

# Polybrominated diphenyl ethers and polychlorinated biphenyls in dust from cars, homes, and offices in Lagos, Nigeria

Harrad, Stuart; Abdallah, Mohamed Abou-Elwafa; Oluseyi, Temilola

DOI:

[10.1016/j.chemosphere.2015.12.045](https://doi.org/10.1016/j.chemosphere.2015.12.045)

License:

Creative Commons: Attribution-NonCommercial-NoDerivs (CC BY-NC-ND)

*Document Version*

Peer reviewed version

*Citation for published version (Harvard):*

Harrad, S, Abdallah, MA-E & Oluseyi, T 2016, 'Polybrominated diphenyl ethers and polychlorinated biphenyls in dust from cars, homes, and offices in Lagos, Nigeria', *Chemosphere*, vol. 146, pp. 346-353.  
<https://doi.org/10.1016/j.chemosphere.2015.12.045>

[Link to publication on Research at Birmingham portal](#)

## **Publisher Rights Statement:**

After an embargo period this document is subject to the terms of a Creative Commons Attribution Non-Commercial No Derivatives license

## **General rights**

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

## **Take down policy**

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact [UBIRA@lists.bham.ac.uk](mailto:UBIRA@lists.bham.ac.uk) providing details and we will remove access to the work immediately and investigate.

**POLYBROMINATED DIPHENYL ETHERS AND  
POLYCHLORINATED BIPHENYLS IN DUST FROM  
CARS, HOMES, AND OFFICES IN LAGOS, NIGERIA**

Stuart Harrad<sup>a</sup>, Mohamed Abou-Elwafa Abdallah<sup>a,b</sup>, Temilola Oluseyi<sup>c</sup>

<sup>a</sup>School of Geography, Earth, and Environmental Sciences, University of Birmingham,  
Birmingham, B15 2TT, UK

<sup>b</sup>Department of Analytical Chemistry, Faculty of Pharmacy, Assiut University, 71526 Assiut,  
Egypt

<sup>c</sup>Department of Chemistry, Faculty of Science, University of Lagos, Lagos, Nigeria

Contact: S.J.Harrad@bham.ac.uk

## ABSTRACT

Polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs) were measured in dust from 16 cars, 12 homes, and 18 offices in Lagos, Nigeria. These represent the first and second reports respectively of contamination of Nigerian indoor dust with these contaminants, and the second report on PCBs in car dust worldwide. Concentrations of BDE-47 and BDE-99 in two car dust samples (9,300 and 3,700 ng g<sup>-1</sup> for BDE-47 and 4,200 and 19,000 ng g<sup>-1</sup> for BDE-99), are amongst the highest ever reported in car dust. ANOVA comparison with Canada, New Zealand, the UK, and the USA; reveals concentrations of BDEs-28, 49, 47, 66, 100, 99, 154, and 153 in Nigerian house dust, to be significantly lower than in Canada and the USA, with those of BDE-49 and 154 significantly lower than in New Zealand and the UK. Concentrations of BDE-209 in Nigeria were significantly lower than concentrations in the UK and the USA; while concentrations of PCB-180 were significantly greater than those in New Zealand, the UK, and the USA. Median concentrations of PCBs in cars were substantially higher than in the only previous study (in Kuwait and Pakistan). While median concentrations of PBDEs in cars generally exceeded those in homes, this was significant only for BDEs-49, 154, and 197, with concentrations in cars significantly greater than those in offices for BDEs-49 and 154. Contrastingly, concentrations of all target PCBs in offices exceeded significantly those in cars. This study underlines the truly global distribution of indoor contamination with PBDEs and PCBs.

36    **KEYWORDS**

37    POPs

38    BFRs

39    PCBs

40    Africa

41    Nigeria

42    Indoor dust

43

## **HIGHLIGHTS**

PBDEs and PCBs measured in Nigerian car, home & office dust

Penta-BDE levels in 2 cars amongst highest ever reported

Only second ever report of PCBs in cars

PCB 180 in Nigerian house dust at high end of global range

Levels of all target PCBs in Nigerian offices exceed those in cars

## 1. INTRODUCTION

Polybrominated diphenyl ethers (PBDEs) are chemicals added to a wide range of consumer products (electrical and electronic equipment, textiles, polyurethane and polystyrene foams) to meet flame retardancy standards set by various jurisdictions worldwide (Alaee et al, 2003). Since these chemicals are used additively in most applications - i.e. they are not covalently bound to the products to which they are added - they can transfer from such products into the environment. An extensive body of evidence exists concerning the presence of PBDEs in indoor air (Allen et al, 2007; Harrad et al, 2004; Newton et al, 2015) and indoor dust (Harrad et al, 2008a,b; Jones-Otazo et al, 2005; Stapleton et al, 2005). Evidence of their persistence and capacity for bioaccumulation, coupled with concerns about their adverse health effects (Birnbaum and Staskal, 2004), have led to widespread bans and restrictions on the manufacture and use of both the Penta- and Octa-BDE mixtures and their listing under the Stockholm Convention on Persistent Organic Pollutants (POPs) (UNEP, 2007). Moreover, manufacture and use of Deca-BDE has been progressively restricted and it is currently under consideration for listing under the Stockholm Convention (UNEP, 2013).

Human exposure to PBDEs occurs via the diet, and via inhalation of (primarily indoor) air, as well as ingestion of indoor dust (Harrad et al, 2004; 2006; Jones-Otazo et al, 2005; Lorber, 2008). The relative significance of each pathway varies considerably according to factors such as: geographical location (dust ingestion appears more important in North America than elsewhere (Harrad et al, 2008b)), age (dust ingestion is considered of greater magnitude for young children than adults (Jones-Otazo et al, 2005)), and the physicochemical properties of a given PBDE congener (exposure to decabromodiphenyl ether (BDE-209) is dominated by dust ingestion as a consequence of its very low vapour pressure and comparatively low capacity for bioaccumulation).

To date, the vast majority of exposure assessments conducted for PBDEs, have been conducted in East Asia (China, Korea, and Japan), Europe, and North America (Besis and Samara, 2012; Harrad et al, 2010). While data is emerging for other regions (including Egypt (Hassan and Shoeib, 2015), Kuwait (Ali et al, 2013; Gevao et al, 2006), and South Africa (Kefeni and Okwonkwo, 2012; Obafe and Martincigh, 2015)), to our knowledge only two previous studies exist concerning the presence of PBDEs in indoor dust in Nigerian car and house dust respectively (Olukunle et al, 2015a,b).

