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Occurrence, Toxic Equivalency and Human Health Risk Assessment of Selected Polychlorinated Biphenyl Congeners in Commercial Sanitary Pads Produced in Nigeria

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ABSTRACT
Polychlorinated biphenyls (PCBs) are persistent organic pollutants recognized for their environmental persistence, bioaccumulative potential, and adverse toxicological effects. Despite association of PCBs with chemical contaminants in consumer products, limited information exists of their occurrence in feminine hygiene products. This study investigated the occurrence, toxic equivalency (TEQ), and potential human health risks associated with PCB congeners in sanitary pads produced in Nigeria. Six brands were randomly purchased from retail outlets in Lagos, Abuja, and Porthacourt. Samples were extracted with a mixture of hexane and acetone, and analyzed using high resolution gas chromatography (HRGC) coupled to high resolution mass spectrometry (HRMS). Ten PCB congeners were detected across all brands, with total concentrations ranging from 0.0102 to 0.3200 $ng.g^{-1}$. Higher chlorinated congeners (PCB-138 and PCB-153) dominated concentration profiles, whereas PCB-126 contributed disproportionately to toxic equivalency values. Two-way Analysis of Variance (ANOVA) indicated significant variability in sanitary pad brands, PCB congener type, and interactions between sanitary brand and PCB congeners ($p < 0.05$). The results indicated that PCB contamination were influenced by combination of sanitary pad brands, congeners characteristics and interactions of brands and congeners. Toxic equivalency (TEQ) calculations indicated that PCB-126 contributed most significantly to overall toxicity among the detected congeners. Absorbed daily dose values ranged from 0.00064 to 0.01761 $pg.kg^{-1}.day^{-1}$, while hazard quotient values were substantially below unity, suggesting minimal non-carcinogenic health risk under the assumed exposure scenario. Lifetime cancer risk estimates varied between 2.70×10^{-9} and 7.42×10^{-8}. Multivariate statistical analyses, including principal component analysis and hierarchical cluster analysis, indicated similar contamination patterns among most brands, suggesting common contamination sources associated with manufacturing materials. Although calculated risk levels were low, the presence of persistent organic pollutants in sanitary hygiene products highlights the need for continuous monitoring and improved regulatory oversight.

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INTRODUCTION

Polychlorinated biphenyls (PCBs) are persistent organic pollutants (POPs) of global concern owing to their toxicity, environmental persistence, and tendency to bioaccumulate in living organisms. Since their extensive industrial application during the twentieth century, PCBs have become ubiquitous environmental contaminants, posing significant risks to both ecosystems and human health. Despite restrictions and bans imposed under international agreements such as the Stockholm Convention, PCBs remain detectable in environmental matrices and consumer products due to their persistence and continued release from legacy sources.

Chemically, PCBs comprise two benzene rings linked by a single carbon–carbon bond and substituted with one to ten chlorine atoms, giving rise to 209 congeners with distinct physicochemical and toxicological properties. The environmental behaviour and biological activity of individual congeners are largely determined by their structural configuration, source, and formation processes. PCBs are generally classified into dioxin-like PCBs (DL-PCBs) and non-dioxin-like PCBs (NDL-PCBs). Dioxin-like congeners exhibit toxicological properties similar to those of dioxins through activation of the aryl hydrocarbon receptor (AhR), which mediates a range of adverse biological effects, including immunotoxicity, endocrine disruption, reproductive impairment, developmental toxicity, and carcinogenicity (Van den Berg et al., 2006).

PCBs are characterised by high lipophilicity, resistance to degradation, and the ability to undergo long-range environmental transport, resulting in their widespread distribution across environmental compartments (World Health Organization [WHO], 2023). Although historically manufactured for various industrial applications, PCBs are also formed unintentionally as by-products of anthropogenic activities such as incomplete combustion, waste incineration, chlorine-based bleaching processes, and certain industrial operations (United Nations Environment Programme [UNEP], 2023). Consequently, environmental contamination and chronic human exposure persist despite regulatory controls (Weber et al., 2018).

Human exposure to PCBs occurs through multiple pathways, including dietary intake, inhalation, and dermal absorption. Dietary exposure is considered the predominant route and has been associated with the consumption of contaminated foods of animal origin, including milk and dairy products, meat, eggs, fish, seafood, and animal fats, where PCB

concentrations are commonly expressed as pg WHO toxic equivalents (WHO-TEQ) per gram of food or body weight (European Food Safety Authority [EFSA], 2018). Maternal transfer of PCBs during pregnancy and lactation has also been reported, highlighting the potential for early-life exposure (Xu et al., 2022). Inhalation exposure may occur through contaminated air emissions from industrial activities and waste incineration facilities. For instance, Li et al. (2020) reported the release of PCBs and other hazardous compounds in flue gases from municipal waste incinerators in Japan. Furthermore, biomonitoring studies have detected measurable concentrations of PCBs in human tissues and serum samples from individuals without known occupational exposure, demonstrating their widespread environmental occurrence and chronic low-level exposure among the general population (Santa Marina et al., 2023).

