HQ_{Inh}$ for both children and adults' exposure. The HI values ranged from 4.08×10^{-2} to 3.67×10^{-1} for children and 5.66×10^{-3} to 5.08×10^{-2} for adults in both seasons. The HI values adults were lower than those of children. This implied that children will be more prone to risk compared to adults. The HI values were < 1. This indicates there were no adverse non-carcinogenic risk for human exposures to PBDEs in the dust. Moreover, the TCR computed for children and adults' exposure to PBDEs in the dusts from the PGPs are shown in Table 5. The TCR values ranged from 2.00×10^{-6} to 1.80×10^{-5} for children and 1.87×10^{-7} to 1.68×10^{-6} for adults in both seasons. The TCR values were $< 1 \times 10^{-6}$. This indicates absence of carcinogenic risk for human exposures to PBDEs in the dust.

Table 4: Hazard Index of PBDEs in the dusts

		Children Exposures				Adults' Exposure			
		HQ_{Ing}	HQ_{Inh}	HQ_{Derm}	HI	HQ_{Ing}	HQ_{Inh}	HQ_{Derm}	HI
BPP	Wet	9.10E-02	1.00E-04	2.55E-02	1.17E-01	1.14E-02	2.51E-04	4.54E-03	1.62E-02
	Dry	1.01E-01	1.12E-04	2.83E-02	1.30E-01	1.27E-02	2.79E-04	5.05E-03	1.80E-02
CPP	Wet	7.76E-02	8.55E-05	2.17E-02	9.94E-02	9.69E-03	2.14E-04	3.87E-03	1.38E-02
	Dry	1.28E-01	1.41E-04	3.58E-02	1.64E-01	1.60E-02	3.53E-04	6.38E-03	2.27E-02
GPP	Wet	3.19E-02	3.52E-05	8.93E-03	4.08E-02	3.99E-03	8.79E-05	1.59E-03	5.66E-03
	Dry	1.30E-01	1.43E-04	3.64E-02	1.67E-01	1.63E-02	3.58E-04	6.48E-03	2.31E-02
SPP	Wet	9.97E-02	1.10E-04	2.79E-02	1.28E-01	1.25E-02	2.75E-04	4.97E-03	1.77E-02
	Dry	2.86E-01	3.16E-04	8.01E-02	3.67E-01	3.58E-02	7.89E-04	1.43E-02	5.08E-02

Table 5: Total Cancer Risk of PBDEs in the Dust

		Children Exposures				Adults' Exposure			
		$RISK_{Ing}$	$RISK_{Inh}$	$RISK_{Derm}$	TCR	$RISK_{Ing}$	$RISK_{Inh}$	$RISK_{Derm}$	TCR
BPP	Wet	4.46E-06	4.92E-09	1.25E-06	5.71E-06	3.04E-07	6.71E-09	2.22E-07	5.33E-07
	Dry	4.96E-06	5.47E-09	1.39E-06	6.35E-06	3.38E-07	7.46E-09	2.47E-07	5.93E-07
CPP	Wet	3.80E-06	4.19E-09	1.06E-06	4.87E-06	2.59E-07	5.72E-09	1.90E-07	4.54E-07
	Dry	6.27E-06	6.92E-09	1.76E-06	8.03E-06	4.27E-07	9.43E-09	3.13E-07	7.50E-07
GPP	Wet	1.56E-06	1.72E-09	4.37E-07	2.00E-06	1.07E-07	2.35E-09	7.79E-08	1.87E-07
	Dry	6.37E-06	7.03E-09	1.78E-06	8.16E-06	4.34E-07	9.58E-09	3.18E-07	7.62E-07
SPP	Wet	4.88E-06	5.39E-09	1.37E-06	6.26E-06	3.33E-07	7.34E-09	2.44E-07	5.84E-07
	Dry	1.40E-05	1.55E-08	3.93E-06	1.80E-05	9.56E-07	2.11E-08	6.99E-07	1.68E-06

Pearson's Correlation Analysis

The Pearson's correlation coefficients of PBDE homologues in the dust from the PGPs are shown in Table 6. The PBDE homologues correlated with each other except mono- and hepta-BDEs that do not correlate with any other homologue. These implied that, both mono- and hepta-BDEs in the dust have different sources and/or fate in the environment.