Another class of POPs listed under the Stockholm Convention are polychlorinated biphenyls (PCBs). Despite almost universal cessation of their manufacture and new use in the late 1970s, their extensive use in applications such as plasticisers in building sealants and dielectric fluids in capacitors and transformers (Harrad et al, 1994), coupled with their persistence, means that they maintain a discernible environmental presence even today. Their substantial use in indoor applications is manifested by numerous reports of elevated concentrations of PCBs in indoor environments (Currado and Harrad, 1998; Harrad et al, 2006; Herrick et al, 2004; Kohler et al, 2005). Given their comparatively higher vapour pressures than PBDEs, far fewer data exist about concentrations of PCBs in indoor dust than for PBDEs. However, a previous study by our group suggests that although inhalation is the principal indoor exposure pathway under a typical dust ingestion scenario, exposure via dust ingestion exceeds that from either inhalation or diet for a small proportion of North American toddlers (Harrad et al, 2009). To our knowledge, this study constitutes the first measurements of PCBs in indoor dust in Nigeria. Moreover, PCBs in car dust have only been reported in one previous study conducted in Kuwait and Pakistan (Ali et al, 2013).

Against this background, this study seeks to corroborate the recently reported presence of PBDEs in indoor dust from various microenvironments in Makurdi, Benue State, Nigeria (Olukunle et al, 2015a,b), and to provide the first data on concentrations of PCBs in Nigerian indoor dust. We examine exposure in homes, offices and cars because they are oft-frequented environments. Moreover, we provide only the second such report worldwide on concentrations of PCBs in cars. We place our data for Nigerian indoor dust in an international context by comparing the levels found with those reported previously elsewhere. While the Nigerian economy is growing, it is not yet at the level of countries in North America and the EU for example, and thus our overarching hypothesis was that concentrations of PBDEs in Nigeria would be lower than those in more developed countries. However, it has been suggested that import of older electrical and electronic equipment may be an important source of BFRs like PBDEs in countries such as Nigeria (Nnorom and Osibanjo, 2008). As similar considerations may apply to PCBs, we tested our hypothesis by determining concentrations of PBDEs and PCBs in samples of settled dust from 16 cars, 12 homes, and 18 offices in Lagos, Nigeria.

## **2. MATERIALS AND METHODS**

### **2.1 Sample collection**

Dust samples were collected from 16 private cars, 18 offices, and the living areas of 12 houses in Lagos, Nigeria (the largest city in Nigeria) between September and October 2014. House and office dust samples were collected using a vacuum cleaner, according to a standardised method (Harrad et al, 2008b). Briefly, 1 m<sup>2</sup> of carpeted floor was vacuumed for 2 min, while for bare floors, 4 m<sup>2</sup> surface was vacuumed for 4 min. Dust was retained using 25 µm pore size nylon sample socks (Allied Filter Fabric Pty Ltd, Australia) mounted in the furniture attachment tube of the vacuum cleaner. In cars, dust was sampled from the dashboard, seats, and the floor in the passenger cabin, as well as in the boot. After sampling, socks were closed with a twist tie, sealed in a plastic bag and stored at -20 °C until transportation via courier to the University of Birmingham for sieving and analysis. Before sampling, the furniture attachment and the vacuum tubing were cleaned thoroughly using an isopropanol-impregnated disposable wipe. At the time of sample collection, information on potential influences on BFR contamination was recorded. In homes and offices, this comprised the number and type of putative sources like electronic devices, foam-filled furniture and floor material; while in cars, the vehicle manufacturer and age was recorded. Prior to analysis, all dust samples were passed through a pre-cleaned, n-hexane rinsed 500 µm mesh testing sieve (UKGE Limited, UK), covered with the lid and shaken for 2-4 min. Sieved samples were stored in clean, n-hexane rinsed glass jars and stored at 4 °C until analysis.

## **2.2 Sample extraction**

Accurately weighted aliquots of dust (~0.15 g) were loaded into pre-cleaned 66 mL cells containing 1.5 g Florisil and Hydromatrix (Varian Inc., UK) to fill the void volume of the cells, and spiked with internal (surrogate) standards (15 ng of each of BDE 77, BDE 128 and 30 ng of <sup>13</sup>C<sub>12</sub>-BDE 209) prior to pressurised liquid extraction (ASE 350, Dionex, Hemel Hempstead, UK) using hexane:dichloromethane (1:9, v/v) at 90 °C and 1500 psi. The heating time was 5 minutes, static time 4 min, purge time 90 s, flush volume 50 %, with three static cycles (Harrad and Abdallah, 2011).

## **2.3 Clean up**

The crude extracts were concentrated to 0.5 mL using a Zymark Turbovap® II then purified by loading onto SPE cartridges filled with 8 g of pre-cleaned acidified silica (44% concentrated sulfuric acid, w/w). The analytes were eluted with 25 mL of hexane:dichloromethane (1:1, v/v). The eluate was evaporated to dryness under a gentle



stream of nitrogen then reconstituted in 100  $\mu$ L of isooctane containing 2.5 ng of  $^{13}\text{C}_{12}$ -BDE 100 used as recovery determination (syringe) standard for QA/QC purposes.

## **2.4 Instrumental analysis**

Target PBDEs (BDEs 17, 28, 49, 66, 100, 99, 85, 154, 153, 183, 197, 203, 196, 208, 207, 206, and 209) were quantified using a TRACE<sup>TM</sup> 1310 Gas Chromatograph coupled to ISQ<sup>TM</sup> single quadrupole mass spectrometer (ThermoScientific, Austin, TX, USA) operated in negative chemical ionisation mode. Chromatographic resolution of PBDEs was achieved on a HP5-MS capillary column (15 m x 0.25 mm x 0.1  $\mu$ m; Agilent, CA, USA) according to a previously reported method (Harrad et al., 2008b). PCB analysis was conducted in accordance with our previous study of PCBs in indoor dust (Harrad et al, 2009) using an Agilent 5975C GC-MSD. In this study, our target PCBs were the ICES (International Council for the Exploration of the Seas) 6 indicator congeners 28, 52, 1010, 138, 153, and 180.

## **2.5 Quality Assurance/Quality Control**

Recoveries of the internal standards used for PBDE analysis in individual samples ranged from 71 to 104 %. Those for PCB analysis fell in the range 71 to 102 %. Method blanks (n = 10) consisting of sodium sulfate were found to contain concentrations of target PBDEs and PCBs no greater than 5 % of the concentrations found in the corresponding samples. Our data are thus not corrected for blank concentrations. For target compounds that were detected in the blanks. The limit of detection (LOD) was calculated as average blank level + 3\*standard deviation of the blanks. For compounds that were not detected in the blanks. LOD was calculated as the sample level that produces a signal to noise ratio of 3:1.

## **2.6 Statistical analysis**

Statistical analysis of our data was performed using IBM SPSS for Mac software (v. 22.0.0.0). For the purposes of statistical evaluation, all concentrations below the limit of detection (LOD) were assigned a value of  $f \times \text{LOD}$ , where  $f$  is the fractional detection frequency of the contaminant in samples from that microenvironment in this study (Roosens et al, 2009). The distribution of our concentration data for PBDEs and PCBs were tested separately for each microenvironment using the Shapiro-Wilk test. This - combined with visual inspection of frequency plots – indicated that while our PCB data displayed a normal distribution, those for PBDEs were log-normally skewed ( $P < 0.05$ ), therefore all PBDE data

were log-transformed prior to comparison of means via ANOVA, as well as regression analysis. A P value <0.05 was used as the level indicating statistical significance.

