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Polybrominated Diphenyl Ethers in Office Dust from Primary Schools in Ijebu Ode, Nigeria

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ABSTRACT

Polybrominated diphenyl ethers (PBDEs) are persistent organic pollutants widely used as flame retardants in consumer products. This study accessed the concentration and distribution of polybrominated diphenyl ethers in dust samples collected from offices primary schools across Ijebu Ode, Nigeria. Dust collection was performed by brushing settled dust onto pre-cleaned aluminum foil. The collected dust samples underwent preparation, including solvent extraction and purification to remove interfering organic matter. The resulting extract was analysed for PBDEs using gas chromatography-mass spectrometry (GC-MS). Results revealed concentrations spanning from as low as 2.98 ppb at ISO to a maximum of 20.94 ppb at 1MO, and similarly elevated levels at OBO and ILGO locations. The mean concentrations corroborated these trends, confirming that schools such as 1MO (0.54 ppb), OBO (0.53 ppb), and ILGO (0.49 ppb) are hotspots of PBDE contamination. Among the 30 schools, certain congeners including BDE-17, BDE-71, BDE-77, BDE-100, BDE-154, and BDE-10 were consistently detected at appreciable levels, suggesting their pervasive presence likely due to their roles as flame retardants in consumer products commonly found in indoor environments like upholstery, electronics, and textiles.

Key words: Congeners, flame retardant, indoor contamination, PBDE, dust,

INTRODUCTION

The issue of poor indoor air quality has become a worldwide public health priority because of multiple environmental pollutants. Among these numerous pollutants are the polybrominated diphenyl ethers, which are commonly used as flame retardants in many consumer products

such as furniture, electronics, textiles, and plastics [1]. Primary schools create distinctive indoor environments that expose children to dust as a major pollutant source because of their susceptibility and unique facility features and educational activities [2]. The complex nature of dust particles found in primary schools creates a hidden public health problem that generates significant negative effects for student health, alongside their development and academic achievements [3]. Educational facilities at the primary level host specific environmental conditions that generate unique dust distribution patterns as well as distinct exposure circumstances [2]. Investigating dust composition alongside accumulation patterns and associated health effects should receive focused attention in educational institutions because children face increased health risks during their developmental stages. A detailed assessment explores current conditions regarding dust pollution inside Ijebu-Ode's primary school buildings.

Environmental pollution outcomes in public health reach their maximum levels when focusing on indoor air contamination within spaces where children spend extensive time, like primary schools [4]. The United States faces major challenges regarding its primary school facilities because more than 40% of public schools built before 1970 now exist in the nation's school building stock [5]. Older buildings harbour different types of contamination within their dust from deteriorating paint that releases lead, deteriorated caulking materials with PBDEs, and airborne asbestos fibers from insulation. School facilities typically receive poor grades from the American Society of Civil Engineers as a result of extensive deferred maintenance that enables dust to build up and spread throughout buildings [6]. Major concerns about flame retardants in classroom dust led some states to pass furniture flammability standards, which omit these chemicals [7]. Also, urban schools face the added obstacle of traffic-related contaminants seeping into their facilities. The Environmental Working Group conducted laboratory analysis, which revealed PFAS chemical contamination at worrisome levels across elementary school dust samples from various states where the chemicals most likely originate from stain-resistant treatments used on carpets and furnishings.

Canadian elementary schools face comparable issues but show variations in dust composition because Canada features different geographical and climatic terrains across its regions [8]. Results from the Canadian Partnership for Children's Health and Environment national assessment showed that 28% of schools had visible dust accumulation, with older buildings and facilities located in low-income districts experiencing higher incidences of dust

accumulation [9]. The Canadian educational system faces specific problems regarding mining site soil contamination alongside high numbers of flame retardants stemming from historical building material flammability mandates [10]. The education facilities in First Nations communities encounter systemic barriers because of their insufficient building infrastructure, coupled with insufficient environmental management support [11].

The distinct environmental conditions of Australia create specific dust-related problems that primary schools need to address nationwide. Drought times and bushfires enable fine mineral dust and smoke particles to settle inside schools where they combine with indoor material contaminants to produce complicated mixtures. The research carried out at Queensland universities revealed increased silica measurements in classroom dust during drought seasons together with maritime schools displaying higher salt content which modifies dust composition and alters the exposure levels of contaminants [12]. The prevalence of outdoor learning spaces in Australian education results in diminished distinctions between students' indoor and outdoor exposure areas [3].