Table 6: Pearson's Correlation Coefficient of PBDE Homologues in the Dust

	Mono-BDEs	Di-BDEs	Tri-BDEs	Tetra-BDEs	Penta-BDEs	Hexa-BDEs	Hepta-BDEs	Deca-BDEs
Mono-BDEs	1.00	-0.08	0.30	-0.09	-0.04	-0.10	-0.08	0.06
Di-BDEs		1.00	0.75**	0.55*	0.75**	0.82**	-0.09	0.91**
Tri-BDEs			1.00	0.41*	0.73**	0.55*	-0.18	0.87**
Tetra-BDEs				1.00	0.22	0.28	-0.05	0.65*
Penta-BDEs					1.00	0.82**	0.35	0.84**
Hexa-BDEs						1.00	0.32	0.76**
Hepta-BDEs							1.00	0.07
Deca-BDEs								1.00

**Significant at 0.01 level of significance; *Significant at 0.05 level of significance

Principal Component Analysis (PCA)
The PCA of PBDEs homologues in the dusts from the power generation plants are shown in Table 7. The PCA for BDE homologues in the dust has three components accounting for 86.732 % of the total variances. Component 1 has high positive loadings for all the PBDE homologues except mono- and hepta-BDEs and explained 54.616 % of the variance. Component 1 is associated with discharges from common plastics used in electrical and electronic equipment such as computers, televisions, air conditioners, cell phones, remote controls, computer monitors, plumbing pipes (Iwegbue *et al.*, 2025). Component 2 has high positive loadings for hepta-BDE and explained 17.560 % of the variance while component 3 has high positive loadings for mono-BDE with 14.555 % of the total variance.

Table 7: PCA of PBDEs Homologues in the Dusts

	Component		
	1	**2**	**3**
Mono-BDE	.019	-.086	.947
Di-BDE	.950	-.062	-.102
Tri-BDE	.866	-.146	.367
Tetra-BDE	.616	-.380	-.316
Penta-BDE	.835	.484	.052
Hexa-BDE	.810	.419	-.094
Hepta-BDE	.022	.904	-.104
Deca-BDE	.991	.014	.030
Variance (%)	54.616	17.560	14.555
Cumm. Variance (%)	54.616	72.176	86.732

CONCLUSION
The study provides information on the occurrence of PBDEs in dust samples from power generation plants in Nigeria. The occurrence pattern indicated that penta-BDEs were the dominant PBDEs in the dust. There were significant spatial and temporal variations in the PBDEs concentrations with higher concentrations observed during the dry seasons. Human risk assessment indicated the absence of health risk from exposure to these dusts. Even though the PBDEs concentrations in the dusts presently pose no health risk, we recommend that the Federal Ministry of Environment should establish environmental policy and enforceable regulatory frameworks for the control of PBDEs in order to minimize the levels environmental PBDEs and the risk to human and ecosystems.

REFERENCES

Adesanmi, A. J., Badmos, S. A., Gbadebo, O. A., and Sonibare, J. A. (2019). Emission inventory of electricity generation from thermal power plants in Nigeria. *Global Scientific Journals*, 7(2),

Adeyi, A. A., and Torto, N. (2014). Profiling heavy metal distribution and contamination in soil of old power generation station in Lagos, Nigeria. *Americal Journal of Science and Technology*, 1(1), 1-10.

Adeyi, A.A., Akanmu, F. R., Babalola, B. A., and Akpotu, S. O. (2020). Levels of polyrominated diphenyl ethers (PBDEs) in indoor dust in Lagos and Ibadan, Nigeria. *Microchemical Journal*, 158, 105132.

Aganbi, E., Iwegbue, C.M.A., Martincigh, B.S. (2019). Concentrations and risks of polychlorinated biphenyls (PCBs) in transformer oils and the environment of a power plant in the Niger Delta, Nigeria. *Toxicology Reports*, 6, 933–939

Anh, H.Q., Tomioka, K., Tue, N.M., Tri, T.M., Minh, T.B. & Takahashi S. (2018). PBDEs and novel brominated flame retardants in road dust from northern Vietnam: Levels, congener profiles, emission sources and implications for human exposure. *Chemosphere* 197, 389-398.

Araujo, J., de S., dos Santos, I. C., Melo, H. D. B., and Rosa, A. H. (2024). Polybrominated diphenyl ethers in indoor dust from Brazil: assessing demographic differences and human health exposure. *Environmental Science and Pollution Research*, 31(35), 48122-48134. https://doi.org/10.1007/s11356-024-34388-2

Bramwell, L., Glinianaia, S. V., Rankin, J., Rose, M., Fernandes, A., Harrad, S., and Pless-Mulolli, T. (2016). Associations between human exposure to polybrominated diphenyl ether flame retardants via diet and indoor dust, and internal dose: A systematic review. *Environment International*, 92-93, 680-694.