### **3. RESULTS AND DISCUSSION**

#### **3.1 Concentrations of PBDEs and PCBs in Nigerian house dust**

Statistical summaries of concentrations of selected PBDEs and PCBs in samples analysed in this study are provided as Tables 1 and 2 respectively, with concentrations of all target contaminants in each individual sample supplied as supplementary material. Each target PCB was detected in every sample. By comparison, detection frequency varied between PBDE congeners. BDEs 47, 99, 100, 183, and 209 were detected in nearly all samples, with detection frequencies for other congeners ranging from 17 % for BDE-17 in house and office dust to 88 % for BDEs-197, 203, and 196 in car dust.

#### **3.2 Do concentrations of PBDEs and PCBs vary between microenvironment categories?**

Significant differences in concentrations of PBDEs in dust samples from different microenvironment categories have been reported (Harrad et al, 2008a; 2010). While similar differences have not been reported for PCBs, this may possibly be due to the far more limited database on these contaminants in indoor dust. We therefore hypothesised that significant differences would exist in concentrations of PBDEs and PCBs in cars, homes, and offices in this study. To test this hypothesis, we subjected our data to ANOVA. This analysis revealed the following significant differences between concentrations of target contaminants in different microenvironments. For BDEs-49 and -154, concentrations in car dust exceeded significantly those in both homes and offices; while for BDE-197, concentrations in cars were significantly greater than those in homes. In addition, concentrations of each individual target PCB in office dust were significantly higher than those in car dust; with concentrations of PCBs in car dust also exceeded significantly by those in house dust. No other significant differences were observed.

#### **3.3 How do concentrations of PBDEs and PCBs in this study compare with previous studies?**

Particularly noteworthy, are the highly elevated concentrations of Penta-BDE congeners in 2 car dust samples. At 9,300 and 3,700 ng g<sup>-1</sup> for BDE-47 and 4,200 and 19,000 ng g<sup>-1</sup> for BDE-99, these concentrations approach the maximum values reported anywhere in car dust of 30,000 ng g<sup>-1</sup> and 63,000 ng g<sup>-1</sup> (Batterman et al, 2009). These two samples came from

vehicles that were respectively 14 and 11 years old at the time of sampling. Both were Japanese marques that to our knowledge were manufactured in Japan. Further discussion of the relationship between PBDE concentrations and potential influencing factors follows in section 3.4.

Median concentrations detected in dust from cars, homes, and offices in this study are compared with those from selected other studies in Tables 3 and 4 for PBDEs and PCBs respectively. Median concentrations of PBDEs in both house and office dust in this study are lower than those reported in the only other studies conducted in Nigeria (Olukunle et al, 2015a,b). This difference may be due to small sample numbers in these studies, and perhaps also due to the different regions sampled (Makurdi, Benue State versus Lagos) but may also be explained by the different sampling method employed in the previous Nigerian studies (Olukunle et al, 2015a,b), in which the dust samples analysed comprised of a mix of floor dust and dust sampled from product surfaces. We have shown elsewhere that PBDE transfer from products to dust via direct product:dust contact is substantial (Rauert and Harrad, 2015), and thus dust sampled from product surfaces would likely contain higher concentrations than dust taken from the floor. Elsewhere in the African region, our concentrations of PBDEs in house and office dust are lower than those reported recently for South Africa (Abafe and Martincigh, 2015), but exceed those in earlier South African studies (Kefeni and Okwonkwo, 2012; Kefeni et al, 2014), and those reported elsewhere for Egypt and Iraq (Al-Omran and Harrad, in press; Hassan and Shoeib, 2015).

For PCBs, concentrations in this study are lower than those reported for South African homes and offices (Abafe and Martincigh, 2015), but exceed substantially those in Kuwaiti and Pakistani homes (Ali et al, 2013), and also those in Hong Kong offices (Kang et al, 2013). To the best of our knowledge, there is only one other study of PCBs in car dust, and concentrations of all target congeners in this study exceed substantially those reported for cars in Kuwait and Pakistan (Ali et al, 2013).

In addition, we used ANOVA to test whether concentrations of both PBDEs and PCBs in house dust in this study were significantly different to those reported previously by our research group using identical sampling and analytical procedures in house dust from Canada, New Zealand, the UK, and the USA (Harrad et al, 2008b, 2009). As New Zealand

dust samples were only analysed for PCBs and Penta-BDE congeners, our comparison here for Octa- and Deca-BDE components does not include New Zealand.

This ANOVA comparison revealed concentrations of BDEs 28, 49, 47, 66, 100, 99, 154, and 153 to be significantly lower in Nigerian house dust than in dust from Canadian and USA homes. This is consistent with the well-documented greater use of the Penta-BDE product in North America. In addition, concentrations of BDEs-49 and 154 in New Zealand and UK dust exceeded significantly those in house dust from Nigeria in this study. While concentrations of the Octa-BDE marker congener BDE-183 in this study were statistically indistinguishable from those in the other countries examined; concentrations of the Deca-BDE indicator (BDE-209) were significantly lower in this study than in house dust from both the UK and the USA.

Similar comparison for PCBs, showed concentrations in this study to be statistically indistinguishable from those in Canadian, New Zealand, UK, and USA house dust, with the exception of PCB-180. For this congener, concentrations in this study exceeded significantly those in New Zealand, the UK, and the USA. As PCB-180 was most prevalent in the highly chlorinated commercial formulations such as Aroclor 1260 manufactured by Monsanto, this may indicate more extensive application of this product in Nigeria.

### **3.4 What influences concentrations of PBDEs in indoor dust samples?**

We examined our data on concentrations of PBDEs and potential factors influencing these concentrations. For car dust, we noted no correlation between vehicle age (which ranged between 3 and 29 years, with an average of 11.6 years) and log-transformed concentration of any target PBDE. Moreover, there was no apparent relationship between PBDE concentrations and the car marque (5 Honda, 4 Toyota, 2 Nissan, and 1 each of Geely, Kia, Lexus, Mercedes, and Rover). For example, the highest BDE-99 concentration (19,000 ng g<sup>-1</sup>) was observed in an 11 year old vehicle, while the same congener was not detected in a 13 year old car of the same marque. This observation is consistent with previous observations that the year of vehicle manufacture is not the only factor influencing concentrations of PBDEs in cars (Hazrati and Harrad, 2006).