European national policies show increased caution in managing school dust issues. The educational institutions in Scandinavian countries lead the way in dust reduction through special entry solutions and floor materials without specific treatments on furniture according to regulatory restrictions [3]. The European Commission's Indoor Air Quality Observatory conducted a nationwide assessment of school dust which revealed substantial decreases in lead alongside brominated flame retardants since European regulatory limits were established. The presence of alternative flame retardants PBDEs and microplastics continues to persist alongside other emerging contaminants [13]. Multiple European countries have implemented dedicated indoor environmental quality criteria for schools through which they have set restrictions for both dust amounts and pollutant levels.

Different Asian nations show diverse approaches to managing school dust. The educational system in Japan features exceptional methods that require students to clean their classrooms and make teachers enforce full shoe removal policies, which decrease the amount of outdoor debris entering the space. Rapidly developing urban areas of China and India face acute contamination challenges from outdoor air pollution, which has led to heavy metal measurements in school dust above established health guidelines [14]. Research has discovered elevated electronic waste-related pollutants in South Korean primary school dust due to increased technology usage in education [15]. The government of Singapore has launched

extensive school environmental management systems with routine dust surveillance and response steps that have created clear improvements in indoor environmental conditions.

The Nigerian educational sector faces complex dust-related issues resulting from quick urbanisation alongside industrial growth and limited educational funding. The oil extraction areas of the Niger Delta exhibit particular dust contamination patterns linked to petroleum sources [16], yet schools in northern regions encounter Sahara-originating dust during the seasonal Harmattan season. Schools located in metropolitan Lagos areas experience pollution from automobile emissions and factory contaminants as they infiltrate educational spaces [17].

The profile within Ogun State, Nigeria, including the particular location of Ijebu Ode, marks this specific research area with its unique characteristics of an environment between Lagos's intense urbanisation and more rural settings. Rapid industrial development across Ogun State creates dust problems that affect primary schools, especially in areas like Ota, Sagamu, and the Redeemed Camp section of the Lagos-Ibadan expressway. Research shows that Cement manufacturing operations produce substantial amounts of fine particulate matter detected in school dust samples [16]. Schools located in agricultural parts of Ogun State exhibit seasonal fluctuations in dust characteristics linked to farming practice contaminants, such as pesticide residues that are present during planting and chemical application periods. Ogun State serves as a transportation bridge between northern Nigeria and Lagos, which positions numerous educational facilities directly next to major highways, thus subjecting them to dust particles generated by vehicle traffic that contains combustion byproducts from vehicles.

PBDEs form a major chemical subclass within primary school dust that creates multiple interrelated effects with other dust-related educational environmental issues [18]. Synthetic flame retardants, which used to be extensively added to building materials and furnishings alongside electronic equipment, have spread across the environment through widespread production despite government manufacturing limitations [19]. Dust habitat contains PBDEs in an insulated form because these compounds play a simultaneous role in the existing dust problems [20]. Multiple pathways connect PBDE contamination with dust via chemical properties and sources and exposure mechanisms, and health effects, which form a unique PBDE-dust relationship in primary school environments [21].

PBDEs exhibit physio-chemical characteristics that strongly attach to dust particles, thus establishing school dust as a major route of exposure [22]. These organic chemicals show low water solubility and high affinity for lipids since their log Know values lie between 4.8-

9.5 per congeners, which makes them partition toward organic materials in dust rather than staying in the air. Particles of the high-brominated PBDE class (BDE-209 as the main congener in DecaBDE) bind strongly to dust surfaces because of their lower tendency to evaporate [23]. Scientific evidence indicates PBDEs exist at levels between 500-10,000 ng/g weight in educational institutions while showing higher concentrations when compared to residential settings [24]. The electrostatic characteristics between dust and flame retardants enhance their permanent bond formation, which results in long-term retention despite routine cleaning methods. Research revealed that PBDEs show a strong binding affinity to tiny dust particles measuring less than 75 micrometres in size, which increases the risk of respiratory exposure from airborne dust in school environments.

This study addresses a critical gap in environmental health research by providing the first comprehensive assessment of PBDE contamination in primary school environments within Ijebu Ode, Nigeria. While extensive research has documented PBDE levels in educational facilities across developed nations, similar investigations in Nigerian schools remain scarce, particularly in smaller urban centers where regulatory oversight and environmental monitoring are limited. The novelty of this research lies in its systematic characterization of PBDE congener profiles in school office dust, establishing baseline contamination levels for a previously unstudied region where children spend substantial portions of their developmental years.

