Polychlorinated Biphenyl Levels and Associated Health Risks in Indoor Atmosphere of Beauty Salons

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ABSTRACT: Exposure to high concentrations of Polychlorinated Biphenyl (PCBs) has negative impacts on human wellbeing and the climate. This study determined the concentration, sources and health risks of PCBs in selected beauty shops in Ilorin, Kwara state. Air samples from fourteen beauty salons were taken using Solvent-Impregnated Polyurethane Foam (SIP-PUF) passive samplers for 30 days. The concentration of PCBs was determined with Gas Chromatography-Mass Spectrometry (GC–MS) operated in a Selected Ionization Mode (SIM). The health risk assessment of the PCBs was estimated using the Toxicity Equivalence Quotient (TEQ), Incremental Life Cancer Risk (ILCR), and Hazard Quotient (HQ) prescribed by United State Environmental Protection Agency (USEPA). The Positive Matrix Factorization (PMF) method was used in the source apportionment study. The average concentration of the PCBs ranged from 0.11–3.32 μg/m^3. The average TEQs for the PCBs in the beauty salon ambient air ranged between 2.96 × 10^{-1} - 9.30 × 10^{-1} ng WHO-TEQ/m^3. ILCRs and HQs estimated for the beauty shops considered were lower than 10^{-6} and 1 (USEPA set limit) for both adults and children. Eight factors were identified to be associated with the PCB sources; the most predominant sources are combined paint and pigment and mixed sources, which accounted for 20.08 and 28.91% of the total PCBs, respectively.

KEYWORDS: Indoor air, cancer risk, hazard quotient, source apportionment, Polychlorinated biphenyls (PCBs)

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I. INTRODUCTION

Reducing Indoor Air Pollution (IAP) is a global challenge that needs concerted efforts, to protect the environment and human health. IAP has been identified as part of the 10 risks of the global burden of diseases by the World Health Organization (WHO) (WHO, 2018). IAP is a global issue arising in dwelling places and workspaces, such as schools, offices, laboratory spaces, restaurants, cinemas, and beauty salons (Sonne, Xia, Dadvand, Targino, and Lam, 2022). Most people spend most of their time in indoor environments where the pollutant levels can be about 2–5 times higher than outdoors (Evtyugina, Vicente, Vicente, Nunes, Lucarelli, Calzolai, Nava, Blanco-Alegre, Calvo, and Castro, 2021). IAP was attributed to approximately 2.3 million deaths in 2019 accounting for about 4% of 2019 mortality rate (Bennitt, Wozniak, Causey, Burkart, and Brauer, 2021). Health issues such as asthma, reproductive disorders (Odediran, Yusuf, and Adeniran, 2022), and skin diseases have been associated with hairdressers and nail technicians as a result of the dangerous cosmetic products they use (Evtyugina *et al.*, 2021).

Beauty salons' cosmetic products and treatment techniques emit pollutants that harm salon personnel and customers (Foss-Skiftesvik, Winther, Johnsen, Søsted, Mosbech, Zachariae, and Johansen, 2017). Common air pollutants in beauty salons are volatile organic compounds (VOCs), ammonia (NH_3), particulates (PM), Polycyclic Aromatic Hydrocarbons (PAHs) and Polychlorinated biphenyls (PCBs) (Evtyugina *et al.*, 2021; Mahmoodi, Arfaeinia, Fazlzadeh, Soleimani, Samaei, Arfaeinia, Hosseini, Omidvar, and Baghmollaie, 2023). The concentration levels of these pollutants depend on the type of activities carried out, the efficiency of air exchange, the number of people in the salon, the location of the beauty shop, and the type of products used (Evtyugina *et al.*, 2021). PCBs have been identified among the 12 initial Persistent Organic Pollutants (POPs) known as the "dirty dozen" under the Stockholm Convention (Othman, Ismail, Selamat, Sheikh Abdul Kadir, and Shibraumalisi, 2022). PCBs are not manufactured in Nigeria; they are commonly used in making transformers, capacitors, plastics, and some household products, which are usually imported from the United States of America, Germany and France (Adesina, Ezengwa, Abdulraheem, Adewole, and Oyetunji, 2023; Melymuk, Blumenthal, Sáňka, Shu-Yin, Singla, Šebková, Pullen Fedinick, and Diamond, 2022).

PCBs are synthetic organic compounds with chlorine atoms and have been widely used in various industrial applications, including as coolants and lubricants in electrical

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equipment, as plasticizers in paints, and as additives in cosmetic products (Vallejos and Miguel, 2024). They exist in large quantities in the environment due to biological and chemical stability over time and are present throughout the food chain (Donato, Moneda, Portolani, Rossini, Molfino, Ministrini, Contessi, Pesenti, Palma, Gai, Zanardini, Vito, and Magoni, 2021; Lopez, Coscolla, Hernandez, Pardo, and Yusa, 2020; López, Coscollà, Hernández, Pardo, and Yusà, 2021). PCBs consist of technical mixtures with about 209 congeners, which differ in the number and position of chlorine atoms. The variation in PCB congeners' physical and chemical properties. PCBs get into the human body through ingesting contaminated food, inhaling contaminated air, or dermal adsorption from a polluted indoor space (Adesina, Nwogu, Lala, Adeyemo, and Sonibare, 2021b; Sedha, Kumar, and Shukla, 2015). PCBs have been associated with adverse effects on human health, including cardiovascular diseases, hormone disruptions, cancer, learning disabilities, neurological diseases, obesity, and infertility (Shen, Han, Guan, Cai, Zheng, Meng, Chen, Li, and Wu, 2022). Sources of PCBs in the atmosphere can be from the evaporation of PCB-containing products or poorly preserved hazardous waste sites that contain PCB spills and leaks during chemical transport (Othman *et al.*, 2022). PCBs are persistent in the environment, can travel a long distance in the atmosphere, accumulate in plant and animal tissues, and be biomagnified inside the food chain (Altshul, Covaci, and Hauser, 2004; Othman *et al.*, 2022; Shen *et al.*, 2022).

Numerous studies around the world have reported the concentrations and health risks of PCBs in indoor spaces such as homes, schools, vehicles and offices (Andersen and Frederiksen, 2021; Bräuner, Andersen, Frederiksen, Specht, Hougaard, Ebbehøj, Bailey, Giwercman, Steenland, and Longnecker, 2016; Folarin, Poma, Yin, Altamirano, Oluseyi, Badru, and Covaci, 2024; Güzel, Çetintürk, Canlı, and Karademir, 2024; Hammel, Andersen, Knudsen, and Frederiksen, 2023; Montano, Pironti, Pinto, Ricciardi, Buono, Brogna, Venier, Piscopo, Amoresano, and Motta, 2022; Sari, Esen, Del Aguila, and Karakus, 2020; Shen, Liu, Zhou, Yin, and Arif, 2023; Zhang, Zhang, Darisaw, Ehie, and Wang, 2007) but only few studies have been documented in Nigeria.