We next conducted multiple linear regression analysis of our data for office and house dust using automatic linear modelling with log-transformed PBDE concentrations as the

dependent variable and the numbers of: PUF-containing furniture, TVs, PCs, printers/copiers, microwaves, and fridge/freezers as independent variables. In homes, we also incorporated whether the home was air conditioned or naturally ventilated as an independent variable – all offices were air-conditioned. Office and house dust data were examined separately. Results of this automatic linear modelling showed no significant relationships, except that concentrations of  $\Sigma$ tri-through hexa-BDEs (a proxy for the Penta-BDE formulation) were significantly ( $p=0.04$ ) positively correlated with the number of TVs in offices. While we have no information on the age of the TVs in the offices studied, this is not inconsistent with the reported past use of the Penta-BDE formulation in printed circuit boards (Betts, 2006).

### 3.5 Human exposure implications

Tables 5, 6, and 7 give illustrative estimates of human exposure to (respectively) BDE-99, BDE-209, and  $\Sigma$ ICES-6 PCBs that would arise from ingestion of the dust samples measured in this study. In common with the vast majority of other studies, we have conservatively assumed 100% absorption of intake and used average adult and toddler dust ingestion figures of 20 and 50  $\text{mg day}^{-1}$ , and high dust ingestion figures for adults and toddlers of 50 and 200  $\text{mg day}^{-1}$  (Jones-Otazo et al., 2005). We have then estimated exposure under various dust ingestion scenarios for homes, offices, and cars separately, assuming ingested dust is contaminated at the 5<sup>th</sup> percentile, median, and 95<sup>th</sup> percentile concentrations in our dust samples from each microenvironment category. Overall dust ingestion exposure estimates are then calculated taking into account ingestion of dust in each of the relevant microenvironments. Dust ingestion is assumed to occur pro-rata to typical activity patterns (i.e. for adults: 72% home, 23.8% office, 4.2% car, for toddlers: 95.8% home and 4.2% car).

In summary, based on our data, Nigerian adult exposure via dust ingestion ranges between 0.08 and 22  $\text{ng day}^{-1}$ , 1.3 and 180  $\text{ng day}^{-1}$ , and 0.37 and 3.3  $\text{ng day}^{-1}$  for BDE-99, BDE-209, and  $\Sigma$ ICES-6 PCBs respectively. The equivalent exposure estimates for Nigerian toddlers are 0.21 to 87  $\text{ng day}^{-1}$ , 4.3 to 600  $\text{ng day}^{-1}$ , and 0.91 and 12  $\text{ng day}^{-1}$ . While to our knowledge there are no health based limit values (HBLVs) against which we can compare our estimate of exposure to  $\Sigma$ ICES-6 PCBs, such values do exist for BDEs-99 and -209. For BDE-99, the relevant value is the USEPA's reference dose RfD of 100  $\text{ng kg body weight}^{-1} \text{ day}^{-1}$  (USEPA, 2008a), while for BDE-209 the USEPA RfD is 7,000  $\text{ng kg body weight}^{-1} \text{ day}^{-1}$  (USEPA, 2008b). Assuming a child weight of 20 kg, our worst-case exposure estimate (high-end for

toddlers) for BDEs-99 and -209 are 4.35 and 30 ng kg body weight<sup>-1</sup> day<sup>-1</sup> respectively. While we have not considered exposure via other pathways such as inhalation, diet, and dermal contact with dust and BFR-treated materials, there is a clearly substantial margin of safety between apparent exposure of the Nigerian population to these PBDEs and the USEPA RfD values. As a caveat to this reassuring message, we highlight the existence of a HBLV (albeit of no legislative standing) for BDE-99 proposed by researchers from the Netherlands of 0.23-0.30 ng kg body weight<sup>-1</sup> day<sup>-1</sup> for which impaired spermatogenesis is the end point of concern (Bakker et al, 2008). Our estimates of exposure of a 20 kg child arising from ingestion of dust contaminated with BDE-99 at the 95<sup>th</sup> percentile concentration at both the average (1.1 ng kg body weight<sup>-1</sup> day<sup>-1</sup>) and high ingestion rates (4.35 ng kg body weight<sup>-1</sup> day<sup>-1</sup>), both exceed this HBLV. Continued monitoring of human exposure to PBDEs would therefore appear warranted.

#### **4. CONCLUSIONS**

This study shows both PBDEs and PCBs to be ubiquitous in Nigerian cars, homes, and offices. While concentrations are in the main at the lower end of those reported globally, concentrations of PCB 180 in Nigerian homes are significantly higher than those recorded previously for New Zealand, the UK, and the USA. Moreover, concentrations of Penta-BDE congeners in 2 car dust samples are amongst the highest ever reported. Overall, this study underlines the truly global distribution of indoor contamination with PBDEs and PCBs, and the continuing need for action to reduce and eventually eliminate this potential public health hazard.

#### **ACKNOWLEDGEMENTS**

The authors express their thanks to all the dust donors. Temilola Oluseyi acknowledges gratefully funding from the Commonwealth Scholarship Commission.

#### **APPENDIX A. SUPPLEMENTARY MATERIAL**

Tables of concentrations of individual PBDEs and PCBs in all samples analysed, as well as information on factors potentially influencing concentrations. Supplementary data associated with this article can be found, in the online version, at

#### **REFERENCES**

Abafe, O. A., Martincigh, B. S., 2015. Polybrominated diphenyl ethers and

347 polychlorinated biphenyls in indoor dust in Durban, South Africa. *Indoor Air* 25, 547–556.

348 Alaei, M., Arias, P., Sjödin, A., Bergman, A. 2003. An overview of commercially used  
 349 brominated flame retardants, their applications, their use patterns in different  
 350 countries/regions and possible modes of release. *Environ. Int.* 29, 683-689.

351 Ali, N., Ali, L., Mehdi, T., Dirtu, A. C., Al-Shammari, F., Neels, H., Covaci, A., 2013.  
 352 Levels and profiles of organochlorines and flame retardants in car and house dust from  
 353 Kuwait and Pakistan: Implication for human exposure via dust ingestion. *Environ. Int.* 55,  
 354 62-70.

355 Allen, J. G., McClean, M. D., Stapleton, H. M., Nelson, J. W., Webster, T. F. 2007.  
 356 Personal Exposure to Polybrominated Diphenyl Ethers (PBDEs) in Residential Indoor Air.  
 357 *Environ. Sci. Technol.* 41, 4574-4579.

358 Al-Omran, L., Harrad, S. 2015. Polybrominated diphenyl ethers and “novel” brominated  
 359 flame retardants in floor and elevated surface house dust from Iraq: implications for human  
 360 exposure assessment. *Emerging Contaminants*,  
 361 <http://dx.doi.org/10.1016/j.emcon.2015.10.001>

362 Bakker, M. I.; de Winter-Sorkina, R.; de Mul, A.; Boon, P. E.; van Donkersgoed, G.;  
 363 van Klaveren, J. D.; Baumann, B. A.; Hijman, W. C.; van Lewuwen, S. P. J.; de Boer, J.;  
 364 Zeilmaker, M. J. Dietary intake and risk evaluation of polybrominated diphenyl ethers in The  
 365 Netherlands. *Mol. Nutr. Food Res.* 2008, 52, 204–216.