The aim of this study was to quantify and characterise the distribution patterns of PBDEs in dust samples collected from primary school offices across Ijebu Ode. The specific objectives were to: (i) determine the concentrations of individual PBDE congeners in office dust samples from 30 primary schools; (ii) identify spatial distribution patterns and contamination hotspots within the study area; (iii) assess the predominant congener profiles to understand potential sources of contamination; and (iv) establish baseline data that can inform future risk assessment studies and guide policy development for indoor environmental quality standards in Nigerian educational facilities. This investigation provides essential data for understanding children's exposure to persistent organic pollutants in African educational settings, contributing to the global understanding of PBDE contamination patterns and supporting evidence-based interventions to protect vulnerable populations.

MATERIALS AND METHODS

This study adopted a quantitative research design to assess the presence and concentration levels of polybrominated diphenyl ethers in dust samples. The research involved both field sampling and laboratory analysis to determine organic pollutants in school environments.

Study area

Ijebu-Ode is located in Ogun State, southwestern Nigeria, and is known for its growing population, educational institutions, and industrial activities. The primary schools selected for this study vary in their proximity to roads, industrial areas, and agricultural fields, which may contribute to the presence of organic pollutants in indoor dust. The selection includes both public and private schools to ensure a comprehensive assessment of environmental pollution across different educational settings. The sampling locations and the codes were Victorial Nursery/Primary School (AVO), Catholic Church Primary School (ICSC), Adeola-Odutola school (IAO), International Brain (SIO) and Calvary Schools (SCO), Molipa Primary School (1MO), Excel Molipa Primary School (2MEO), Molipa Fomwan Primary School (3MFO), Hope Foundation School (CHO), Hope Schools (EHO), African Church Primary School (IPO), Moslem Primary School (IMPO), Augustine Catholic Primary School (IAOO), St. Anthony (INO), Treasure Land (IDO), Shalom Primary School (ISO), Oritameta Baptist School in Oke-aje area (OBO), Community Primary School in Ita-osu (HCO), St. John's Primary School in Isasa-Epe (UJO), Premier Primary School in Itanrin (UPO), St. Saviour's School in Igbeba (SGO), Ogunnaike Memorial Primary School in Itoro (OMO), Methodist Primary School Igodo in Igodo area (IGO), Surulere Primary School in Molipa (SUO), All Saints Primary School in Ilese (ALO), Muslim Comprehensive Primary School in Oju-ega (MJO), God's Heritage in Mobalufon (MHO and MHC), Lux-Dei Primary School in Isonyin (ILGO) and Unity Primary School in Degun (UDO).

Sample collection and preparation

A cross-sectional approach was employed, allowing for the collection of dust samples from 30 primary schools in Ijebu-Ode, Nigeria. Dust samples were collected from 30 primary schools' offices in Ijebu Ode. The dust sampling campaign encompassed thirty primary schools distributed across various locations in Ijebu Ode and its surrounding areas. The sampling process follows the Environmental Protection Agency (EPA) guidelines for dust sample collection [25].

Different brushes were used to collect dust samples into aluminum foil at different locations to avoid cross-contamination. The aluminum foil was well wrapped and labelled accordingly, and taken to the laboratory for analysis.

PBDEs in the samples were extracted using solvent extraction method which involves isolating the PBDEs from the dust matrix. This method was designed to efficiently dissolve these semi-volatile compounds. A small (25 mg) amount of sieved dust is accurately weighed into a clean, inert container to minimise contamination and analyte loss. A mixture of organic solvents (hexane and acetone) in a 50:50 volume ratio (v/v) is added. This solvent combination was effective at dissolving PBDE compounds from the dust due to their semi-volatile and hydrophobic nature. Samples were then sonicated in an ultrasonic water bath. The sample was then centrifuged to pellet the dust, allowing the clear solvent extract containing the dissolved PBDEs to be separated.

To determine the concentrations of PBDEs, gas chromatography-mass spectrometry (Agilent 6890N and Agilent 5975B) was used. The analytical steps include Extraction in which pollutants are extracted using solid-phase extraction (SPE) or liquid-liquid extraction (LLE) methods Purification in which extracts undergo column chromatography to remove unwanted compounds and quantification, where GC-MS are used to identify and quantify each organic pollutant based on retention times and mass spectra comparison with standard reference materials [26].