More recently, sanitary pads have been identified as a potential low-level exposure pathway for environmental contaminants due to their prolonged contact with the highly vascularised vulvovaginal mucosa, which may facilitate the absorption of lipophilic compounds. Several studies have reported the presence of contaminants in commercial sanitary pads, including heavy metals, dioxins, phthalates, parabens, volatile organic compounds (VOCs), and trace levels of PCB congeners, potentially originating from bleached cellulose fibres and synthetic materials used during manufacture (Gore et al., 2015). Although the concentrations detected are generally low, repeated use throughout a woman's reproductive lifetime may contribute to cumulative exposure. Given the potential for systemic absorption and subsequent bioaccumulation in adipose tissues, such exposure may be associated with adverse health outcomes, including endocrine disruption, immunotoxicity, reproductive toxicity, and carcinogenicity (Farage et al., 2021; International Agency for Research on Cancer [IARC], 2016).

The toxic equivalency (TEQ) approach is widely used to assess the cumulative toxicity of dioxin-like compounds relative to the reference compound 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) (Van den Berg et al., 2006). While numerous studies have investigated chemical contaminants in sanitary pads marketed in developed countries, information regarding PCB contamination in products manufactured and sold in developing countries remains limited. In Nigeria, where disposable sanitary pads are widely used by women and adolescent girls, data on the occurrence and potential health risks of PCB contamination are scarce. Therefore, this study investigated the occurrence of selected PCB congeners in commercial sanitary pads produced and marketed in Nigeria, estimated their toxic equivalency concentrations, and assessed the associated human health risks. The findings provide baseline information to support consumer safety evaluations, regulatory oversight, and evidence-based decision-making regarding menstrual hygiene products in Nigeria.

MATERIALS AND METHODS

Sample Collection and Labelling

The study focused on commonly used female sanitary pads manufactured in Nigeria. Six brands were randomly purchased from supermarkets, pharmacies, and open retail outlets in Lagos, Abuja, and Port Harcourt. The six sanitary pad brands analysed were selected based on their widespread use among consumers in low-income socioeconomic groups. The brands were coded as follows: Softcare (A), My Girl (B), Dry Love (C), Joyland (D), Besense (E), and Wonder Girl (F). Sampling was conducted between March and June 2025 to minimise temporal variation in product availability. For each brand, three production batches were obtained to account for batch variability. Samples from different batches of the same brand were analysed to determine batch-to-batch variability, with batches verified using manufacturing codes and expiry dates. All samples were stored at room temperature in clean polyethylene bags prior to analysis, and handled using powder-free gloves to prevent contamination. brands were investigated.

Chemicals and Standards

Certified reference standards of 12 dioxin-like PCB congeners were obtained from AccuStandard, USA via Germany outlet. The standards comprised native and uniformly ^{13}C-labelled congeners supplied as individual solutions and mixed calibration standards. Isotope-labelled internal standards (^{13}C-congeners) were used for quantification following EPA Methods 1613 and 1668. The isotopic standards were also used to correct for any loss of material during both the extraction and clean-up processes. All standards and organic solvents were of high-purity (≥ 98%); silica gel, neutral alumina and activated carbon used for clean-up had been pre-cleaned and activated using established protocols.

Sample Preparation and Extraction

Sanitary pads were manually unwrapped and homogenised using stainless steel scissors. For each brand, three batches were processed separately, and 10 g of each homogenised sample was placed in cellulose extraction thimbles. Samples were extracted by Soxhlet extraction at 70 ºC for 16 hours using a 20 mL hexane–acetone (1:1, v/v) mixture, then concentrated under a gentle nitrogen stream. Extracts were purified to remove lipids and matrix interferences using sequential clean-up with multilayer silica, neutral alumina, and activated carbon columns. The multilayer silica column (1.5 cm internal diameter) was packed from bottom to top with anhydrous sodium sulphate, neutral silica gel, basic silica gel (2% KOH), acidic silica gel (2% H_2SO_4), neutral silica gel, and anhydrous sodium sulphate. After conditioning, samples were loaded and eluted with hexane; the first 10 mL was discarded, and subsequent fractions were collected. This procedure enabled separation of DL-PCBs from co-extracted materials. Purified extracts were concentrated to near dryness under high-purity nitrogen and reconstituted in isooctane prior to analysis by high-resolution gas chromatography coupled with high-resolution mass spectrometry (HRGC–HRMS). Internal standards were added before extraction and prior to instrumental analysis to assess recovery efficiency.