366 Batterman, S. A., Chernyak, S., Jia, C., Godwin, C., Charles, S., 2009. Concentrations  
 367 and emissions of polybrominated diphenyl ethers from U.S. houses and garages. *Environ.*  
 368 *Sci. Technol.* 43, 2693–2700.

369 Batterman, S., Godwin, C., Chernyak, S., Jia, C., Charles, S., 2010. Brominated flame  
 370 retardants in offices in Michigan, U.S.A. *Environ. Int.* 36, 548–556.

371 Basis, A., Samara, C. 2012. Polybrominated diphenyl ethers (PBDEs) in the indoor and  
 372 outdoor environments - A review on occurrence and human exposure. *Environ. Pollut.* 169,  
 373 217-229.

374 Betts, K., 2006. PBDEs and PCBs in computers, cars, and homes. *Environ. Sci.*  
 375 *Technol.* 40, 7452.

376 Birnbaum, L. S., Staskal, D. F., 2004. Brominated flame retardants: cause for concern.  
 377 *Environ. Hlth. Perspect.* 112, 9-17.

378 Currado, G. M., Harrad, S., 1998. A Comparison of Polychlorinated Biphenyl  
 379 Concentrations in Indoor and Outdoor Air and the Potential Significance of Inhalation as a  
 380 Human Exposure Pathway. *Environ. Sci. Technol.* 32, 3043-3047.

381 Dodson, R. E., Perovich, L. J., Covaci, A., Van den Eede, N., Ionas, A. C., Dirtu, A. C.,  
 382 Brody, J. G., Rudel, R. A., 2012. After the PBDE Phase-Out: A Broad Suite of Flame  
 383 Retardants in Repeat House Dust Samples from California, *Environ. Sci. Technol.* 46,  
 384 13056–13066.

385 Gevao, B., Al-Bahloul, M., Al-Ghadban, A., Al-Omair, A., Ali, L., Zafar, J., M.  
 386 Helaleh, M., 2006. House dust as a source of human exposure to polybrominated diphenyl  
 387 ethers in Kuwait, *Chemosphere*, 64, 603–608.

388 Harrad, S. J., Sewart, A. P., Alcock, R., Boumphrey, R., Burnett, V., Duarte-Davidson,  
 389 R., Halsall, C., Sanders, G., Waterhouse, K., Wild, S. R., Jones, K. C. 1994. Polychlorinated  
 390 biphenyls (PCBs) in the British environment: sinks, sources and temporal trends. *Environ.*  
 391 *Pollut.* 85, 131-147.

392 Harrad, S., Wijesekera, R., Halliwell, S., Baker, R. 2004. A Preliminary Assessment of  
 393 UK Human Dietary and Inhalation Exposure to Polybrominated Diphenyl Ethers. *Environ.*  
 394 *Sci. Technol.* 38, 2345-2350.

395 Harrad, S., Hazrati, S., Ibarra, C. 2006. Concentrations of Polybrominated Diphenyl  
 396 Ethers in Indoor Air and Dust and Polychlorinated Biphenyls in Indoor Air in Birmingham,  
 397 United Kingdom: Implications for Human Exposure. *Environ. Sci. Technol.* 40, 4633-4638.

398 Harrad, S., Ibarra, C., Abdallah, M. A., Boon, R., Neels, H., Covaci, A. 2008a.  
 399 Concentrations of brominated flame retardants in dust from United Kingdom cars, homes,  
 400 and offices: Causes of variability and implications for human exposure *Environ. Int.* 34,  
 401 1170-1175.

402 Harrad, S., Ibarra, C., Diamond, M., Melymuk, L., Robson, M., Douwes, J., Roosens,  
 403 L., Dirtu, A. C., Covaci, A. 2008b. Polybrominated diphenyl ethers in domestic indoor dust  
 404 from Canada, New Zealand, United Kingdom and United States *Environ. Int.* 34, 232-238.

405 Harrad, S., Ibarra, C., Robson, M., Melymuk, L., Diamond, M., Douwes, J. 2009.  
 406 Polychlorinated Biphenyls in Indoor Dust from Canada, New Zealand, United Kingdom and  
 407 United States: Implications for Human Exposure. *Chemosphere* 76, 232-238.

408 Harrad, S., de Wit, C. A., Abdallah, M. A-E., Bergh, C., Björklund, J. A., Covaci, A.,  
 409 Darnerud, P. O., de Boer, J., Diamond, M., Huber, S., Leonards, P., Mandalakis, M.,  
 410 Östman, C., Småstuen Haug, L., Thomsen, C., Webster, T. F. 2010. Indoor Contamination  
 411 with Hexabromocyclododecanes, Polybrominated Diphenyl Ethers and Perfluoroalkyl  
 412 Compounds: An Important Exposure Pathway for People? *Environ. Sci. Technol.* 44, 3221–  
 413 3231.

414 Harrad, S., Abdallah, M. A., 2011. Brominated Flame Retardants in Dust from UK



Cars: Within-Vehicle Spatial Variability, Evidence for Degradation and Exposure Implications. *Chemosphere* 82, 1240-1245.

Hassan, Y., Shoeib, T., 2015 Levels of polybrominated diphenyl ethers and novel flame retardants in microenvironment dust from Egypt: An assessment of human exposure. *Sci. Tot. Environ.* 505, 47–55.

Hazrati, S., Harrad, S. 2006. Causes of Variability in Concentrations of Polychlorinated Biphenyls and Polybrominated Diphenyl Ethers in Indoor Air. *Environ. Sci. Technol.* 40, 7584–7589.

Herrick, R. F., McClean, M. D., Meeker, J. D., Baxter, L. K., Weymouth, G. A., 2004. An Unrecognized Source of PCB Contamination in Schools and Other Buildings. *Environ. Hlth. Perspect.* 112, 1051-1053.

Jones-Otazo, H. A., Clarke, J. P., Diamond, M. L., Archbold, J. A. Ferguson, J. A., Harner, T., Richardson, G. M., Ryan, J. J., Wilford, B. 2005. Is House Dust the Missing Exposure Pathway for PBDEs? An Analysis of the Urban Fate and Human Exposure to PBDEs. *Environ. Sci. Technol.* 39, 5121-5130.

Kang, Y., Yin, Y., Man, Y., Li, L., Zhang, Q., Zeng, L., Luo, J., Wong, M. H., 2013. Bioaccessibility of polychlorinated biphenyls in workplace dust and its implication for risk assessment. *Chemosphere* 93, 924–930.

Kefeni, K. K., Okonkwo, J. O. 2012. Analysis of major congeners of polybromobiphenyls and polybromodiphenyl ethers in office dust using high resolution gas chromatography–mass spectrometry. *Chemosphere* 87, 1070–1075.

Kefeni, K. K., Okonkwo, J. O., Botha, B. M., 2014. Concentrations of polybromobiphenyls and polybromodiphenyl ethers in home dust: Relevance to socio-economic status and human exposure rate, *Sci. Tot. Environ.* 470–471, 1250–1256.