RESULTS AND DISCUSSION

The PBDE concentration data collected from dust samples in 30 primary schools' offices showed the presence of multiple polybrominated diphenyl ether congeners at varying levels.

Table 1 shows a considerable variability in the total PBDE concentrations present in various school locations in Ijebu Ode, ranging from as low as 2.98 ppb in ISO to as high as 20.9 ppb in IMO. The highest total PBDE concentrations were found at (1MO) 20.9 ppb, (OBO) 20.7 ppb, and 19.07 ppb (ILGO). The lowest total PBDEs were detected at ISO (2.98 ppb), IPO (5.68 ppb), and IDO (6.14 ppb). Mean PBDE concentrations ranged from 0.076 ppb (ISO) to 0.537 ppb (1MO). Schools with the highest mean concentrations include 1MO (0.537 ppb), OBO (0.531 ppb), and ILGO (0.489 ppb). INO also shows higher variability (0.458 ppb) compared to most other locations. Most locations have maximum values below 1.00 ppb. ILGO has an exceptionally high maximum value (5.04 ppb) and the widest range (5.02 ppb). Generally, most schools have minimum values close to zero (0.00-0.020 ppb), indicating that

certain PBDE congeners might be present at very low levels or below detection limits across all locations. Maximum values mostly lie between 0.70 ppb and 1.00 ppb (except for ILGO with 5.04 ppb and INO with 1.78 ppb), indicating peak contamination levels. Ranges are generally high (up to ~1.00 ppb), indicating that PBDE concentrations vary considerably within each school.

Table 1: The sum of PBDEs, mean PBDEs, Standard deviation, minimum value, maximum value, and range of the concentration of PBDEs (ppb) in dust samples collected from Ijebu-ode primary schools

NAMES	Total PBDEs (ppb)	Mean	STD	MIN	MAX	RANGE
AVO	14.8	0.38	0.4	0.01	0.90	0.89
ICSCO	8.01	0.21	0.17	0.01	0.73	0.72
IAO	15.8	0.40	0.31	0.01	0.98	0.97
SCO	14.0	0.36	0.30	0.01	0.90	0.89
1MO	20.9	0.54	0.26	0.13	0.94	0.81
2MEO	13.1	0.34	0.25	0.00	0.95	0.95
3MFO	6.35	0.29	0.291	0.01	0.85	0.84
OPO	7.70	0.20	0.19	0.01	0.71	0.7
OHO	14.1	0.36	0.26	0.01	0.99	0.98
OBO	20.7	0.53	0.27	0.03	0.94	0.91
1IBRO	10.5	0.27	0.25	0.01	0.93	0.92
ICSO	16.2	0.42	0.28	0.01	0.98	0.97
IFO	10.7	0.28	0.27	0.02	0.97	0.95
LPSO	8.20	0.23	0.31	0.01	0.97	0.96
LOO	11.9	0.30	0.27	0.00	0.92	0.92
IMO	9.83	0.25	0.22	0.00	0.98	0.98
2IMO	8.75	0.22	0.22	0.01	0.75	0.74
LAO	15.8	0.40	0.30	0.01	0.98	0.97
ILGO	19.1	0.49	0.97	0.02	5.04	5.02
IGO	16.5	0.42	0.27	0.02	0.98	0.96
MJO	7.49	0.19	0.19	0.01	0.77	0.76
MHO	7.89	0.20	0.20	0.01	0.73	0.72

EHO	15.9	0.41	0.29	0.02	0.99	0.97
IPO	5.68	0.15	0.17	0.02	0.72	0.7
IMPO	7.57	0.19	0.21	0.00	0.86	0.86
IAOO	15.7	0.40	0.27	0.02	0.9	0.88
INO	11.6	0.30	0.46	0.01	1.78	1.77
IDO	6.14	0.16	0.15	0.01	0.67	0.66
ISO	2.98	0.08	0.07	0.01	0.32	0.31
SIO	12.2	0.31	0.28	0.01	0.97	0.96