Instrumental Analysis

HRGC with HRMS were used in selected ion monitoring mode to quantify the sample extract. PCB congeners were analysed by high-resolution gas chromatography coupled with high-resolution mass spectrometry (HRGC–HRMS) using a DB-5MS capillary column (60 m × 0.25 mm × 0.25 μm). Helium was used as the carrier gas at 1.0 mL min^{-1}. Samples (1 μL) were injected in splitless mode with the injector temperature maintained at 280 °C. The oven temperature was programmed from 120 °C to 300 °C under a multi-step gradient. Detection was performed by electron ionisation (EI, 35–70 eV) in selected ion monitoring mode at a mass resolution ≥10,000, following EPA Method 1668C. A capillary column designed specifically for the separation of chlorinated aromatic compounds was used to separate the chromatographic samples. Five-point calibration curves used to calibrate instruments were developed from standard mixtures that fall within the expected concentration range.

Calibration linearity was established via coefficients of correlation greater than 0.995. Method detection limits for the congeners measured were between 0.01 and 0.05 pg.g^{-1}. Quality assurance and quality control protocols included assessing the quality of procedural blanks, matrix spikes, replicate samples, and recovery standards. Recoveries of congeners occurred within the range of 60 to 120%. Duplicate analysis and RSD values were less than 10% of the samples.

Toxic Equivalency Calculation

To assess the overall degree of toxicity of the congeners that were detected; the Toxic Equivalency Values (TEQs) were calculated based on the 2005 Toxic Equivalency Factors (TEFs) created by the World Health Organization (Van den Berg et al., 2006). The following equation (1) was used to calculate TEQ values:

$$TEQ = \sum(C_i.TEF_i) \quad (1)$$

where C represents the concentration of each detected congener and TEF represents the corresponding toxic equivalency factor. The TEF values for PCB-77, PCB-118, PCB-126 and PCB-169 are 1 x 10^{-4}, 3 x 10^{-5}, 1x 10^{-1} and 3x 10^{-2} ng.g^{-1} respectively (DeVito et al., 2024; Van den Berg et al., 2006). Total TEQ values were obtained by summing contributions from all quantified DL-PCB congeners.

Exposure and Risk Assessment

The daily exposure was estimated through skin contact via the external use of menstrual hygiene products (sanitary pads). The absorbed daily dose (ADD) was determined using the estimated daily intake (EDI) formula based on exposure parameters developed from both published patterns of menstrual hygiene usage and from toxicological guidance documents. Assumptions made in the model are: (i) average use of 20 sanitary pads per menstrual cycle, (ii) mean pad mass of 8 g, (iii) dermal absorption fraction of 3% (WHO in Kumar et al., 2024), and (iv) average adult female body weight of 60 kg. Integration of concentrations of contaminants, frequency of use of the product and absorption of those contaminants determined the ADD. The formula for calculating the dermal ADD is presented in equation (2) (Ishii et al., 2015; Gao et al., 2020).

$$ADD_{dermal} = \frac{C \text{ x } W \text{ x } N \text{ x } AF}{BW} \quad (2)$$

This formula is explained as follows: C is the concentration of PCB in sanitary pads (ng.g^{-1}), W is the mean weight of one pad (i.e. 8 g), N is the number of pads used per day (4 per day for 5 days; Kumar et al., 2024), AF is the dermal/mucosa absorption fraction (3% ≡ 0.03; unitless; Ma et al. 2024 used 15%), and BW is the body weight (i.e. 60 kg). According to Gao et al., (2020), an average weight of women in China is 52 kg, and in United States of America, an average weight of woman is 75 kg (Gao and Kannan, 2020). Akinpelu et al. (2015) reported a mean body weight of 62 kg among adult women residing in rural Nigerian communities. For this study, 60 kg is considered a middle ground between the two studies. In summary, the calculation of ADD of each brand can be achieved by determining the product of C and 0.016.

For ADD of dl-PCBs, measured as TEQ equivalent, equation (3) is used to calculate their values

$$ADD_{TEQ} = TEQ \text{ x } 0.016 \quad (3)$$

Here, TEQs of the dl-PCBs are used in place of their concentration.

The hazard quotient (HQ) was used to quantify the non-cancer risk, and the HQ was calculated using the following formula in equation (4):

$$HQ = \frac{ADD_{dermal}}{TDI} \quad (4)$$

where the tolerable daily intake (TDI) values were obtained from internationally accepted toxicological benchmarks. The provisional TDI set by WHO (1998) is 1-4 pg TEQ.kg-bw^{-1}.day^{-1} for dioxins, and dioxin-like PCBs. HQ values below 1 were interpreted as indicating acceptable non-cancer risk.

To calculate lifetime cancer risk, the oral slope factor provided by the U.S. EPA (2024) was used. While the oral slope factors provide a conservative measure, they are often used as screening-level measures when dermal-specific toxicity factors are not available.