Iwegbue, Eyengho, Egobueze, Odali, Tesi, Nwajei and Martincigh (2019) reported the concentration levels of 18 Polybrominated Diphenyl Ethers (PBPEs) and 28 PCBs from electronic repair workshops in southern Nigeria to be 14-2578 ng/g and 96.6 to 3949 ng/g, respectively, from which high risk was estimated because of exposure. Adesina *et al.* (2021b) found 0.15–0.17 μg/m^3 PCBs in public bars, and non-carcinogenic and carcinogenic risks were higher than WHO specifications. Akinrinade, Abou-Elwafa, Ayejuyo, Alani and Harrad (2021) reported the total concentration of PBDEs, hexabromo cyclo dodecane (HBCDD), and PCBs in dust samples from fifteen (15) homes in Lagos, to be 43–810 ng/g, 32-2600 ng/g, and 3.8–61 ng/g respectively. Investigation of the concentration levels of PCBs in beauty shops provides useful information for occupational safety and indoor air quality assessment. There is limited data on the health risks associated with exposure to PCBs in indoor environments in Nigeria. Hence, this study therefore focuses on estimating PCB contamination levels in the indoor environment of selected beauty salons in the North Central region of Nigeria. The concentration levels were used to estimate health risks associated with air contamination of these pollutants and to quantify the contribution of various sources of air pollutants in the indoor environment of the beauty salons.

II. METHODOLOGY

A. Description of sampling location

Air samples were collected from fourteen (14) beauty shops within the Ilorin metropolis of Kwara State, Nigeria, as shown by the red dots on the map depicted in Figure 1. Ilorin is the capital city of Kwara State in Nigeria, located between latitudes 8º30'00"and 8º50'00"NN and longitudes 4º20'00" and 4º35'00"E. The town occupies a land area of about 468 km^2 and is situated in the transitional zone within the forest and the Guinea savannah regions of Nigeria. It is the most populated town in Kwara state, with a population of about 3.2 million as of 2016. It is a significant trade Centre between the Hausa of the north and the Yoruba of the south (Damilare, 2021). The economy in Ilorin is rapidly growing, the service industry is developing, consumer culture is becoming more sophisticated, and so are hairdressing and beauty businesses. The fourteen beauty shops were selected based on their proximity to higher institutions where there is more patronage as a result of student drive. The description of the beauty shops considered in the study is shown in Table A.1.

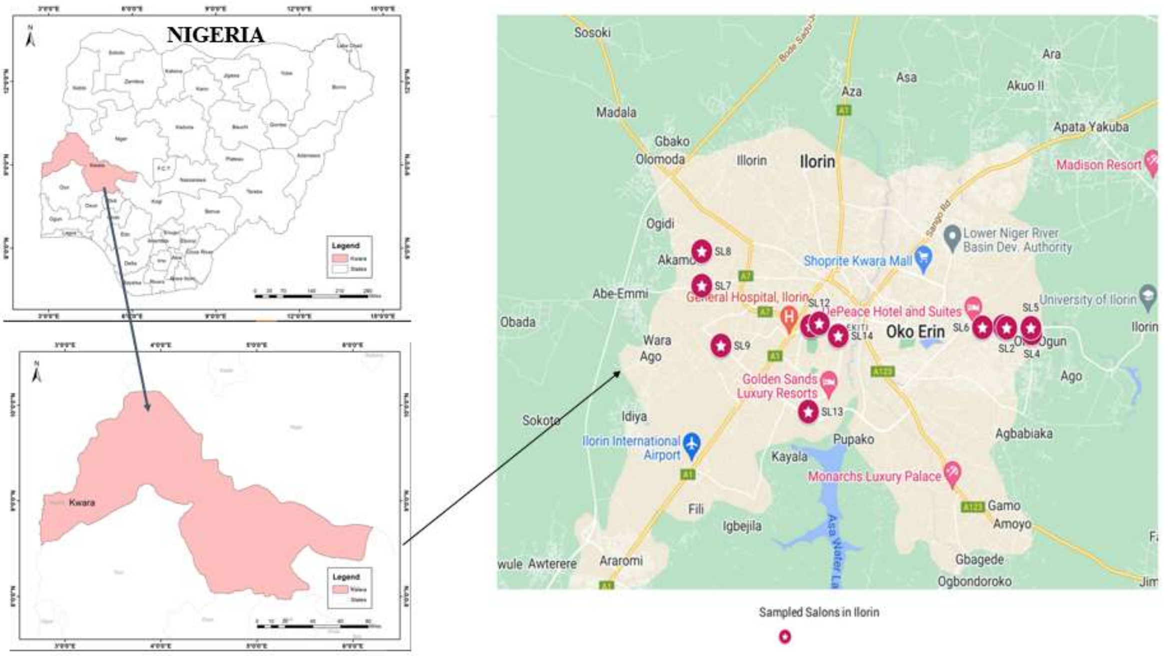

Figure 1: Map showing locations of sample collection.

B. Sample collection

The PCBs in the indoor air samples were collected using a Polyurethane Foam (PUF) passive sampler with slight modification as described by Strandberg *et al*. (2018) and Adesina, Nwogu, Lala, Adeyemo and Sonibare (2021a), shown in Figure 2. The PUFs were impregnated with XAD-4/hexane slurry (6.4 g/L) to improve the absorptive capacity of PCBs (Shoeib, Harner, Lee, Lane, and Zhu, 2008). Beauty shops were chosen as specific PCB sources because hairdressers frequently work in a setting where they are exposed to many PCBs included in hair styling products without wearing personal protective equipment such respirators, hand gloves, aprons, hand gloves, and respiratory masks within a short period (Ana, Alli, Uhiara, and Shendell, 2019). The samplers were placed in beauty shops for 30 days for the collection of samples and health risk assessment of the PCBs