The decreasing order of PBDE concentration with a mean ± standard deviation in the samples as shown in Table 1 was 0.537 ± 0.26 ppb (1MO) > 0.531 ± 0.27 ppb (OBO) > 0.489 ± 0.97 ppb (ILGO) > 0.423 ± 0.27 ppb (IGO) > 0.415 ± 0.28 ppb (ICSO) > 0.408 ± 0.29 ppb (EHO) > 0.404 ± 0.31 ppb (IAO) > 0.404 ± 0.30 ppb (LAO) > 0.402 ± 0.27 ppb (IAOO) > 0.379 ± 0.40 ppb (AVO) > 0.361 ± 0.26 ppb (OHO) > 0.359 ± 0.30 ppb (SCO) > 0.335 ± 0.25 ppb (2MEO) > 0.312 ± 0.28 ppb (SIO) > 0.304 ± 0.27 ppb (LOO) > 0.298 ± 0.46 ppb (INO) > 0.289 ± 0.29 ppb (3MFO) > 0.275 ± 0.27 ppb (IFO) > 0.268 ± 0.25 ppb (1IBRO) > 0.252 ± 0.22 ppb (IMO) > 0.234 ± 0.31 ppb (LPSO) > 0.224 ± 0.22 ppb (2IMO) > 0.205 ± 0.17 ppb (ICSCO) > 0.202 ± 0.20 ppb (MHO) > 0.197 ± 0.19 ppb (OPO) > 0.194 ± 0.21 ppb (IMPO) > 0.192 ± 0.19 ppb (MJO) > 0.157 ± 0.15 ppb (IDO) > 0.146 ± 0.17 ppb (IPO) > 0.076 ± 0.07 ppb (ISO). High variability in PBDE concentration was evident, with minimum and maximum ∑PBDE concentrations between 0 and 5 ppb. This indicates that dust samples in Ijebu Ode contain a minimum concentration of PBDEs.

PBDE Congeners Concentration in Dust

Most congeners were detected in nearly all schools with very few non-detects (N.D), indicating widespread PBDE contamination in primary school environments. 39 congeners were detected which include BDE-1, BDE-2, BDE-3, BDE-7, BDE-8, BDE-10, BDE-11, BDE-12, BDE-13, BDE-15, BDE-17, BDE-25, BDE-28, BDE-30, BDE-32, BDE-33, BDE-35, BDE-37, BDE-47, BDE-49, BDE-66, BDE-71, BDE-75, BDE-77, BDE-85, BDE-99, BDE-100, BDE-116, BDE-118, BDE-119, BDE-126, BDE-137, BDE-153, BDE-154, BDE-155, BDE-166, BDE-181, BDE-183 and BDE-209.

The PBDE analysis revealed 39 congeners ranging from mono- to deca-brominated compounds. Lower brominated congeners included mono-BDEs (BDE-1, -2, -3) and di-BDEs

(BDE-7, -8, -10, -11, -12, -13, -15, -17), which exhibit higher volatility and bioavailability. Tri-brominated (BDE-25, -28, -30, -32, -33, -35, -37) and tetra-brominated congeners (BDE-47, -49, -66, -71, -75, -77) were detected, with BDE-47 representing a predominant environmental contaminant. Penta-BDEs (BDE-85, -99, -100), major components of commercial PentaBDE mixtures, demonstrated significant bioaccumulative potential. Hexa-brominated congeners (BDE-153, -154, -155) showed high persistence, particularly BDE-153. Higher brominated compounds included hepta-BDEs (BDE-181, -183), BDE-166, and the fully brominated BDE-209 (DecaBDE). The diverse congener profile suggests exposure to multiple commercial PBDE formulations or environmental debromination processes. The presence of various bromination patterns across BDE-116, -118, -119, -126, and -137 indicates comprehensive analytical coverage of PBDE isomers with distinct toxicological and environmental behaviours. These flame-retardant chemicals were detected consistently across samples, highlighting ubiquitous indoor contamination.

Figure 1 shows that BDE-17, BDE-71, BDE-77, BDE-100, BDE-154, and BDE-10 are the most prominent PBDE congeners detected consistently across the 30 primary schools, indicating their widespread presence. These congeners, including lower and higher brominated forms, suggest a mixture of persistent and bioavailable pollutants. Some samples show localised spikes (e.g., BDE-17 in IGO at 5.04 ppb), implying specific contamination hotspots. The overall congener profile reflects typical environmental PBDE contamination sources, with potential persistence and toxicological implications in the school environments. This underscores the need for targeted monitoring and mitigation strategies in locations exhibiting higher concentrations. Congener concentrations vary from sample to sample, but overall, the pattern is consistent for key congeners, implying a common contamination source or similar exposure conditions. Tri- and tetra-brominated congeners (BDE-17, BDE-28, BDE-47) generally show moderate to high concentration levels. Penta- and hexa-brominated congeners (BDE-99, BDE-100, BDE-153, BDE-154) appear prominently and are often the most abundant congeners in environmental samples due to their persistence. Deca-BDE (BDE-209), which is fully brominated, shows moderate concentrations but is lower than some penta- to hexa-brominated congeners. These congeners are peculiar due to their chemical stability, inclusion in common flame-retardant formulations, and ability to persist and accumulate in indoor dust through continuous release from consumer products such as furniture foam, electronics, and

textiles. Their prominence in dust samples is driven by their persistence, widespread usage, partitioning behavior, and indoor environmental dynamics.