The lifetime average daily dose (LADD) for cancer risk through dermal/mucosa absorption can be calculated using the relationship in equation (5) (Ma et al.,2019)

$$LADD_{dermal} = \frac{ADD_{dermal} \text{ x } EF \text{ x } ED}{AT} \quad (5)$$

Where EF is the exposure frequency (day/year; 13 cycles per year; Upson et al., 2022), ED is the exposure duration (year; 30 years exposure, which is 10, 950 days; Upson et al., 2022), and AT is the averaging time for cancer risk (70 years x 365 days). Lifetime cancer risk (LCR) can be calculated using the relationship in equation (6) (ATSDR, 2023).

$$LDR = LADD_{dermal} \text{ x } SF \quad (6)$$

The cancer slope factor (SF) used for the assessment of dioxin-like PCBs was 1.5 × 10^5 (mg kg^{-1} day^{-1})$^{-1}$, based on the United States Environmental Protection Agency's adoption of the toxic equivalency approach, which expresses the toxicity of dioxin-like PCBs relative to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). The average daily dose (ADD), initially expressed in pg TEQ kg^{-1} day^{-1}, was converted to mg TEQ kg^{-1} day^{-1} prior to the application of Equation (6) to ensure consistency with the units of the slope factor. The toxic equivalency (TEQ)-based approach was considered more appropriate for estimating lifetime cancer risk than the hazard quotient (HQ) approach because it accounts for the carcinogenic potency of dioxin-like congeners and is particularly relevant for exposure pathways involving dermal and mucosal absorption.

Statistical Analysis

For each congener and total TEQ value, descriptive statistics (means, standard deviations, minimum, maximum, and sum of concentrations) were produced. A two-way ANOVA was performed to determine whether differences in contaminant levels occurred by brand and sampling location. Tukey honestly significant difference (HSD) post-hoc tests were conducted for pairwise comparisons. All statistical analyses were completed using Microsoft Excel and SPSS version 25, and an alpha level of $p < .05$ was used to determine whether results were statistically significant. Prior to conducting inferential analyses, both normality of distribution and homogeneity of variance were assessed.

Quality Assurance and Quality Control

Analytical-grade solvents and certified reference standards of PCB congeners were used throughout the study. Calibration standards were prepared at multiple concentration levels, and calibration curves were generated for each target analyte at appropriate concentration range. Instrumental performance was verified through periodic analysis of calibration verification standards and continuing calibration checks. Instrument calibration was considered acceptable when the coefficient of determination (R^2) exceeded 0.995. The surrogate recoveries reported in this study ranged between 76 and 103%. Recoveries from each labelled congeners were calculated individually while comparing with the internal standard recoveries added before each analysis. The recovery

range occurred within the established guidelines from persistent organic pollutants' analysis (EPA 1668C).

The limit of detection (LOD) was calculated as three times the standard deviation of the blank measurements divided by the mean concentration of the blank, whereas the limit of quantification (LOQ) was calculated as ten times the standard deviation of the blank measurements divided by the mean concentration of the blank. The LOD and LOQ are presented in equations (7) and (8)

$$LOD = \frac{3\alpha}{\beta} \quad (7)$$

$$\text{LOQ} = \frac{10\alpha}{\beta} \quad (8)$$

Where α and β are standard deviation and mean concentration respectively of the blank and the calibration curves.

Data validation involved verification of chromatographic peak identification based on retention times and characteristic ion ratios. Toxic equivalent (TEQ) values for dioxin-like PCB congeners were calculated using the World Health Organization toxic equivalency factors (WHO-TEFs) established by Van den Berg et al. (2006). All analytical procedures complied with internationally recognised quality control requirements for the determination of persistent organic pollutants in environmental and consumer-product matrices.

RESULTS AND DISCUSSION

Polychlorobiphenyls (PCBs) Concentrations in Sanitary Pad Brands

The study showed that all analyzed sanitary pad brands contained detectable concentrations of ten targeted PCB congeners, which suggests the widespread presence of PCB residues across all locally produced sanitary products (Table 1). Total PCB concentrations (∑10 PCBs) vary across brands, and these values ranged from 0.0102 ng.g^{-1} in Brand A to 0.3200 ng.g^{-1} in Brand D. The overall concentration trends are presented in descending order as follows: Brand D > Brand E > Brand C > Brand F > Brand B > Brand A.

Table 1: Mean PCB Concentrations (ng.g^{-1}) for 10 PCB Congeners and Descriptive Statistics Across Sanitary Pad Brands

Brand	Brand Name	Mean±SD (ng.g^{-1})	Minimum	Maximum	Total PCBs (ng.g^{-1})
Brand A	Softcare	0.00102 ± 0.00088	0.0001	0.0030	0.0102
Brand B	My Girl	0.00169 ± 0.00122	0.0002	0.0040	0.0169
Brand C	Dry Love	0.00653 ± 0.00455	0.0003	0.0150	0.0653
Brand D	Joyland	0.03200 ± 0.02585	0.0050	0.0800	0.3200
Brand E	Besense	0.01170 ± 0.00817	0.0020	0.0250	0.1170
Brand F	Wonder Girl	0.00318 ± 0.00210	0.0003	0.0080	0.0318

DL-PCB congeners (PCB-77, PCB-118, PCB-126, and PCB-169) were detected in trace amount in all sanitary pad samples. PCB-126, which is a congener known to possess the highest toxicity equivalent factor, ranged from 0.0001 ng.g^{-1} in Brand A to 0.005 ng.g^{-1} in Brand D. Despite their low concentrations in sanitary pads, DL-PCB congeners possess high toxicological significance due to their high potency.