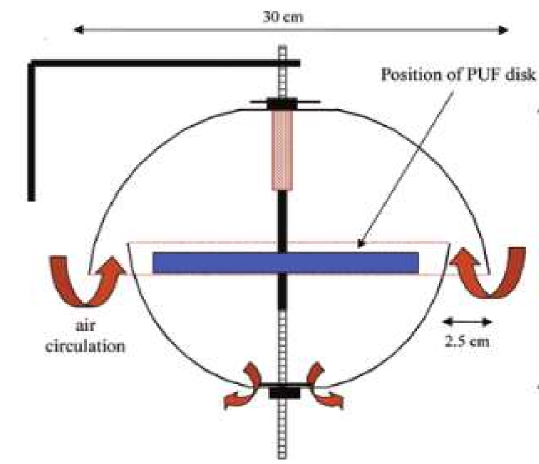

Figure 2: Schematic diagram of passive sampler

I. Preparation of sorbent-impregnated polyurethane foam (SIP-PUFs) disk

PUF disk (Fig. A.1) was cut to 7 cm diameter and a thickness of 1 cm (99 cm^2 surface area and density of 0.0104 g/cm^3) (Liu, Lin, Liu, Hu, Ruan, and Jiang, 2016) and then washed with distilled water. Soxhlet extraction was used to clean the PUFs with acetone for 6 hours at 56 °C. Amberlite XAD-4 resin (20 g, as shown in Fig. A.2) was washed with a water bath shaker with 30 ml each of methanol, dichloromethane (DCM), and hexane for 30 min each. The wet XAD-4 was blown under a stream of N_2 and then dehydrated for 3 days in a vacuum desiccator containing a molecular sieve of 0.75 µm. A 6.4 g of XAD-4 powder was mixed with one litre of hexane in a glass breaker to give a homogenous emulsion. A homogenizer at 1500 rpm for 10 min was used for further mixing to ensure a thorough mixture of XAD-4/ Hexane slurry. The XAD-4 resins were impregnated onto the PUF disks, dipping them into the XAD-hexane slurry three times to deposit them onto the porous surface of PUFs. The coated PUFs were kept in a vacuum desiccator for 24 hours to dry and then stored in a zip lock to avoid capture of untargeted pollutants.

II. Deployment of samplers

All Passive Air Samplers (PAS) parts were pre-cleaned with hexane and acetone solvents in sequence before assembly to ensure they were free from the targeted pollutants. The SIP-PUFs were attached with a hinge to avoid contact with the stainless bowls, as presented in Figure 2. The samplers were hung at 1.5 m above the ground in 14 beauty shops within the Ilorin metropolis for 30 days. Field blank was collected and treated as exposed dirt.

C. *Chemical analysis and quality control*

At the end of the 30 days sampling period, the samples were spiked with PCB surrogate standard (Akinrinade *et al.*, 2021; Herrero, Gonzalez, Roviva, Marques, Domingo, Abalos, Abad, and Nadal, 2022; Megson, Benoit, Sandau, Chaudhuri, Long, Coulthard, and Johnson, 2019) consisting of PCB 2, PCB 15, PCB 18, PCB 28, PCB 44, PCB 101, PCB 105, PCB 110, PCB 114, PCB 118, PCB 138 and PCB 153 mixtures. Dichloromethane was used to extract PCB congeners from the PUF disks for 24 h using a Soxhlet extractor (Adesina *et al.*, 2021b). The extract was concentrated with a rotary evaporator under a mild stream of nitrogen. PCBs were analysed using a Varian 3800/4000 Gas Chromatograph Mass Spectrometer (GC/MS) with an Agilent capillary column DB5ms (30.0m x 0.25mm, 0.25µm film thickness). The injector temperature was kept at 250ºC with an injection volume of 1.0 µL in the spitless mode. The oven temperature was maintained at 70 ºC for 2 min, then increased to 150 ºC at the rate of 25 ºC min^{-1}, to 200 ºC at 3 ºC min^{-1}, to 270º C at 8ºC min^{-1}, to 290 ºC at 25 ºC min^{-1}, and held for 5 min at 290 ºC. Data was acquired using the Selected Ion Monitoring (SIM) mode with two characteristic ions and a programmed window in full scan mode in the range of 50-500 m/z. Quantification was performed using the internal standard method, and PCBs' surrogate standard, along with confirmation ions, was employed to determine PCB identities of PCBs in the sample.

D. *Health risk assessment*

The toxicity equivalence o the PCBs was estimated by finding the product the concentration of PCBs and the toxicity equivalent factor (TEF) using Equation 1 (Adesina *et al.*, 2021b). taken from the WHO-revised TEF value in 2005, presents the TEF used for the PCBs considered. The TEQ can be used to estimate PCB ecological risk (Wang, Yan, Chang, Qu, Tian, Song, and Guo, 2023)

$$\text{Toxicity equivalency } (\text{ngWHOTEQ}/m^3) = \text{C} \times \text{TEF} \quad (1)$$

Where C is the concentration of PCBs and TEF is the Toxicity Equivalent Factor.

Unintended exposure to PCBs can be through inhalation, ingestion, and dermal contact for children and adults. The non-carcinogenic risk of the PCBs was estimated with the hazard quotient (HQ) computed from the average daily dose (López *et al.*, 2021). The average daily dose of PCBs for children and adults in $mg/(kgday)$ through the exposure paths: ingestion (ADD_{ing}), inhalation (ADD_{in}) and dermal contact (ADD_{derm}) were estimated using Equations 2, 3 and 4 respectively (Makokha, Ndung'u, Mungai, Yan, and Wang, 2018; USEPA, 2001).

$$ADD_{ing} = \frac{C \times \text{IngR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \quad (2)$$

$$ADD_{inh} = \frac{\text{C} \times \text{InhR} \times \text{EF} \times \text{ED}}{\text{PEF} \times \text{BW} \times \text{AT}} \quad (3)$$

$$ADD_{derm} = \frac{\text{C} \times \text{ESA} \times \text{SAF} \times \text{DAF} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \quad (4)$$

Where, C_{ing}= concentration of ingested PCBs; C_{inh}=concentration of inhaled PCBs; C_{derm}=concentration from dermal contact; IngR=ingestion rate; EF= exposure frequency; ED= exposure duration; BW= body weight; AT=average exposure time; ESA=Exposed skin area; SAF=skin adherence factor; DAF= dermal adsorption factor. A summary of data used for the health risk assessment calculation can be found in Table A.2

The non-carcinogenic risk and cancer risk for the pollutants are calculated using Equations 5- 7 (Abdulraheem *et al.*, 2022; Odediran *et al.*, 2021; Zhou *et al.*, 2019) . The incremental lifetime cancer risks (ILCR) were estimated by multiplying ADD with carcinogenic slope factor SF. The cancer risk was estimated by adding all the incremental lifetime risks for all the exposure pathways.

$$\text{HQ}_\text{i} = \frac{\text{ADD}}{\text{RfD}} \quad (5)$$

$$\text{ILCR} = \text{ADD} \times \text{SF} \quad (6)$$

$$\text{CR} = \sum \text{ILCR} \quad (7)$$

Where *i* is the exposure pathway

The RfD is the reference dose, and SF is the slope factor of PCBs (Odediran *et al.*, 2021)

A lower average daily dose (ADD) value than the reference dose suggests no harmful health effects; on the other hand, a larger ADD value than the RfD suggests that the exposure pathway is likely to result in harmful health effects for humans. The non-carcinogenic risk from numerous pathways is represented by the Hazard index (HI). HQ plus HI is the same for any exposure pathway. There is a chance that the non-carcinogenic risk is significant when HI > 1, while an insignificant non-carcinogenic risk is shown when HI < 1 (Senthong & Wittayasilp, 2021). The international threshold levels approved by the International Agency for Research on Cancer (IARC) and the USEPA were used in this investigation for regulatory purposes (Du *et al.*, 2013; IARC, 2011; Men *et al.*, 2018; USEPA, 2011).