Choi, S., Ekpe, O. D., Sim, W., Choo, G., and Oh, J. E. (2023). Exposure and risk assessment of Korean firefighter to PBDEs and PAHs via fire vehicle dust and personal protective equipment. *Environmental Science and Technology*, 57, 520-530.

Emebu, V., Adeleke, A., and Oronsaye, J. (2024). Assessment of legacy and alternative halogenated organic pollutants in outdoor dust and soil from e-waste sites in Nigeria: Concentrations, patterns, and implications for human exposure. *Environmental Pollution*, 341, 123989. https://doi.org/10.1016/j.envpol.2023.12988

Emoyan, O.O., Adjerese, W. and Tesi, G.O. (2022). Concentrations, origin, and associated exposure risk of polycyclic aromatic hydrocarbons in soil depths from selected petroleum tank farms in Western Delta, Nigeria. *Polycyclic Aromatic Compounds*, http://dx.doi.org/10.1080/10406638.2022.2041051

Folarin, B.T., Abdallah, M.A., Oluseyi, T., Olayinka, K. and Harrad, S. (2018). Concentrations of polychlorinated biphenyls in soil and indoor dust associated with electricity generation facilities in Lagos, Nigeria. *Chemosphere*, 207: 620-625

Gedik, K. & Imamoglu, I. (2011) A preliminary investigation of the environmental impact of a thermal power plant in relation to PCB contamination. *Environ Sci Pollut Res*, 18, 968–977.

Gevao, B., Ghadban, A. N., Uddin, S., Jaward, F. M., Bahloul, M., and Zafar, J. (2011). Polybrominated diphenyl ethers (PBDEs) in soil along rural-urban-rural transect: Sources, concentration gradients, and profiles. *Environmental Pollution*, 159, 3666-3672.

Gomes, J., Begum, M., and Kumarathasan, P. (2024). Polybrominated diphenyl ether (PBDE) exposure and advance maternal and infant health outcomes: systematic review. *Chemosphere*, 547, 140367

Gune, M. M., Ma, W., Sampath, S., Li, W., Li, Y., Udayashankar, H.N., Balakrishna, K. and Zhang, Z. (2019) Occurrence of polycyclic aromatic hydrocarbons (PAHs) in air and soil surrounding a coal-fired thermal power plant in the south-west. *Environ Sci Pollut Res* 26, 22772–22782

Han, W., Fan, T., Xu, B., Feng, J., Zhang, G., Wu, M., Yu, Y. & Fu, J. (2016). Passive sampling of polybrominated diphenyl ethers in indoor and outdoor air in Shanghai, China: seasonal variations, sources, and inhalation exposure. *Environ. Sci. Pollut. Res. Int*. 23, 5771-5781

Idowu, G. A., Olonimoyo, E. A., Idowu, A. M. and Aiyesanmi, A. F. (2020). Impact of gas and oil-fired power plants on proximal water and soil environment: case study of Egbin power plant, Ikorodu, Lagos State, Nigeria. *SN Applied Sciences*, 2, 1352

Igbokwe, J. O., Nwufo, O. C., and Ononogbo, C. (2015). The health and environmental implication of thermal power generation in Nigeria. *IIARD International Journal of Mechanical Engineering Research*, 1(2), 1-10.

Iwegbue, C. M. A., Eyengho, S. B., Egobueze, F. E., Odali, E. W., Tesi, G. O., Nwajei, G. E., and Martincigh, B. S. (2019). Polybrominated diphenyl ethers and polychlorinated biphenyls in indoor dust from electronic repair workshops in southern Nigeria: Implications for onsite human exposure. *Science of the Total Environment*, 671, 914-927. https://doi.org/10.1016/j.csitotenv.2019.04.265

Iwegbue, C. M. A., Ossai, C. J., Ogwu, I. F., Odali, E. W., Olisah, C., Ujam, O. T., Nwajei, G. E., and Martincigh, B. S. (2025). Sources and risk evaluation of polybrominated diphenyl ethers in dust and soil from an urban environment in Nigeria. *Environmental Chemistry*, 22(4), EN25007. https://doi.org/10.1071/EN25007.