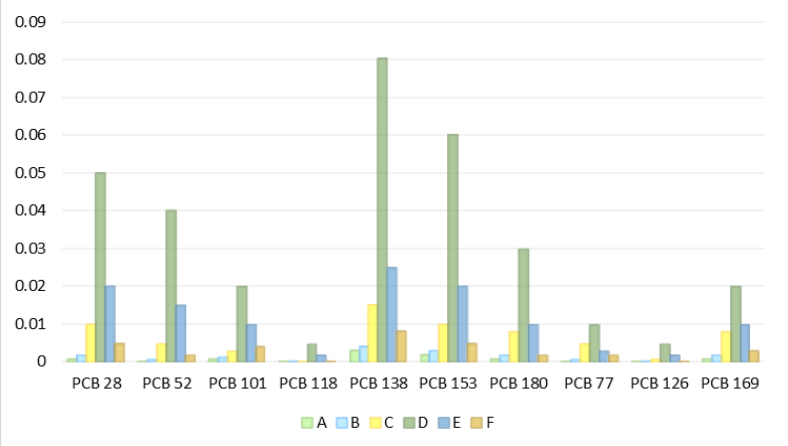

Figure 1: Profile of PCB Congeners Present in Different Brands of Sanitary Pads Produced in Nigeria

Higher chlorinated congeners, such as PCB-138 and PCB-153, dominated the contaminant profiles across all brands (Figure 1). These congeners are known for their persistence, and affinity for organic matrices, an indication that contaminants originated from recycled raw materials, or long-lived environmental reservoirs, other than recent additions (Weber et al., 2018).

Lower chlorinated congeners, such as PCB-28 and PCB-52, were present at lower concentrations, invariably indicating negligible contribution from recent volatilisation sources. Similar congener distributions across brands suggest diffuse contamination rather than isolated production failure.

Shared upstream contamination pathways, likely as a result of pulp processing or packaging materials, can explain the similarities in co-occurrence among brands. In contrast to these similarities, differences in quantitative amounts among brands indicate diversity in the way products were manufactured or produced quality control procedures.

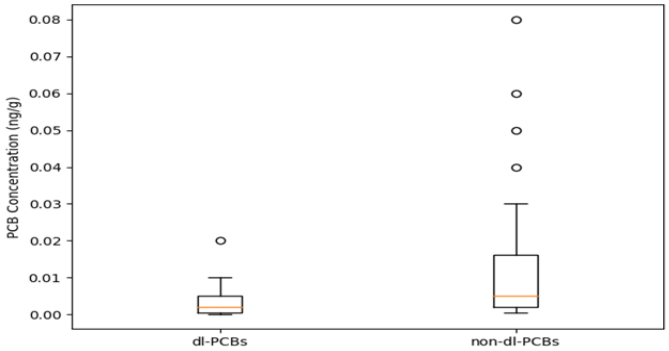

Figure 2: Boxplot Expressing Comparison Between DL-PCBs and NDL-PCBs

The polychlorinated biphenyls (PCBs) detected in this study can be categorised into DL- and NDL- congeners based on their toxicological behaviour. NDL-PCBs comprise congeners that do not exhibit DL-biological activity through binding to the aryl hydrocarbon receptor (AhR). They include PCB-28, PCB-52, PCB-101, PCB-138, PCB-153, and PCB-180. In contrast, DL-PCBs share a similar mechanism of toxicity with dioxins, primarily exerting their effects through activation of the AhR signalling pathway. Representative congeners within this group include PCB-77, PCB-118, PCB-126, and PCB-169. The magnitude of the two PCB congeners is presented in Figure 2.

Statistical Evaluation of Inter-Brand Differences

Two-way Analysis of Variance (ANOVA) with replication was performed on variation in PCB concentrations among brands, and the effect of interaction between sanitary pad brand and the PCB congeners (Table 2).