Kohler, M., Tremp, J., Zennegg, M., Seiler, C., Minder-Kohler, S., Beck, M., Lienemann, P., Wegmann, L., Schmid, P. 2005. Joint Sealants: An Overlooked Diffuse Source of Polychlorinated Biphenyls in Buildings, *Environ. Sci. Technol.* 39, 1967-1973.

Lorber, M. 2008. Exposure of Americans to polybrominated diphenyl ethers. *J. Exposure Sci. Environ. Epidemiol.* 18, 2–19.

Newton, S., Sellström, U., de Wit, C. A., 2015. Emerging Flame Retardants, PBDEs, and HBCDDs in Indoor and Outdoor Media in Stockholm, Sweden *Environ. Sci. Technol.* 49, 2912–2920.

Nnorom, I.C., Osibanjo, O., 2008. Sound management of brominated flame retarded (BFR) plastics from electronic wastes: State of the art options in Nigeria. *Resour. Conserv.*

Recycl. 52, 1362–1372.

Olukunle, O. I., Okonkwo, O. J., Sha'ato, R., Wase, G. A., 2015a. Levels of polybrominated diphenyl ethers in indoor dust and human exposure estimates from Makurdi, Nigeria. *Ecotoxicol. Environ. Safety* 120, 394–399.

Olukunle, O. I., Okonkwo, O. J., Sha'ato, R., Wase, G. A., 2015b. Polybrominated diphenyl ethers in car dust in Nigeria: Concentrations and implications for non-dietary human exposure, *Microchem. J.* 123, 99–104.

Rauert, C., Harrad, S., 2015. Mass transfer of PBDEs from plastic TV casing to indoor dust via three migration pathways - A test chamber investigation. *Sci. Tot. Environ.* 536, 568-574.

Roosens, L., Abdallah, M.A., Harrad, S., Neels, H., Covaci, A., 2009. Exposure to hexabromocyclododecanes (HBCDs) via dust ingestion, but not diet, correlates with concentrations in human serum: preliminary results. *Environ Health Perspect* 117, 1707-1712.

Stapleton, H. M., Dodder, N. G., Offenberg, J. H., Schantz, M. M., Wise, S. A., 2005. Polybrominated diphenyl ethers in house dust and clothes dryer lint. *Environ. Sci. Technol.* 39, 925-931.

UNEP, 2007, online, <http://chm.pops.int/default.aspx>

UNEP, 2013, online, <http://chm.pops.int/Portals/0/download.aspx?d=UNEP-POPS-POPRC.9-2>

U.S. EPA., 2008a. IRIS Toxicological Review of 2,2',4,4',5-Pentabromodiphenyl Ether (BDE-99) (Final Report), EPA/635/R-07/006F; U.S. Environmental Protection Agency: Washington, DC, 2008; [http://cfpub.epa.gov/ncea/iris/iris\\_documents/documents/toxreviews/1008tr.pdf](http://cfpub.epa.gov/ncea/iris/iris_documents/documents/toxreviews/1008tr.pdf) (accessed October 2015).

U.S. EPA., 2008b. IRIS Toxicological Review of Decabromodiphenyl Ether (Final Report), EPA/635/R-07/008F; U.S. Environmental Protection Agency: Washington, DC, 2008; <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=190307> (accessed October 2015).

479 **Table 1: Statistical Summary<sup>a</sup> of Concentrations (ng g<sup>-1</sup>) of Selected PBDEs in Dust**  
480 **from Nigerian Cars, Homes, and Offices.**

Compound	Microenvironment	Detection %	Minimum	Median	Average	Maximum
BDE -28	Cars	81	<0.04	1.1	7.0	65
	Homes	83	<0.04	0.48	0.75	3.1
	Offices	83	<0.04	1.1	4.7	65
BDE- 47	Cars	88	<0.05	28	900	9300
	Homes	100	2.2	8.0	13	50
	Offices	100	2.8	14	20	100
BDE-49	Cars	81	<0.02	3.0	39	440
	Homes	33	<0.02	<0.02	0.46	2.6
	Offices	67	<0.03	1.0	1.1	4.2
BDE -100	Cars	94	<0.03	12	330	3100
	Homes	92	<0.03	4.0	8.4	44
	Offices	94	<0.03	4.2	7.3	24
BDE -99	Cars	88	<0.04	49	1700	19000
	Homes	100	1.5	14	31	170
	Offices	94	<0.04	18	28	110
BDE -154	Cars	69	<0.04	3.6	450	3500
	Homes	42	<0.04	<0.04	1.7	7.9
	Offices	22	<0.04	<0.04	0.97	6.4
BDE – 153	Cars	69	<0.05	9.0	720	6000
	Homes	92	<0.05	3.9	5.3	22
	Offices	72	<0.05	3.7	5.4	24
BDE – 183	Cars	88	<0.04	8.8	83	480
	Homes	100	2.9	18	26	90
	Offices	100	4.3	26	66	350
BDE – 197	Cars	88	<0.06	7.7	19	97
	Homes	58	<0.06	1.8	2.1	8.4
	Offices	72	<0.06	4.5	8.4	39
BDE – 203	Cars	88	<0.06	4.7	12	76
	Homes	83	<0.06	1.6	1.9	7.9
	Offices	67	<0.06	2.8	3.8	13
BDE – 206	Cars	75	<0.08	61	300	3100
	Homes	58	<0.08	15	19	61
	Offices	72	<0.08	52	56	180
BDE - 208	Cars	63	<0.08	22	84	870
	Homes	42	<0.08	<0.08	6.1	23
	Offices	56	<0.08	9.2	15	88
BDE - 209	Cars	81	<0.11	780	10000	52000
	Homes	100	77	390	420	940
	Offices	89	<0.11	930	1200	4900

481 <sup>a</sup>For the purposes of statistical evaluation, all concentrations below the limit of detection  
482 (LOD) were assigned a value of  $f \times \text{LOD}$ , where  $f$  is the fractional detection frequency of the  
483 contaminant in samples from that microenvironment  
484

**Table 2: Statistical summary<sup>a</sup> of concentrations (ng g<sup>-1</sup>) of PCBs detected in dust from Nigerian cars, homes, and offices**

Compound	Microenvironment	Minimum	Median	Average	Maximum
PCB-28	Cars	0.24	1.9	1.9	4.0
	Homes	1.5	3.8	3.9	7.8
	Offices	0.74	5.2	4.8	11
PCB-52	Cars	0.08	2.1	2.3	5.9
	Homes	0.80	4.2	4.5	8.6
	Offices	0.54	4.4	4.6	11
PCB-101	Cars	0.14	0.72	1.3	5.5
	Homes	0.37	2.7	3.7	9.4
	Offices	2.6	6.2	8.7	24
PCB-153	Cars	0.08	1.6	2.5	9.1
	Homes	0.22	5.8	7.3	22
	Offices	3.8	6.5	10	23
PCB-138	Cars	0.40	1.4	1.9	6.7
	Homes	0.31	6.0	7.5	22
	Offices	2.3	5.1	7.3	26
PCB-180	Cars	0.46	1.9	2.3	5.7
	Homes	4.4	10	10	24
	Offices	1.9	14	14	34