E. *Source Apportionment*

Positive Matrix Factorization (PMF) is a model developed by the USEPA for analyzing the possible sources of pollutants in the environment (Saha *et al.*, 2022; Wang *et al.*, 2021). PMF model was used for source apportionment of the ambient air beauty shop PCBs using EPA PMF v 5.0.14 software. PMF reduces data sets' variables to species combinations called source types and source contributions with weighted least-squares regression (Duodu *et al.*, 2017). Both the concentration data and its uncertainty are required as input files. Because PMF could provide measurable information on the contribution of each source type, it was used in this study. Unlike earlier models such as Chemical Mass Balance (CMB) and Principal Component Analysis (PCA), the factor matrix is restricted to non-negative values to produce factors with a higher significance (Men *et al.*, 2018). Factor contribution and factor profile are the two matrices that result from breaking down the concentration data matrix in the models. Based on the decomposition results of the matrices and the information obtained about the profiles, the pollutant sources were evaluated using data from emission inventories (Odediran *et al.*, 2021; Saha *et al.*, 2022; Yu *et al.*, 2015). PMF can be calculated using Equation 8 (Manousakas *et al.*, 2017; Saha *et al.*, 2022).

$$X_{ij} = \sum_{k=1}^{p} g_{ik} f_{kf} + e_{ij} \quad (8)$$

Where: X_{ij} represents the concentration of PCBs species j measured on sample i ; p is the number of factors contributing to the samples; g_{ik} is the relative contribution of factor k to sample i; f_{kf} the concentration of species j in factor profile k; and e_{ij} The error of the PMF model for the j species measured on sample i.

To obtain a minimum value of Q for a given g_{ik} and f_{kf} values are adjusted. Q is expressed in equation 9 (Odediran *et al.*, 2021).

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{m} \left(\frac{e_{ij}}{u_{ij}}\right)^2$$

(9)

Where u_{ij} Is the uncertainty of the j_{th} species concentration in sample$i$; n is the number of samples; and m is the number of species.

Equations 10 and 11 were used to estimate the uncertainty values for PCBs concentrations above and below MDL, respectively (Wang *et al.*, 2021):

$$Unc = \sqrt{\left(P_{ij} \times x_{ij}\right)^2 + (0.5 \times MDL)^2}$$

(10)

$$Unc = \frac{5}{6} MDL$$

(11)

Where Unc is the uncertainty; P_{ij} the error fraction; x_{ij} is the concentration of species j measured on sample i; and MDL is the method detection limit.

F. Statistical analysis

The relationship between each sample and the corresponding PCBs was investigated using Spearman's rank correlation coefficient using SPSS 17.0; a probability of $p < 0.05$ was considered the significant level (Odediran *et al.*, 2021). The statistical methods used were non-parametric since there was no normal distribution.

III. RESULTS AND DISCUSSION

A. Spatial distribution of PCB congeners in the Beauty Shop ambient air

Spatial distribution of PCB congeners in the Beauty Shop ambient air

The GCMS analysis identified twelve (12) ambient PCB congeners from the beauty shops. The PCBs congeners include PCB 2 (3-chlorobiphenyl), PCB 15 (4,4′-dichlorobiphenyl), PCB 18 (2,2′,5-trichlorobiphenyl), PCB 28 (2,4,4′-trichlorobiphenyl), PCB 44 (2,2′,3,5′-tetrachlorobiphenyl, PCB 101 (2,2′,4,5,5′-pentachlorobiphenyl), PCB 105 (2,3,3′,4,4′-pentachlorobiphenyl), PCB 110 (2,3,3′,4′,6-pentachlorobiphenyl), PCB 114 (2,3,4,4′,5-pentachlorobiphenyl),PCB 118 (2,3′,4,4′,5-pentachlorobiphenyl), PCB 138 (2,2′,3,4,4′,5′-hexachlorobiphenyl), and PCB 153 (2,2′,4,4′,5,5′-hexachlorobiphenyl). The average concentration level of the PCB congeners in the 14 beauty salons, as presented in Figure 3, ranged from 0. 11- 3.32 µg/m^3. The PCB concentration decreased in the order of PCB 28> PCB 153> PCB 18> PCB 138> PCB 118> PCB 114> PCB 44> PCB 110> PCB 2> PCB 101> PCB 105> PCB 15. PCB 28 had the highest concentration with an average concentration of 3.32 ± 0.90 µg/m^3, accounting for about 16.01% of the total PCBs, followed by PCB 153, 18, and 138, which accounted for about 15.20, 14.16, and 12.28 %, respectively. Although there are no studies available for PCBs in beauty shops in Nigeria. However, The concentration range obtained from the beauty shops is higher than those reported for public bars (0.086–0.089 µg/m^3) in Delta State, Nigeria (Adesina *et al.*, 2021b). In Bursa Turkey, PCBs concentration levels in living rooms were reported by (Sari *et al.*, 2020) to range between 6.04±2.10-6.39±2.5 x 10^{-4} µg/m^3. The higher concentration of PCBs in beauty shops can be attributed to the numerous PCB-containing products in the salon, such as nail paint and hairspray.