Table 2: Two-Way ANOVA with Replication Summary for PCB Concentrations Among Brands (α = 0.05 Significance Level)

Source of Variation	SS	df	MS	F	p-value
Brand	0.023316	5	0.004663	30.24	< .05
PCB Congener	0.010805	9	0.001201	7.79	<.05
Brand vs PCB Congener	0.016435	45	0.000365	2.37	<.05
Error	0.018504	120	0.000154		
Total	0.069060	179			

This result (Table 2) reveals that both sanitary pad brand and type of PCB congener have statistically significant effects on PCB concentrations ($p < 0.05$). In addition, a significant interaction between brand and congener was observed, indicating that the distribution of individual PCB congeners varied across the different brands. These results suggest that PCB contamination is influenced by both the brands of sanitary pad ($F(5, 120) = 30.24$, $p < 0.05$) analysed and PCB congener characteristics ($F(9, 120) = 7.79$, $p < 0.05$). This reflects differences in manufacturing inputs and contamination patterns among the analysed sanitary pad brands. Tukey's Honestly Significant Difference (HSD) post-hoc comparisons (Table 3) shows clear differences in PCB concentrations among sanitary pad brands. Brand D had significantly higher concentrations of PCB concentrations than all other brands ($p < 0.05$), while Brands A and B exhibited the lowest and statistically similar contamination levels. Relative to Brand E, no statistically significant differences were observed between Brand C; however, significant statistical differences were observed among Brands A, B and F. This is an indication that Brands E and C are non-similar possessing higher levels of PCB contamination within the group. But Brands E, A, B, and F are relatively similar and have lower levels of PCB contamination within the group. The absence of significant differences among several lower-contamination brands suggests similar raw material sources or manufacturing processes, whereas the elevated levels observed in Brand D may reflect distinct production inputs or quality control differences.

Table 3: Post-Hoc Tukey HSD Multiple Comparison Test for PCB Concentrations Among Sanitary Pad Brands ($p < 0.05$)

Comparison	Mean Difference	P-value	Significance
Brand A vs B	0.0011	0.997	Not Significant
Brand A vs C	0.0070	0.086	Not Significant
Brand A vs D	0.0328	<0.05	Significant
Brand A vs E	0.0111	<0.05	Significant
Brand A vs F	0.0013	0.992	Not Significant
Brand B vs C	0.0059	0.178	Not Significant
Brand B vs D	0.0317	<0.05	Significant
Brand B vs E	0.0101	<0.05	Significant
Brand B vs F	0.0002	1.000	Not Significant
Brand C vs D	0.0258	<0.05	Significant
Brand C vs E	0.0041	0.506	Not Significant

Comparison	Mean Difference	P-value	Significance
Brand C vs F	-0.0057	0.208	Not Significant
Brand D vs E	-0.0216	<0.05	Significant
Brand D vs F	-0.0315	<0.05	Significant
Brand E vs F	-0.0098	<0.05	Significant

From the log-transformed boxplot (Figure 3), Brand D exhibits the highest median concentration and the widest inter-quartile range. These suggest elevated contamination in the brand, and greater variability in concentration distribution. Conversely, Brands A and B show the lowest medians with very narrow dispersion. These indicate low level of contamination as well as consistent PCB levels. Contamination of Brands C and F falls between those of Brand A-B and Brand D. Brand E is second in rank with respect to spread. The distribution is skewed to the right for Brand D due to higher chlorinated PCB congeners (PCB-138 and PCB-153).

The pronounced separation of Brand D in log-transformed boxplots (Figure 3) indicates potential differences in source materials or manufacturing processes. Importantly, the existence of low-contamination brands demonstrates that reduced PCB levels are achievable under local production conditions.

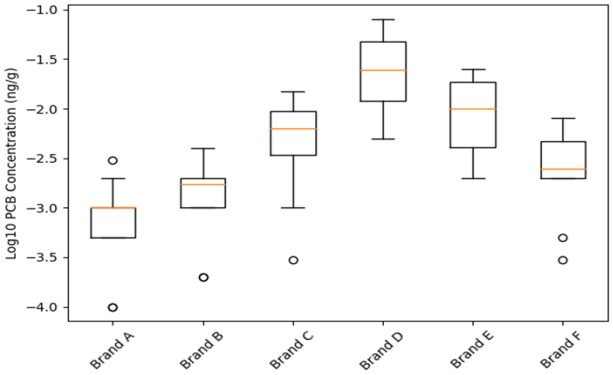

Figure 3: Log-Transformed Boxplot of PCB Concentrations by Brands

Toxic Equivalency (TEQ) Assessment of Dioxin-like PCBs

The results of toxic equivalency calculations (Table 4) suggest that DL-PCB congeners made a much larger contribution to overall toxicity. Toxic equivalency contribution analysis revealed that PCB-126 accounted for the largest proportion of total TEQ, followed by PCB-169. In contrast, PCB-77 and PCB-118 contributed minimally due to their comparatively low toxic equivalency factors. Thus, PCB-126 was responsible for the majority (approximately 85-90%) of TEQ across all brands.