<sup>a</sup>For the purposes of statistical evaluation, all concentrations below the limit of detection (LOD) were assigned a value of  $f \times \text{LOD}$ , where  $f$  is the fractional detection frequency of the contaminant in samples from that microenvironment

492 **Table 3: Comparison of median concentrations (ng g<sup>-1</sup>) of selected PBDEs detected in dust in this study with selected previous reports.**  
493

Sampling year-Country (Reference)	n	BDE 28	BDE 47	BDE 100	BDE 99	BDE 154	BDE 153	BDE 183	BDE 208	BDE 207	BDE 206	BDE 209
<b>Cars</b>												
2013 – Nigeria (this study)	16	1.1	28	12	49	3.6	9.0	8.8	22	42	61	780
2014 - Nigeria (Olukunle et al, 2015b)	12	n.a.	68	17	14	19	16	25	n.a.	n.a.	n.a.	122
2013 - Egypt (Hassan and Shoeib, 2015)	5	1.2	5.7	4.8	23	3.6	16	5.8	n.a.	n.a.	n.a.	1,540
2009 - UK (Harrad and Abdallah, 2011)	14	n.a.	100	17	130	10	14	6	4,100	3,700	4,800	190,000
2006/07- USA (Batterman et al, 2009)	12	13	1,800	790	2,600	120	77	73	580	490	250	3,100
<b>Homes</b>												
2013 – Nigeria (this study)	12	0.48	8.0	4.0	14	<0.042	3.9	18	<0.081	13	15	390
2012 - Nigeria (Olunkunle et al 2015a)	10	n.a.	47	43	46	45	50	30	n.a.	n.a.	n.a.	139
2012 - South Africa (Abafe and Martincigh, 2015)	10	n.a.	156	37	507	97	65	45	n.a.	n.a.	n.a.	1,550
2010/11 - South Africa (Kefeni et al, 2014)	31	n.a.	2.6	<0.13	2.6	<LOD	<LOD	n.a.	n.a.	n.a.	n.a.	<1.8
2013 - Iraq (Al-Omran and Harrad, 2015)	18	<0.10	3.6	0.60	6.7	0.61	0.54	7.5	n.a.	n.a.	n.a.	610
2013 - Egypt (Hassan and Shoeib, 2015)	17	0.34	1.7	0.37	2.7	0.38	6.3	1.1	n.a.	n.a.	n.a.	40
2006 - UK (Harrad et al, 2008b)	28	0.53	13	4.2	23	3.3	5.2	13	n.a.	n.a.	n.a.	2,800
2006 - USA (Harrad et al, 2008b)	20	14	410	160	820	89	110	16	n.a.	n.a.	n.a.	1,300
<b>Offices</b>												
2013 – Nigeria (this study)	18	1.1	14	4.2	18	<0.042	3.7	26	9.2	24	52	930
2012 - Nigeria (Olukunle et al, 2015a)	11	n.a.	47	51	54	59	67	72	n.a.	n.a.	n.a.	140
2013 - Egypt (Hassan and Shoeib, 2015)	9	0.39	2.3	0.60	7.1	0.83	33	2.3	n.a.	n.a.	n.a.	366
2012 - South Africa (Abafe and Martincigh, 2015)	11	n.a.	119	<0.16	148	51	88	75	n.a.	n.a.	n.a.	324
2010 - South Africa (Kefeni and Okwonkwo, 2012)	16	n.a.	44	n.a.	77	n.a.	<0.5	n.a.	n.a.	n.a.	n.a.	<1.2
2006/07 - UK (Harrad et al, 2008a)	18	<0.5	23	3.2	65	5.1	8.7	8.3	n.a.	n.a.	n.a.	6,200
2006/07 - USA (Batterman et al, 2010)	10	3.0	978	399	1,760	78	48	30	n.a.	n.a.	n.a.	1.0

494 n.a. = not available

495 **Table 4: Comparison of median concentrations (ng g<sup>-1</sup>) of selected PCBs detected in**  
496 **dust in this study with selected previous reports.**

Sampling year - Country (Reference)	n	PCB 28	PCB 52	PCB 101	PCB 153	PCB 138	PCB 180
<b>Cars</b>							
2013 – Nigeria (this study)	1 6	1.9	2.1	0.72	1.6	1.4	1.9
2011 – Kuwait (Ali et al, 2013)	1 5	n.a.	n.a.	<0.2	<0.2	<0.1	0.2
2011 – Pakistan (Ali et al, 2013)	1 5	n.a.	n.a.	<0.2	0.3	0.6	0.3
<b>Homes</b>							
2013 – Nigeria (this study)	1 2	3.8	4.1	2.7	5.8	6.0	10
2012 - South Africa (Abafe and Martincigh, 2015)	1 0	10.9	n.a.	n.a.	150	n.a.	585
2006 – Canada (Harrad et al, 2009)	1 0	7.3	7.2	8.8	9.9	9.5	6.8
2011 – Kuwait (Ali et al, 2013)	1 5	n.a.	n.a.	<0.2	<0.2	<0.1	0.4
2006 - New Zealand (Harrad et al, 2009)	2 0	2.3	1.4	1.6	1.4	1.8	1.3
2011 – Pakistan (Ali et al, 2013)	1 5	n.a.	n.a.	<0.2	<0.2	<0.1	0.3
2006 - UK (Harrad et al, 2009)	2 0	3.4	1.8	1.2	1.2	1.1	0.89
2006 - USA (Harrad et al, 2009)	2 0	5.1	6.2	8.7	7.1	6.5	2.6
2011 - USA (Dodson et al, 2012)	1 6	n.a.	n.a.	n.a.	9.5	n.a.	8.5
<b>Offices</b>							
2013 – Nigeria (this study)	1 8	5.2	4.4	6.2	6.5	5.1	14
2012 - South Africa (Abafe and Martincigh, 2015)	1 1	28	n.a.	n.a.	136	n.a.	812
2009 - Hong Kong (Kang et al, 2013)	2 0	7.8	1.9	1.1	4.3	2.2	2.3

n.a. = not available

498 **Table 5: Overall exposure of Nigerian adults and toddlers (ng day<sup>-1</sup>) to BDE-99 via ingestion of dust and percentages arising from**  
499 **ingestion of dust in cars, homes, and offices**