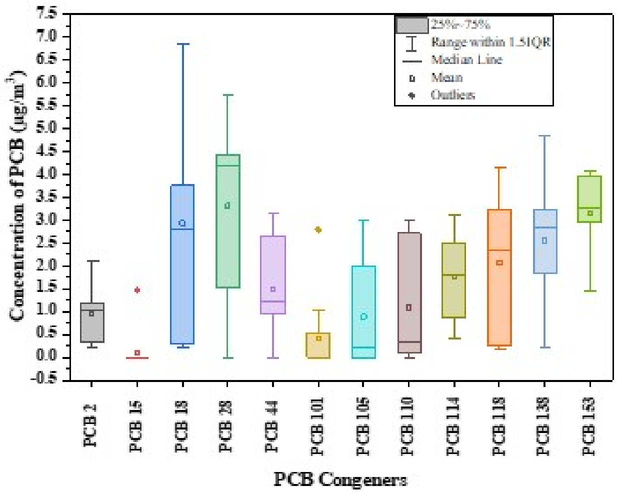

Figure 3: Descriptive statistics of PCBs in beauty shop ambience

Five (5) PCB congeners out of PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB180 are often referred to as the standard PCBs because they are the most common technical mixtures of PCBs across the compositional range (Iwegbue *et al.*, 2019; Megson *et al.*, 2019) were detected in the samples. The abundance of PCB homologue groups containing 1 to 6-Cl atoms in the beauty shops' samples is presented in Figure 4. PCB homologue groups with 1, 2, 3, 4, 5, and 6-Cl atoms were found in all the samples, but PCB with 2-Cl atoms was only detected in SL09. For most of the samples, it was found that the total concentration of PCBs concerning the number of chlorine atoms present is similar. Similar finding was reported by

Rocha, Ribeiro, Campos and RochaEduardo (2021), and their abundance is in order 3 Cl > 4 Cl > 5 Cl>6 Cl >1 Cl >2 Cl. PCBs with 3-Cl atoms were obtained to be the most abundant in all the samples and considered low-chlorinated PCBs (Sari *et al.*, 2020). Highly chlorinated PCBs have the tendency to accumulate in indoor dust and surfaces due to lower solubility and vapour pressures and higher lipophilicity (Iwegbue *et al.*, 2019).

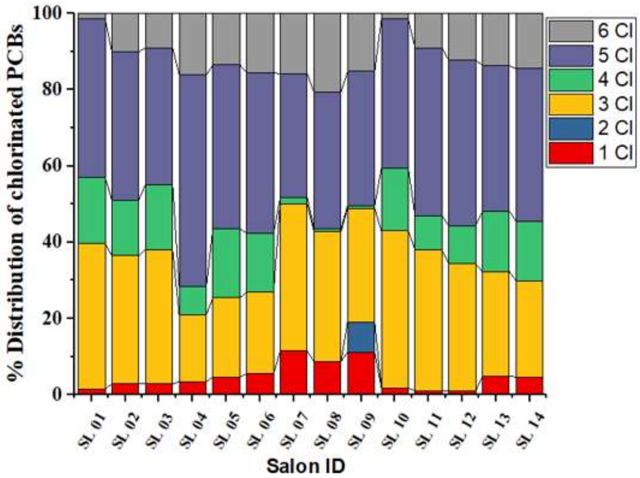

Figure 4: Distribution of Chlorine atoms in PCBs

The dioxin-like and non-dioxin-like percentage distribution of PCBs was estimated and shown in Figure 5. Non-dioxin-like PCBs were the most abundant, constituting an average of 77% for all the beauty shops considered. Non-dioxin-like PCBs are neurotoxic, affecting neurodevelopment and neuro-regeneration (Holland and Pessah, 2021). They also have some detrimental effects on human health, such as damage to the thyroid, liver, and reproductive organs (Ohlhoff, Savvateeva, Leisner, Hartmann, Südekum, Bernsmann, Spolders, Jahnke, Lüth, and Röhe, 2022) due to hepatotoxicity, thyroid toxicity, and neurotoxic effects

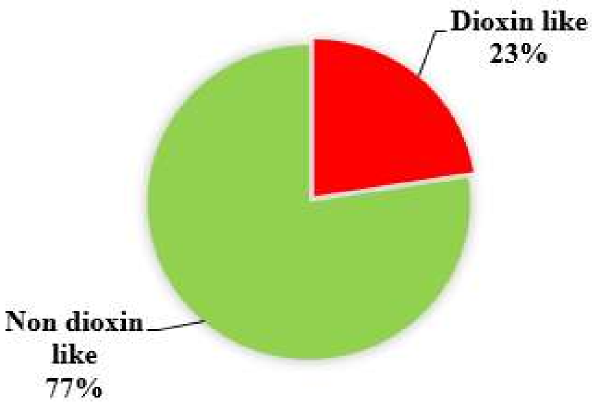

Figure 5: Percentage distribution of dioxin-like and non-dioxin-like PCBs

B, Toxicity Equivalent

The probable ecological risks of PCBs in beauty salons were analysed with the TEQ ecological risk assessment indices (Wang *et al.*, 2023), as presented in Table 1. The PCBs with the highest TEQ value were obtained to be PCB 28 with a TEQ value of 9.30×10^{-1} ng WHO-TEQ /m^3 and the lowest was 2.96×10^{-1} ng WHO-TEQ /m^3 for PCB 15. The total TEQ for all the PCBs considered was 4.35×10^{-1} ng WHO-TEQ /m^3, exceeding the maximum extent of contamination of 30 pg-TEQ-/L set by USEPA. This indicates that exposure to the pollutant harms both the customers and workers in the salon. High concentrations of PCBs in the indoor environment reduce the immunity of a person (Adesina *et al.*, 2021b; Herrero *et al.*, 2022).

Table 1: Toxicity equivalence of PCBs in salon ambient air

PCBs	TEF	TEQ ng/m^3
PCB 2	0.00002	2.66E-01
PCB 44	0.00002	4.15E-01
PCB 101	0.00003	1.83E-01
PCB 138	0.00002	7.14E-01
PCB 114	0.00003	7.39E-01
PCB 15	0.00002	2.96E-02
PCB 18	0.00002	8.23E-01
PCB 105	0.00003	3.73E-01
PCB 118	0.00003	8.73E-01
PCB 28	0.00002	9.30E-01
PCB 153	0.00001	4.42E-01
PCB 110	0.00002	3.05E-01

C. Non-carcinogenic and carcinogenic risk

An estimation of the non-carcinogenic risk resulting from PCB exposure was made using the Hazard Quotient (HQ). The HQ estimated for the beauty salons ranged between 0.46-0.94 and 0.43-0.87 for a child and adults, respectively. SL04 had the highest HQ while SL01 had the lowest HQ presented in Figure 6. The HQ for children all the beauty shops considered was higher than what was obtained for an adult. Children are potentially at high risk as compared to adults because of their lower body weight, less developed immune system, and frequent hand-to-mouth activities (Aslam, Baqar, Qadir, Mumtaz, Li, and Zhang, 2021). Similar findings were reported by Aslam *et al.* (2021) and Iwegbue *et al.* (2019). The estimated hazard quotient for adults and children is below the USEPA limit. The implication is that there was no health risk associated with exposure to PCBs in the beauty salon when the sampling was done. However, there can be a risk when hair care products are more frequently used in the salon because some values are close to 1.