Iwegbue, C.M.A., Kekeke, E.F., Tesi, G.O., Olisah, E., Egobueze, F.E., Chukwu-Madu, E Marticingh, B.S. (2021). Impact of land-use types on the distribution and exposure risk of polycyclic aromatic hydrocarbons in dusts from Benin City, Nigeria. *Archives of Environmental Contamination & Toxicology*, 81, 210. https://doi.org/10.1007/s00244-021-00861-z

Jin, M., Zhang, S., Ye, N., Zhou, S., and Xu, Z. (2022). Distribution and source and health risks associated with ploybrominated diphenyl ethers in dust generated by public transportation. *Environmental Pollution*, 309, 119700

Khanal, R., Furumai, H., Nakajima, F. & Yoshimura, C. (2018). Carcinogenic profile, toxicity and source apportionment of polycyclic aromatic hydrocarbons accumulated from urban road dust in Tokyo, Japan. *Ecotoxicol Environ* Saf. 165, 440–449

Kumari, M., Kumar, A., and Bhattacharya, T. (2023). Assessment of heavy metal contamination in street dust: concentrations, bioaccessibility, and human health risks in coal mine and thermal power plant complex. E*nvironmental Geochemistry and Health*, 45, 7339-7362 https://doi.org/10.1007/s10653-023-01695-5

Li, T., Hu, J., Xu, C., & Jin, J. (2023) PCBs, PCNs, and PCDD/Fs in soil around an industrial park in Northwest China: Levels, source apportionment, and human health risk. *Int J Environ Res Public Health*, 20(4), 3478.

Lin, Y., Yang, L., Xie, M., Li, H., and Zhang, Q. (2024). Exposure to polybrominated diphenyl ethers and thyroid disease: a systematic review and meta- analysis of epidemiological studies. *Curr. Epidemiol. Rep*., 11, 20-31.

Luqman, M., Niazi, A., Kashif, S.U.R., Arooj, F., Reyman, S.A.U., Awan, M.U.F., Wasim M. and Raza, F. (2024). Metal pollution in the topsoil of lands adjacent to Sahiwal coal fired power plant (SCFPP) in Sahiwal, Pakistan. *PLoS One*, 19(2), e0298433

Nakajima, R., Kawato, M., Fujiwara, Y., Tsuchida, S., Ritchie, H., and Fujikura, K. (2022). Occurrence and levels of polybrominated diphenyl ethers (PBDEs) in deep-sea sharks from Suruga Bay, Japan. *Marine Pollution Bulletin*, 176, 113427.

Ohoro, C. R., Adeniji, A. O., Okoh, A. I., and Okoh, O. O. (2021). Polybrominated diphenyl ethers in the environmental systems: a review. *J. Environ. Health Sci. Eng*., 19, 129 – 47

Okedere, O. B., Elehinafe, F. B., Oyelami, S., and Ayeni, A. O. (2021). Drivers of anthropogenic air emissions in Nigeria-A review. *Heliyon*, 7(3), e06398

Oluruntoba, K., Sindiku, O., Osibanjo, O., Herold, C., and Weber, R. (2019). Hydrophobic organic pollutants in soils and dusts at electronic waste recycling sites: Occurrence and possible impacts of polybrominated diphenyl ethers. *Environmental Science and Technology*, 53(5), 2421-2430. https://doi.org/10.1021/acs.est.8b05405.

Ossai, C.J., Iwegbue, C.M.A., Tesi, G.O., Olisah, C., Egobueze, F.E., Nwajeia, G.E. & Martincigh, B.S. (2021). Distribution, sources and exposure risk of polycyclic aromatic hydrocarbons in soils, and indoor and outdoor dust from Port Harcourt city, Nigeria. *Environmental Science Processes & Impacts. DOI: 10.1039/d1em00094b*

Ossai, J.C., Iwegbue, C.M.A., Tesi, G.O., Olisah, C., Egobueze, F.E., Nwajei, G.E. and Martincigh, B.S. (2023). Spatial characteristics, sources and exposure risk of polychlorinated biphenyls in dusts and soils from an urban environment in the Niger Delta of Nigeria. *Science of the Total Environment*, 883: 163513

Qui, J., Wang, X., Fan, L., Gong, S., Wang, X., Wang, C., Li, L., Liu, H., Cao, Y., Liu, M., Yao, X. (2023). Levels, distribution, childhood exposure assessment, and influencing factors of polybrominated diphenyl ethers (PBDEs) in household dust from nine cities in China. *Science of the Total Environment*, 874,162612. https://doi.org/10.1016/j.scitotenv.2023.162612

Sushkova, S., Minkina, T., Deryabkina, I., Rajput, V., Antonenko, E., Nazarenko, O., Yadav, B.K., Hakki, E., Mohan, D. (2019). Environmental pollution of soil with PAHs in energy producing plants zone. *Science of the Total Environment*, 655: 232–241