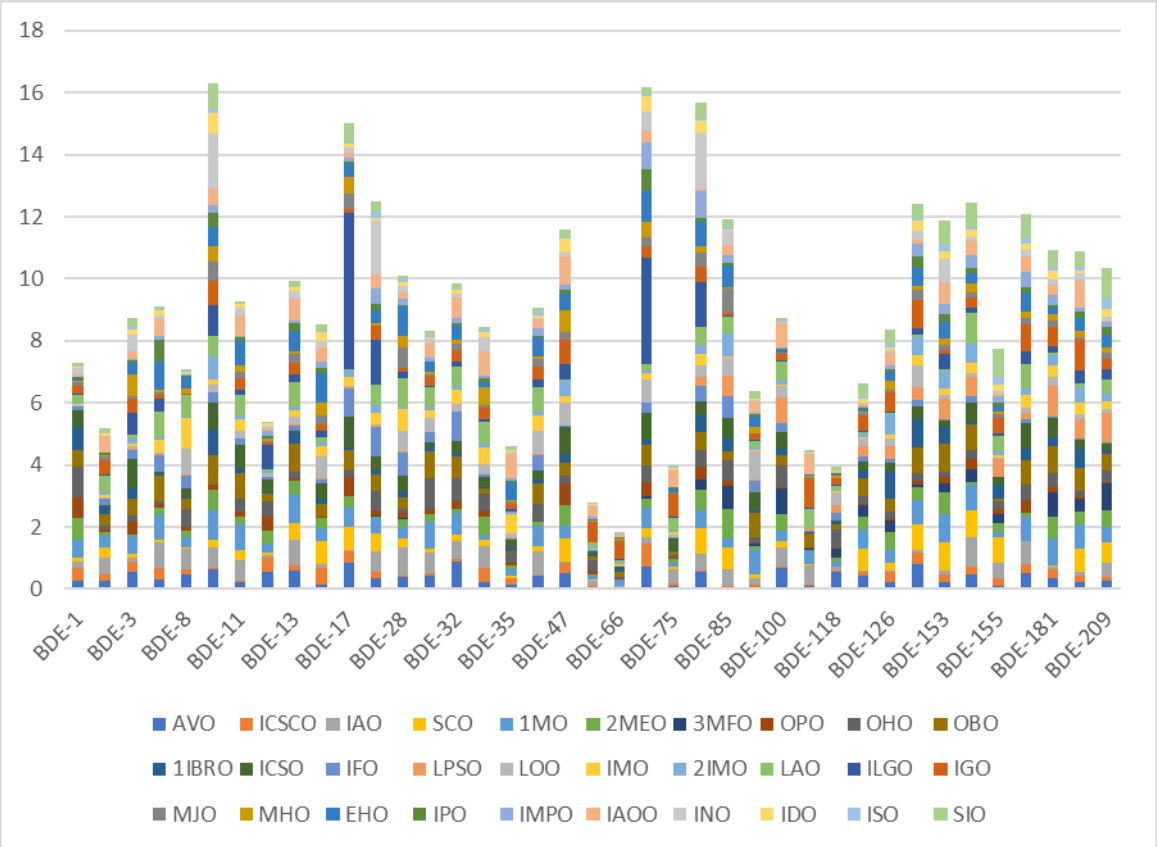

Figure 1: The summary of the PBDEs (ppb) congeners in 30 primary schools.

The means range broadly across congeners as shown in Figure 2, from as low as about 0.060 ppb (BDE-66) to as high as about 0.580 ppb (BDE-10). Congeners like BDE-10, BDE-71 (0.540 ppb), BDE-77 (0.520 ppb), and BDE-25 (0.420 ppb) show relatively elevated average concentrations among the congeners measured. This suggests these congeners are more abundant or more frequently released into dust in these schools.