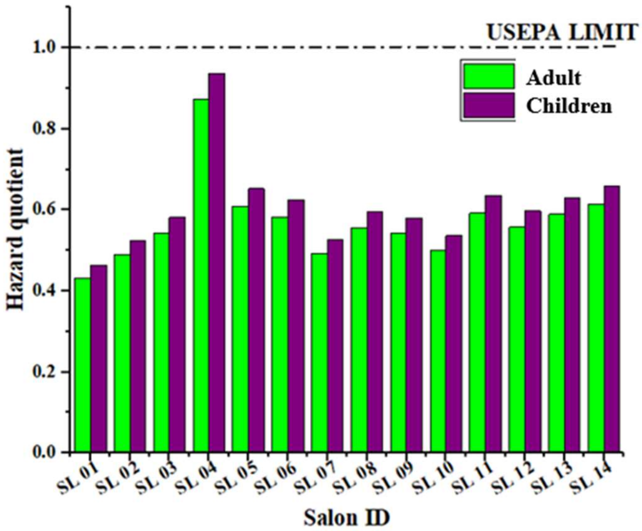

Figure 6: Hazard quotient of PCBs for adults and children in beauty salons

The incremental lifetime cancer risk (ILCR) for the three pathways of exposure, inhalation, ingestion, and dermal, was estimated for both children and adults. The ILCR provides information on the increased risk of cancer that results from exposure to PCBs in the setting of a beauty salon. The ILCR estimated for this study is presented in Table 2. The values of ILCR for ingestion, inhalation, and dermal for adults in all the beauty shops from 5.67-11.40 × 10^{-10}, 4.28-6.07 × 10^{-14}, and 1.01-2.03 × $10^{-9,}$ respectively. For children, the ILCR ranged from 5.67-11.40 × 10^{-10}, 2.57-3.65 × $10^{-14,}$ and 1.75-3.53 × 10^{-9} for ingestion, inhalation, and dermal, respectively. The contribution of the three exposure pathways increased in the following order: inhalation < Ingestion< Dermal, as presented in Figure 7. The dermal pathway had the highest contribution, 55%, for children and 64 % for adults, respectively.

The average cancer risk estimated for an adult and a child was estimated to be 2.0 × 10^{-9} and 4.14 × 10^{-9}, respectively. The cancer risk for a child was higher than what was obtained for an adult. This can be attributed to their inhalation rate and lower body weight. A similar result was reported by Adesina *et al.* (2021b). On the other hand, the cancer risk of both adults and children was below the USEPA permissible limit of 1 × 10^{-6}. These findings imply that exposure to PCBs in the beauty salon is acceptable. However, this can change with the activities within and around the beauty shops. Children are at a higher risk of getting cancer than adults. Higher cancer risk values could be obtained if other indoor pollutants, such as PAHs and heavy metals, were considered. Incremental lifetime cancer risk (ILCR) for the three pathways of exposure, inhalation, ingestion, and dermal, was estimated for both children and adults. The ILCR provides information on the increased risk of cancer that results from exposure to PCBs in the setting of a beauty salon. The ILCR estimated for this study is presented in Table 3. The values of ILCR for ingestion, inhalation, and dermal for adults in all the beauty shops from 5.67-11.40 × 10^{-10}, 4.28-6.07 × 10^{-14}, and 1.01-2.03 × $10^{-9,}$ respectively. For children, the ILCR ranged from 5.67-11.40 × 10^{-10}, 2.57-3.65 × $10^{-14,}$ and 1.75-3.53 × 10^{-9} for ingestion, inhalation, and dermal, respectively. The contribution of the three exposure pathways increased in the following order: inhalation < Ingestion< Dermal, as presented in Figure 6. The dermal pathway had the highest contribution, 55%, for children and 64 % for adults, respectively.

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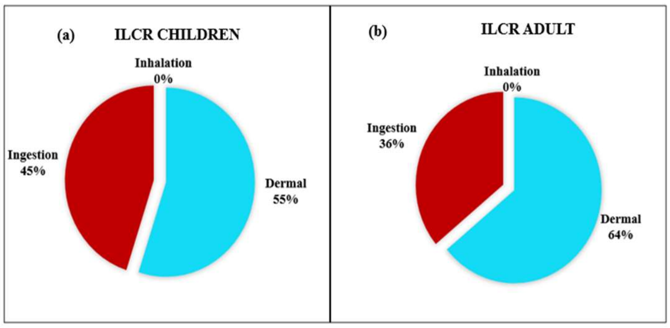

Figure 7: Percentage contribution of PCB exposure pathways to cancer risk for (a) Children and (b) Adult

Table 2: Cancer risk of Children and Adults PCBS in salon ambient air

Salon ID	ADULT				CHILDREN			
	Ingestion$\times 10^{-10}$	inhalation$\times 10^{-14}$	Dermal $\times 10^{-9}$	Cancer Risk $\times 10^{-9}$	Ingestion $\times 10^{-10}$	Inhalation $\times 10^{-14}$	Dermal $\times 10^{-9}$	Cancer Risk $\times 10^{-9}$
SL 01	5.67	4.28	1.01	1.57	1.40	2.57	1.75	3.15
SL 02	6.41	4.84	1.14	1.78	1.59	2.91	1.98	3.56
SL 03	7.11	5.36	1.26	1.97	1.76	3.23	2.19	3.95
SL 04	11.40	8.64	2.03	3.18	2.83	5.19	3.53	6.36
SL 05	7.97	6.02	1.42	2.21	1.97	3.62	2.46	4.43
SL 06	7.63	5.76	1.36	2.12	1.89	3.46	2.35	4.24
SL 07	6.44	4.86	1.14	1.79	1.59	2.92	1.99	3.58
SL 08	7.29	5.50	1.30	2.02	1.80	3.31	2.25	4.05
SL 09	7.09	5.35	1.26	1.97	1.75	3.21	2.18	3.94
SL 10	6.55	4.94	1.16	1.82	1.62	2.97	2.02	3.64
SL 11	7.76	5.86	1.38	2.15	1.92	3.52	2.39	4.31
SL 12	7.30	5.51	1.30	2.03	1.80	3.31	2.25	4.05
SL 13	7.71	5.82	1.37	2.14	1.91	3.50	2.38	4.28
SL 14	8.05	6.07	1.43	2.24	1.99	3.65	2.48	4.47

D. Source apportionment

The PMF analysis was carried out to quantify the part played by every source of the contribution of each source of PCBs in the salon's ambient air. The factors were set to 2, 3, 4, 5, 6, 7, 8, 9, and 20 runs to ensure an accurate source apportionment result. The eight factors gave the lowest Q value (goodness of fit), and most of the scaled residual lies between -3 and 3. The base run statistics demonstrated a robust relationship between the PCB congeners and the factors with noise, with a to-signal ratio ranging from 0.7 to 10. The eight distinct factors obtained by PMF analysis are presented in Figure 8. Factor 1 was loaded with PCB 105, PCB 153, and PCB 28 with species contributions of 76.70%, 15.50%, and 17.40%, respectively. This factor accounts for 9.78 % of beauty salon ambient air PCBs. PCB 105, PCB 153, and PCB 28 can be attributed to iron and steel production (Wang *et al.*, 2023). There is an iron and steel production in Ilorin where the sampling was carried out, although not close to the beauty shops; however, their presence can be attributed to PCBs traveling over a long distance.