Table 4: The Toxicity Equivalency of DL-PCB Congeners in Brands of Sanitary Pads

Brand	PCB-77 (x 10^{-4})	PCB-118 (x10^{-6})	PCB-126	PCB-169	di-PCB TEQ (pg TEQ.g^{-1})
Brand A	5.00	3.00	0.01	0.03	0.0405
Brand B	10.00	6.00	0.02	0.06	0.0810
Brand C	50.00	9.00	0.10	0.24	0.3450
Brand D	100.00	15.00	0.50	0.60	1.1102
Brand E	30.00	60.00	0.20	0.30	0.5031
Brand F	20.00	1.50	0.03	0.09	0.1220

This study emphasized utilization of WHO toxic equivalency factors against evaluating the concentration of these compounds, since even trace concentrations can potentially represent significant toxicological importance (Van den Berg et al., 2006). Brands that demonstrated high concentrations of total PCBs also exhibited correspondingly higher TEQs, whereby Brands D and E had the greatest toxic burden in comparison to other brands (Table 4).

Health Risk Assessment

Absorbed Daily Dose (ADD) and Hazard Quotient (HQ) Evaluation

The absorbed daily dose (ADD) values ranged from 0.00064 to 0.01761 pg TEQ/kg/day, while the Hazard Quotient (HQ) values ranged from 1.75 x 10^{-4} to 4.45 x 10^{-3} (Table 5). All hazard quotients were well below the threshold of 1, which indicate that dermal exposure to PCBs via sanitary pads would exhibit negligible non-cancer risk. Brand D exhibited the highest total PCB concentration and correspondingly the highest ADD, and HQ, though all values remained within ranges associated with minimal concern.

Table 5: The ADD of Total PCB Congeners and DL-PCBs in Brands of Sanitary Pads

Brand	Total PCB (ng/g)	ADD (ng/kg-bw/day)	ADD (pg TEQ/kg-bw/day)	% ADD (TEQ) in Brand	HQ (x 10^{-3})	Lifetime Cancer Risk
Brand A	0.0102	0.0001632	0.0007	0.43%	0.175	2.70 x 10^{-9}
Brand B	0.0169	0.0002704	0.0013	0.48%	0.400	5.36 x 10^{-9}
Brand C	0.0653	0.0010448	0.0055	0.53%	1.375	2.28 x 10^{-8}
Brand D	0.3200	0.005120	0.0178	0.35%	4.450	7.42 x 10^{-8}
Brand E	0.1170	0.001872	0.0081	0.43%	2.025	3.36 x 10^{-8}
Brand F	0.0318	0.0005088	0.0020	0.39%	0.500	8.20 x 10^{-9}

Lifetime Health Risk Evaluation

The estimated lifetime cancer risk associated with exposure to PCB congeners in the analysed sanitary pad brands indicated measurable variability across products (Table 5). Brands with higher concentrations of DL-PCBs, particularly those dominated by PCB-126 and PCB-169, exhibited elevated cancer risk estimates compared with other brands. In general, calculated lifetime cancer risks for most brands, which ranged from 2.70 x 10^{-9} and 7.42 x 10^{-8}, fell below the range of 10^{-6} to 10^{-4}, which is commonly regarded as the acceptable to tolerable risk range in environmental health assessments. The contribution of dioxin-like congeners to overall cancer risk was substantially greater than that of NDL-PCBs due to their higher toxic equivalency factors. Variability in risk estimates across brands reflects differences in both total PCB burden and congener composition. Although dermal exposure assumptions were conservative, the findings highlight the importance of cumulative exposure over time. Ultimately, the results suggest that while most products may pose low to moderate cancer risk, certain brands could contribute to elevated lifetime risk under continuous use. These findings underscore the need for stricter quality control and regulatory monitoring of consumer hygiene products.

Multivariate Analysis of PCB Congener Patterns

Principal Component and Cluster Analysis

Principal component analysis (PCA) was conducted to evaluate similarities and differences in PCB congener distributions among the analysed sanitary pad brands (Figure 4). The first two principal components accounted for most of the variability in the dataset, indicating that the observed contamination patterns could be adequately described by two dominant factors. Brand D was distinctly separated from the other brands, reflecting its considerably higher PCB concentrations across multiple congeners. In contrast, Brands A and B clustered closely together, suggesting similar congener profiles and relatively low contamination levels. Brands C and F occupied intermediate positions, indicating moderate PCB contamination, while Brand E formed a slightly distinct cluster due to differences in congener composition. PCA loading analysis showed that the higher chlorinated congeners, particularly PCB-138 and PCB-153, contributed most strongly to the first principal component and were the primary drivers of variability among brands (Figure 5). Lower chlorinated congeners, including PCB-28 and PCB-52, also contributed positively, suggesting that differences among brands were largely attributable to overall contamination intensity rather than distinct sources of PCB contamination.