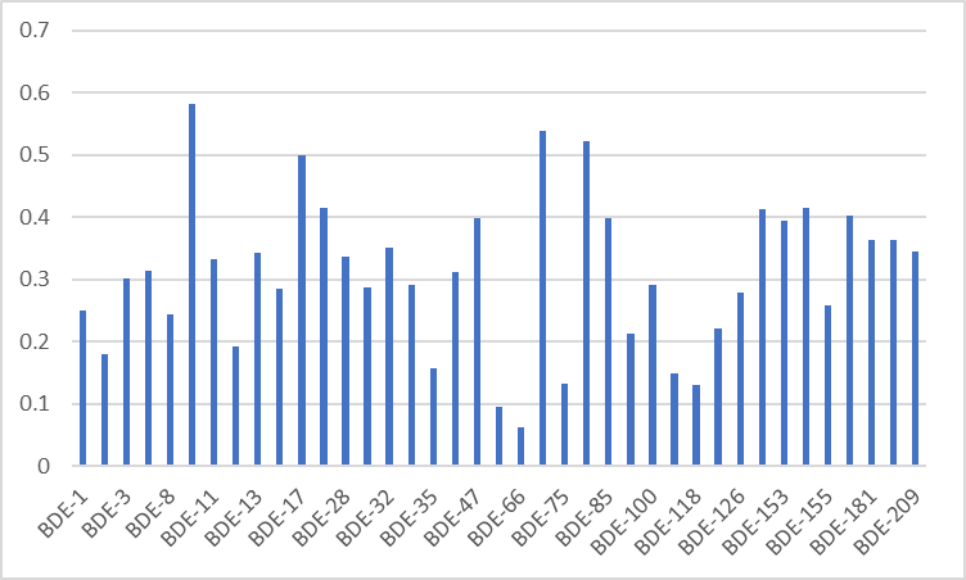

Figure 2: The mean (ppb) of the PBDE congeners in the samples

Large standard deviations relative to mean (Figure 3) indicate high variability of concentrations across samples. For example, BDE-17 has a mean of 0.5 but a very large standard deviation of 0.91, suggesting some samples have very high concentrations while others have low values. Similarly, BDE-71 and BDE-77 also show substantial variability. This variability points to heterogeneity in contamination sources or degrees of exposure at different school sites. Most congeners have minimum concentrations at or near zero (0 to 0.04 ppb), indicating that in some dust samples these congeners were either undetectable or present at very low levels, reflecting spatial variability in congener distribution. Maximum concentrations vary widely, with a few notable high peaks such as BDE-17 (5.04 ppb), BDE-25 (1.71 ppb), and BDE-10 (1.76 ppb). These maxima are significantly higher than most other congeners' maxima, indicating potential hotspots or localised sources of these specific congeners. The range, calculated as max - min, also highlights the spread of concentrations and confirms high variation for congeners like BDE-17 (5.02 ppb), BDE-71 (3.41 ppb), and BDE-77 (1.76 ppb). For most other congeners, ranges are close to 0.9 ppb to 1.0 ppb, showing substantial variation but less extreme than these high-range congeners.

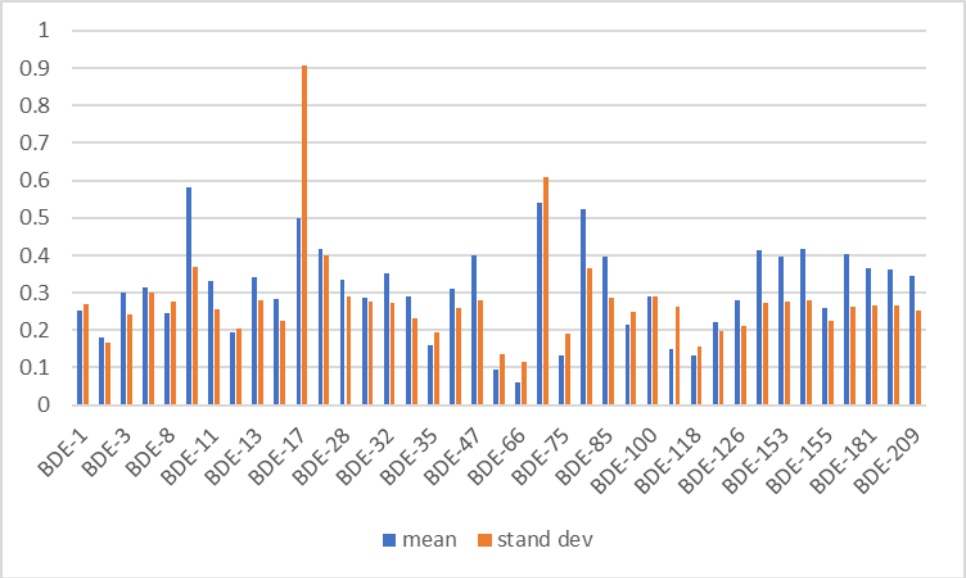

Figure 3: The mean and standard deviation in ppb of the congeners in the samples.