	Exposure in offices		Exposure in homes		Exposure in cars		Overall exposure		RfD <sup>b</sup>
	Mean dust ingestion <sup>a</sup>	High dust ingestion <sup>a</sup>	Mean dust ingestion <sup>a</sup>	High dust ingestion <sup>a</sup>	Mean dust ingestion <sup>a</sup>	High dust ingestion <sup>a</sup>	Mean dust ingestion <sup>a</sup>	High dust ingestion <sup>a</sup>	
<b>Adult 5<sup>th</sup> percentile</b>	0.01 (17.3)	0.03	0.06 (76)	0.15	0.01 (6.7)	0.01	0.08	0.20	7,000
<b>Adult median</b>	0.08 (25.8)	0.21	0.20 (61.5)	0.50	0.04 (12.6)	0.10	0.33	0.82	7,000
<b>Adult 95<sup>th</sup> percentile</b>	0.39 (4.5)	0.96	1.5 (17.2)	3.7	6.7 (78.3)	17	8.6	22	7,000
<b>Toddler 5<sup>th</sup> percentile</b>	-	-	0.20	0.80	0.01 (6.2)	0.05	0.21	0.85	2,000
<b>Toddler median</b>	-	-	0.67	2.67	0.10 (13.4)	0.41	0.77	3.1	2,000
<b>Toddler 95<sup>th</sup> percentile</b>	-	-	4.9	20	17 (77.3)	67	22	87	2,000

500 <sup>a</sup>assuming mean and high dust ingestion rates of 20 and 50 mg day<sup>-1</sup> for adults and 50 and 200 mg day<sup>-1</sup> for toddlers, that dust ingestion is pro  
501 rata to estimated time spent in each microenvironment category: for adults 72 % homes, 23.8 % offices, 4.2 % cars; for toddlers 95.8% homes,  
502 4.2 % cars; and that concentration in dust is either 5<sup>th</sup>, 50<sup>th</sup>, or 95<sup>th</sup> percentile for that microenvironment  
503 Figures in parentheses denote percentage of overall exposure received in that microenvironment category; note percentage is same for both dust  
504 ingestion rate scenarios

505 <sup>b</sup>RfD is USEPA reference dose for BDE-99 (100 ng (kg body weight) day<sup>-1</sup>), converted to ng day<sup>-1</sup> assuming 70 kg and 20 kg body weight for  
506 adults and toddlers respectively.  
507



508 **Table 6: Overall exposure of Nigerian adults and toddlers (ng day<sup>-1</sup>) to BDE-209 via ingestion of dust and percentages arising from**  
509 **ingestion of dust in cars, homes, and offices**

	Exposure in offices		Exposure in homes		Exposure in cars		Overall exposure		RfD <sup>b</sup>
	Mean dust ingestion <sup>a</sup>	High dust ingestion <sup>a</sup>	Mean dust ingestion <sup>a</sup>	High dust ingestion <sup>a</sup>	Mean dust ingestion <sup>a</sup>	High dust ingestion <sup>a</sup>	Mean dust ingestion <sup>a</sup>	High dust ingestion <sup>a</sup>	
<b>Adult 5<sup>th</sup> percentile</b>	<0.01 (0)	<0.01	1.29 (100)	3.2	<0.01 (0)	<0.01	1.3	3.2	490,000
<b>Adult median</b>	4.4 (41.4)	11	5.6 (52.5)	14	0.66 (6.2)	1.7	11	27	490,000
<b>Adult 95<sup>th</sup> percentile</b>	17 (23.5)	43	13 (17.9)	32	43 (58.6)	110	73	180	490,000
<b>Toddler 5<sup>th</sup> percentile</b>	-	-	4.3 (100)	17	<0.01 (0)	<0.01	4.3	17	140,000
<b>Toddler median</b>	-	-	19 (91.9)	75	1.7 (8.1)	6.6	20	81	140,000
<b>Toddler 95<sup>th</sup> percentile</b>	-	-	43 (9.2)	170	110 (71.2)	430	150	600	140,000

510 <sup>a</sup>assuming mean and high dust ingestion rates of 20 and 50 mg day<sup>-1</sup> for adults and 50 and 200 mg day<sup>-1</sup> for toddlers, that dust ingestion is pro  
511 rata to estimated time spent in each microenvironment category: for adults 72 % homes, 23.8 % offices, 4.2 % cars; for toddlers 95.8% homes,  
512 4.2 % cars; and that concentration in dust is either 5<sup>th</sup>, 50<sup>th</sup>, or 95<sup>th</sup> percentile for that microenvironment

513 Figures in parentheses denote percentage of overall exposure received in that microenvironment category; note percentage is same for both dust  
514 ingestion rate scenarios

515 <sup>b</sup>RfD is USEPA reference dose for BDE-209 (7,000 ng (kg body weight) day<sup>-1</sup>), converted to ng day<sup>-1</sup> assuming 70 kg and 20 kg body weight for  
516 adults and toddlers respectively.

517  
518

519 **Table 7: Overall exposure of Nigerian adults and toddlers (ng day<sup>-1</sup>) to ΣICES-6 PCBs via ingestion of dust and percentages arising**  
520 **from ingestion of dust in cars, homes, and offices**

	Exposure in offices		Exposure in homes		Exposure in cars		Overall exposure	
	Mean dust ingestion <sup>a</sup>	High dust ingestion <sup>a</sup>	Mean dust ingestion <sup>a</sup>	High dust ingestion <sup>a</sup>	Mean dust ingestion <sup>a</sup>	High dust ingestion <sup>a</sup>	Mean dust ingestion	High dust ingestion
<b>Adult 5<sup>th</sup> percentile</b>	0.09 (25.6)	0.24	0.27 (73.7)	0.68	<0.01 (0.7)	0.01	0.37	0.92
<b>Adult median</b>	0.20 (28.4)	0.50	0.49 (70.2)	1.2	0.01 (1.4)	0.02	0.70	1.8
<b>Adult 95<sup>th</sup> percentile</b>	0.42 (31.6)	1.0	0.88 (66.7)	2.2	0.02 (1.8)	0.06	1.3	3.3
<b>Toddler 5<sup>th</sup> percentile</b>	-	-	0.90 (99.3)	3.6	0.01 (0.7)	0.02	0.91	3.6
<b>Toddler median</b>	-	-	1.6 (98.5)	6.5	0.02 (1.5)	0.10	1.7	6.6
<b>Toddler 95<sup>th</sup> percentile</b>	-	-	2.9 (98)	12	0.06 (2)	0.23	3.0	12

521 <sup>a</sup>assuming mean and high dust ingestion rates of 20 and 50 mg day<sup>-1</sup> for adults and 50 and 200 mg day<sup>-1</sup> for toddlers; that dust ingestion is pro  
522 rata to estimated time spent in each microenvironment category: for adults 72 % homes, 23.8 % offices, 4.2 % cars; for toddlers 95.8% homes,  
523 4.2 % cars; and that concentration in dust is either 5<sup>th</sup>, 50<sup>th</sup>, or 95<sup>th</sup> percentile for that microenvironment  
524 Figures in parentheses denote percentage of overall exposure received in that microenvironment category; note percentage is same for both dust  
525 ingestion rate scenarios

## Supplementary Material

[Click here to download Supplementary Material: Harrad et al, 2015 APPENDIX A.docx](#)