The second factor had a high loading with PCB 138, PCB 114, PCB 2, PCB 110, and PCB 28, which explained 20.08% of the total PCBs in the salon ambient air. These congeners could be attributed to the release of paints and pigment (Wang *et al.*, 2023). Factor 3 was predominated by PCB 2, PCB 18, PCB 28, PCB 118, and PCB 153, with species contributions of 11.30%, 34.10%, 10.70%, 9.8%, 16.90%, and 7.30%, respectively. Previous studies have shown that PCB 22, PCB 28/31, PCB 41/64, PCB 49, PCB 101, PCB 118, PCB 110, and PCB 153/132 can be attributed to domestic fuel burning (Lee, Coleman, Jones, Jones, and Lohmann, 2005; Yurdakul, Çelik, Çelen, Öztürk, and Cetin, 2019). Factor 3 explains that 27.04% of the total PCB can be attributed to combustion processes.

PCB 44, PCB 110, PCB 18, PCB 118, PCB 28, and PCB 153 dominated factor 4 with 43.70%, 10.40%, 36.19%, 47.10%, 42.30%, and 40.90% contributions, respectively accounting for 28.91% of the total PCBs. The combination of these congeners can be traced to mixed industrial sources (Lee *et al.*, 2005; Wang *et al.*, 2023; Yurdakul *et al.*, 2019). Factor 5, which accounted for 7.38%, is heavily loaded with PCB 101, PCB 105, PCB 118, and PCB 110. Thus, factor 4 was attributed to biomass burning, a typical means of waste disposal in Ilorin.

Factor 6 was heavily loaded with PCB 138, 118, 114, 28, and 118; PCB 138 is associated with electrical equipment (Devi, Yadav, Chakraborty, and Shihua, 2018), which accounted for about 7.92% of the total PCBs. Factor 7 was 18.25% of all PCBs and was significantly loaded with PCB 2, 101, 138, 18, and PCB 118. These PCBs mixtures are discharged from manufacturing processes. PCB 15 dominated factor 8 with a 95.10% contribution of PCB 15. These are emitted from different industrial mixtures (Malina, Mazlova, and Kulikova, 2020).

Table 3: Spearman rank correlation coefficients of PCBs concentration (µg/m^3)

	PCB2	PCB44	PCB101	PCB138	PCB114	PCB15	PCB18	PCB105	PCB118	PCB28	PCB153	PCB110
PCB2	1.000											
PCB44	-.827**	1.000										
PCB101	.811**	-.899**	1.000									
PCB138	.612*	-.762**	.838**	1.000								
PCB114	.580*	-.811**	.783**	.911**	1.000							
PCB15	0.448	-0.380	0.251	0.034	0.310	1.000						
PCB18	0.231	-0.338	0.364	-0.029	0.066	0.310	1.000					
PCB105	0.530	-0.473	0.509	.700**	.558*	-0.104	-0.433	1.000				
PCB118	-.641*	0.389	-0.384	-0.444	-0.325	-0.103	0.482	-.634*	1.000			
PCB28	-0.330	0.393	-0.454	-0.088	-0.115	-0.381	-.743**	0.270	-0.197	1.000		
PCB153	-.541*	0.309	-0.281	0.051	0.036	-0.379	-0.306	0.122	0.401	.614*	1.000	
PCB110	-0.194	0.157	0.051	0.377	0.199	-0.380	-.704**	.554*	-0.234	0.437	0.522	1.000

****. Correlation is significant at the 0.01 level (2-tailed).**
***. Correlation is significant at the 0.05 level (2-tailed).**

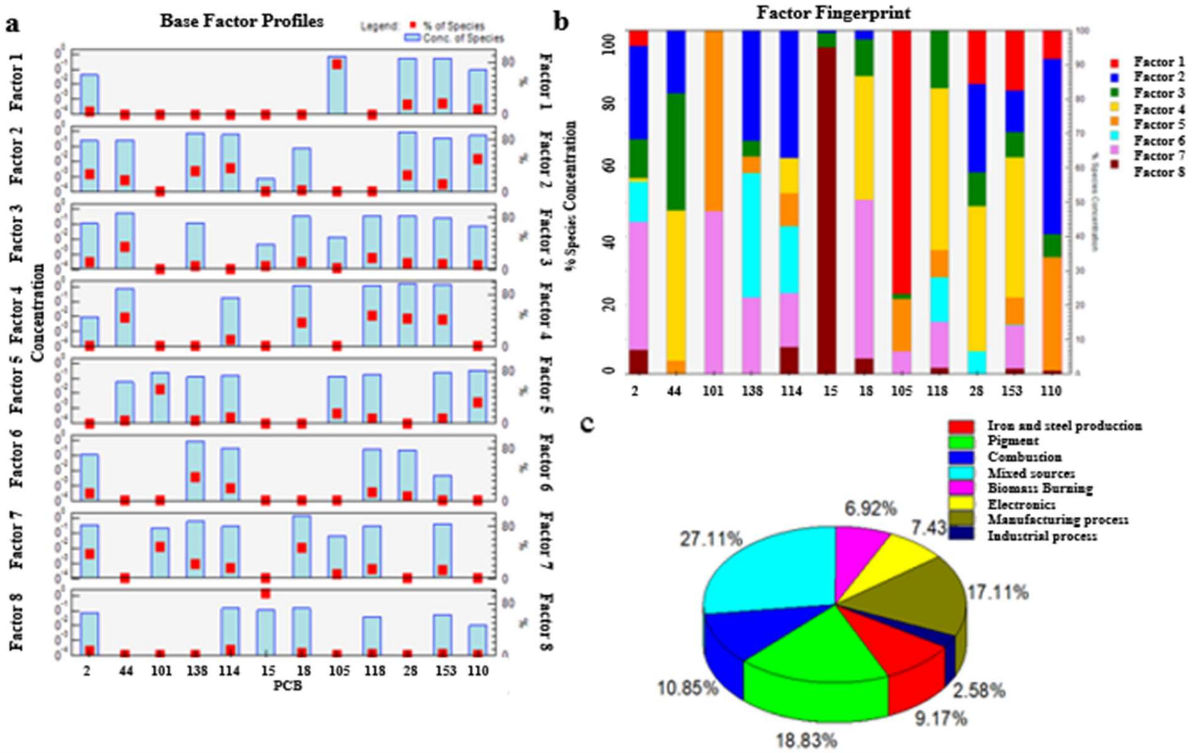

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Figure 8: (a) Source base profiles, (b) factor fingerprint, and (c) source contribution of PCBs in salon ambient air