Tesi, G.O., Lari, B., Ogbuta, A.A., Felagha, I., Obodoka, G.C., Ogbomade, W.E., Okpara, K.E., Osioma, E. and Agbozu, I.E. (2025). Organophosphate pesticides in herbal mixtures from Bayelsa State, Nigeria: implication for human exposure and risks. *Journal of Environmental Exposure Assessment*, 4(2): https://dx.doi.org/10.20517/jeea.2024.30

Tesi, G.O., Obi-Iyeke, G.E., Ossai, J.C., Ogbuta, A.A., Ogbara, E.F., Olorunfemi, D.I. and Agbozu, I.E. (2022). Human exposure to organochlorine pesticides in vegetables from major cities in south-south Nigeria. *Chemosphere* 303(Part 3): 135296 https://doi.org/10.1016/j.chemosphere.2022.135296

Tesi, G.O., Ojegu, J.O. and Akporido, S.O. (2020a). Distribution and risk of metals in soils of refuse dumpsites in some urban towns in Delta State, Nigeria. African Scientist, 21(1): 211-224

USEPA (2009). Risk Assessment Guidance for Superfund, Vol. I: Human Health Evaluation Manual (F, Supplemental Guidance for Inhalation Risk Assessment). EPA/540/R/070/002. Environmental Protection Agency, Washington DC. https://www.epa.gov/risk/risk-assessment-guidance-superfund-rags-part-f

USEPA (2022). Regional screening levels (RSL) summary tables. 2022. http://www.epa.gov/risk/riskbased-screening-table-generic-tables.

Wu, M.H., Pei, J.C., Zheng, M., Tang, L., Bao, Y.Y., Xu, B.T., Sun, R. Sun, Y.F., Xu, G. & Lei, J.Q. (2015). Polybrominated diphenyl ethers (PBDEs) in soil and outdoor dust from a multi-functional area of Shanghai. Levels, compositional profiles and interrelationships. *Chemosphere* 118, 87. https://doi.org/10.1016/j.chemosphere.2014.06.022

Wu, Z., Liu, Y., Lyu, H., Chen, Y., Han, T., Zhang, Y., Xu, P., Song, J., Wu, W. (2021). Polybrominated diphenyl ethers in indoor dusts from university dormitories and printing shops in Xinxiang, China. *Building and Environment*, 187, 107416.

Wu, Z., Liu, Y., Lyu, H., Chen, Y., Han, T., Zhang, Y., Xu, P., Song, J., Wu, W. (2021). Polybrominated diphenyl ethers in indoor dusts from university dormitories and printing shops in Xinxiang, China. *Building and Environment*, 187, 107416.

Yan, Z. (2020). A preliminary study on pollution of polycyclic aromatic hydrocarbons in soil around a thermal power plant of Xi'an city. *E3S Web of Conferences* 204, 01012

Yang. C., Long, C., Huang, Z., Ren, H., and Yu, Y. (2025). Polybrominated diphenyl ethers and Dechlorane Plus in soil from four different industry parks: Identification, emission characteristics, spatial distribution, and health risk assessment. *J. Environ. Expo. Assess.*, 4, 13. https://dx.doi.org/10.20517/jeea.2024.57.

Yu, Y.X., Pang, Y.P., Li, C., Li, J.L., Zhang, X.Y., Yu, Z.Q., Feng, J.L., Wu, M.H., Sheng, G.Y. & Fu, J.M. (2012). Concentrations and seasonal variations of polybrominated diphenyl ethers (PBDEs) in in- and out-house dust and human daily intake via dust ingestion corrected with bioaccessibility of PBDEs. *Environ. Int* 42, 124-131.

Zandona, A., Jagic, K., Dvorscak, M., Madunic, J., Klincic, D., and Katalinic, M. (2022). PBDEs found in house dust impact human lung epithelial cell homeostasis. *Toxics*, 10(2), 97. https://doi.org/10.3390/toxics10020097

Zhang, Y., Wu, D., Wang, C., Fu, X., and Wu, G. (2020). Impact of coal power generation on the characteristics and risk of heavy metal pollution in nearby soil. *Ecosystem Health and Sustainability*, 6(1), 1787092

Zou, Y., Liu, J., Liu, X., & Jia, J. (2021) Health risk assessment of polycyclic aromatic hydrocarbons (PAHs) in the soil around thermal power plants in southwest China. *Journal of Environmental Science and Health, Part A*, 56(7): 786-796.