According to the US EPA, dust greater than 1000 mg/kg is hazardous, air guidelines exist for inhalation exposure [27]. Also, Basel /UNEP numerical limit for PBDEs in dust is 1000 mg/kg, dust above this is hazardous [28]. The PBDE concentrations measured in this study are substantially below established international hazardous waste thresholds, with all samples falling well within regulatory safety margins. The US EPA and Basel/UNEP both classify dust containing 1000 mg/kg (1,000,000 ppb) or greater PBDE concentrations as hazardous waste [23]. The highest individual concentration detected in this study was 5.04 ppb at ILGO, which represents a value that is approximately 198,412 times lower than the hazardous waste threshold. Similarly, the highest mean concentration of 0.537 ppb recorded at 1MO and the maximum sum PBDE value of 20.9 ppb are dramatically below regulatory limits.

Despite these concentrations being well below hazardous waste classification thresholds, the measurable presence of PBDEs across all sampled locations indicates widespread, albeit low-concentration, contamination that warrants continued attention. The absence of specific guidelines from major health organisations like WHO and national regulatory bodies such as FME and NESREA creates a regulatory gap that makes risk assessment challenging, particularly given the bioaccumulative and persistent nature of PBDE compounds. While the enormous safety margins provide reassurance that immediate health risks are minimal, the unique congener profile observed in this study, dominated by BDE-10, BDE-71, and BDE-77 rather than the typical BDE-47, BDE-99, and BDE-209 found in North American and European studies [29] suggests region-specific contamination sources that may

require tailored monitoring approaches even at these relatively low concentrations. The PBDE profiles observed in Ijebu-Ode schools show some similarities to patterns documented in North American studies, particularly regarding the presence of BDE-209. However, the dominance of BDE-10, BDE-71, and BDE-77 in this study contrasts with findings from European and North American schools, where BDE-47, BDE-99, and BDE-209 typically predominate [30]. This may be due to the different types of consumer products historically used in schools. The dominance of lower brominated congeners (BDE-10, BDE-71, BDE-77) might be due to different environmental persistent and degradation rate and age of contamination source. The maximum PBDE concentrations detected in this study, particularly for BDE-17 at 5.04 ppb, exceed typical values reported in many European and Asian [31]. These are generally lower than levels documented in North American schools. This positioning suggests moderate but significant contamination that warrants attention. The dominance of certain congeners (BDE-10, BDE-71) in this study differs from typical profiles reported globally.

CONCLUSION

This research found that primary school dust is frequently contaminated by polybrominated diphenyl ethers (PBDEs), with notable changes from one location to another. The variation may occur due to differences in flame retardants, electronics in use, how often the building is cleaned and the efficiency of its ventilation systems. The results suggest that as PBDEs do not break down easily, they build up in indoor dust which may cause concerns for children because of their activities and developmental stages.

A group of PBDE congeners such as BDE-10, BDE-17, BDE-25, BDE-71 and BDE-77, has high mean values and high variability which suggests that they come from local or product factors inside the school. Since BDE-209 (decaBDE) can be found in every sampling location at the same low concentration. It may have originated from consumer electronics, textiles and building materials. The unusually high values for BDE-17 (5.04ppb) and BDE-71 (3.44ppb), regarded as extreme outliers, suggest that particular locations were contaminated with high concentration of these substances. Some higher-brominated compounds such as BDE-153, BDE-154 and BDE-183, had higher minimum values, suggesting that they are equally present in all the schools and could come from common sources. The presence of increased PBDEs in indoor dust agrees with earlier research suggesting that children have higher exposure to these chemicals from dust than do adults. This is necessary since

complications related to PBDE exposure in children have been linked to issues such as thyroid hormone abnormalities, deficiencies in brain growth, trouble with attention and a higher risk of cancer. The wide spread and variations in PBDE levels among schools highlight that contamination is spotty and may be caused by different numbers and types of sources, variation in building conditions and employees' various habits. Even though some PBDE compounds have been phased out, they are still present in significant amounts in indoor spaces and require us to remain cautious, particularly in school buildings.

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