E. Statistical analysis

The correlation coefficients required for data analysis with a significant level of at least $p < 0.05$ were obtained using Spearman correlation. The correlation coefficients between PCB congeners (PCB 2, 44, 101, 138, 114, 15, 18, 105, 118, 28, 153 and 110) is presented Table 4. PCB 2 possesses a substantial and highly positive correlation with PCB 101 and PCB 138 (r_s = 0.811 and 0.612, respectively) but does not correlate with PCB 44, 28, and 153. PCB 44 did not correlate with PCB congener but positively correlated with PCB 28, 118, 153, and 110 with r_s = 0.389, 0.393, 0.309, and 0.157, respectively. PCB 101 had a strong positive correlation with PCB 138 (r_s = 0.838) and PCB 114 (r_s = 0.783); this could be attributed to the fact they are highly chlorinated, just like PCB 101 with 5 chlorine atoms.

IV. CONCLUSION

This study provides meaningful data on the concentration levels, human health risk assessment, and source apportionment of PCBs in beauty salons in Ilorin, North Central Nigeria. Total average concentrations of PCBs in the beauty shops ranged from 0.11–3.32 μg/m^3. The PCBs were dominated by the non-dioxin-like PCBs that accounted for about 77% of the total PCBs. The mean TEQ at various locations was 5.08×10^{-1} ng WHO-TEQ/m^3. The cancer and non-cancer risks obtained were within the range considered acceptable. ILCR for children and HQs for adults and children were lower than the permissible limits set by USEPA. The PMF analysis identified eight factors associated with PCBs sources, and the predominant sources are mixed sources paint, and pigment, which accounted for 28.91 and 20.08% of the total PCBs. The study found no link between extended exposure to and the risk of cancer and non-carcinogenic PCBs in the beauty shop. Regulatory agencies should ensure beauty salons strictly adhere to regulations and guidelines related to product use, disposal, and management.

AUTHOR CONTRIBUTIONS

A.S. Atanda: conceptualization, methodology, investigation, and writing**. J.A. Adeniran**: conceptualization, methodology, review, editing, visualization and supervision**. L.T. Adewoye**: conceptualization, review, editing, and supervision

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Table A.1: Description of sample locations

Salon ID		Ventilation type	Number of doors and windows	Description
SL01	8.4810786, 4.6175327	FAN, natural ventilation	1 door and no window	Tiled floor, PVC ceiling
SL02	8.4806394, 4.6188957	FAN and natural ventilation	1 door and no window	Tiled floor, asbestos ceiling, painted wall
SL03	8.4791840, 4.6285285	FAN and natural ventilation	1 door and 1 window	Tiled floor, asbestos ceiling, painted wall
SL04	8.4787744, 4.6287951	FAN and natural ventilation	1 door and no window	Tiled floor, asbestos ceiling, wallpaper
SL05	8.4805880,4.6284014	Fan and natural ventilation	1 door and no window	Tiled floor, asbestos ceiling, painted wall
SL06	8.4808198, 4.6093779	AC and fan	1 door and 2 windows	Tiled floor, asbestos ceiling, wallpaper
SL07	8.49492774,4.4988244	AC and fan	1 door and 2 windows	Tiled floor, PVC ceiling, wallpaper
SL08	8.5067072,4.4988244	Fan and natural ventilation	1 door and 1 window	Carpet, tiled floor, asbestos ceiling, painted wall
SL09	8.474542, 4.5063913	Fan and natural ventilation	1 door and no window	Tiled floor, asbestos ceiling, wallpaper
SL10	8.4812, 4.5417	Fan and natural ventilation	1 door and no window	Tiled floor, asbestos ceiling, wallpaper
SL11	8.4812244; 4.54166	Fan and natural ventilation	1 door and no window	Tiled floor, PVC ceiling
SL12	8.4821301;4.54510	1 door and no window	1 door and no window	Tiled floor, PVC ceiling
SL13	8.452099; 4.540753	Fan and natural ventilation	1 door and no window	Wallpaper, tiled floor, PVC ceiling
SL14	8.477850; 4.552505	Fan	1 door and no window	Carpet, asbestos ceiling, painted wall

Table A.2: Exposure factors and parameters for health risk assessment

Exposure factors	Adult	Children	Reference
Ingestion rate (mg/day)	100	200	(Makokha *et al.*, 2018; USEPA, 2011b)
Exposed skin area, SA (cm^2)	5700	2800	(USEPA, 2011b)
Skin adherence factor, AF_{soil} (mg/cm^2)	0.07	0.2	(USEPA, 2011b)
Exposure frequency, EF (days/year)	365	365	(Kumar, Verma, Kumar, and Sharma, 2013)
Exposure duration, ED (year)	24	6	(USEPA, 2011b)
Body weight, BW (kg)	70	18	(ICMR, 2009)
Averaging time, AT (days)	25550	25550	(Makokha *et al.*, 2018; Senthong and Wittayasilp, 2021)
Dermal adsorption fraction (DAF)	0.13	0.13	(USEPA, 2011b)
Inhalation rate (m^3/day)	20	10	(Soltani, Keshavarzi, Moore, Tavakol, Lahijanzadeh, Jaafarzadeh, and Kermani, 2015)
Particulate emission factor (m^3/kg)	1.36×10^9	1.36×10^9	(Adeniran, Abdulraheem, Ameen, Odediran, and Yusuf, 2021; Makokha *et al.*, 2018; Odediran *et al.*, 2021; USEPA, 2011b)
C ingestion (mg/kg/day)	7.3	7.3	(Peng, Chen, Liao, Wang, Ouyang, Jiao, and Bai, 2011)
C inhalation (mg/kg/day)	3.8	3.85	(Peng *et al.*, 2011)
C dermal (mg/kg/day)	25	25	(Peng *et al.*, 2011)

Figure A.1 Polyurethane Foam disk

Figure A.2 Amberlite XAD resin