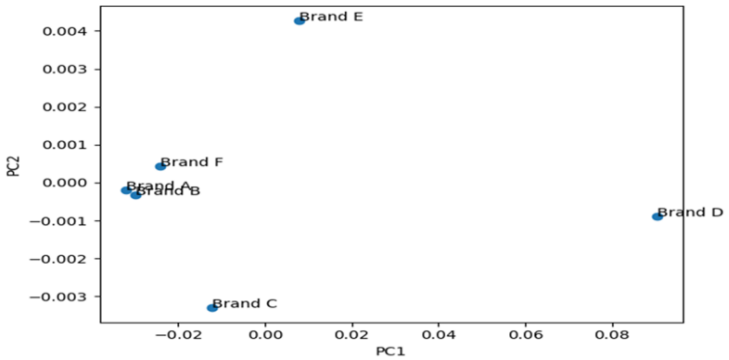

Figure 4: Principal Component Analysis of DL-PCBs in Sanitary Pad Brands

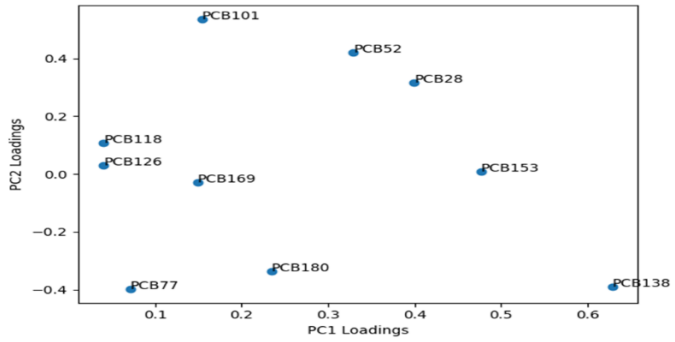

Figure 5: PCA Loading Plot of PCB Congeners in Sanitary Pad Brands

Hierarchical Cluster Dendrogram

Hierarchical cluster analysis revealed two major groups based on PCB contamination patterns among the sanitary pad brands (Figure 6). Brands A, B, F, and C clustered together, indicating similar congener distributions and relatively low to moderate PCB concentrations. Brand E formed a separate cluster, reflecting intermediate contamination levels. Brand D was distinctly isolated from all other brands due to its substantially higher PCB concentrations. These findings suggest a common contamination source for most brands. The elevated contamination in Brand D may be associated with differences in raw materials or manufacturing processes.

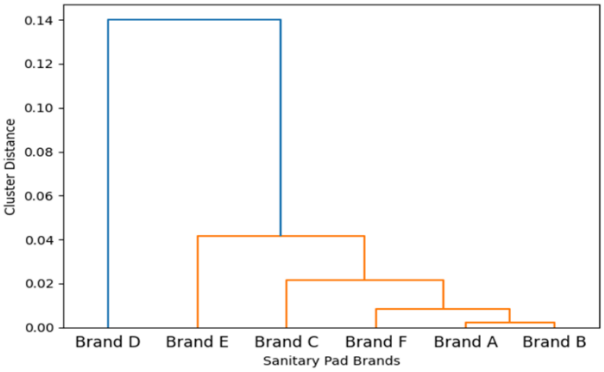

Figure 6: Hierarchical Cluster Analysis of PCB Congeners in Sanitary Brands

Correlation Matrix Analysis of PCB Congeners

The correlation heatmap revealed clear associations among PCB congeners, suggesting similarities in contamination sources across the sanitary pad brands (Figure 7). Strong positive correlations were observed among the higher chlorinated congeners, particularly PCB-138, PCB-153, and PCB-180, indicating their co-occurrence in similar proportions and likely origin from common technical PCB mixtures. Moderate correlations were also identified among lower chlorinated congeners, including PCB-28, PCB-52, and PCB-101, suggesting shared manufacturing inputs or degradation pathways. Furthermore, the dioxin-like congeners PCB-77, PCB-118, PCB-126, and PCB-169 exhibited positive correlations with several non-dioxin-like congeners. These findings indicate that both PCB groups may originate from similar contamination pathways. Generally, the observed correlation patterns reflect systematic co-occurrence and comparable physicochemical behaviour during product manufacture and processing.

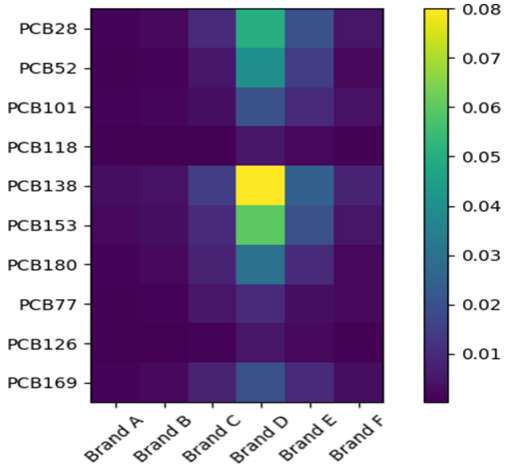

Figure 7: Correlation Heatmap Analysis of DL-PCB Congeners across the Sanitary Brands

Correlation Analysis

Pearson correlation analysis revealed strong positive relationships among most PCB congeners detected in the sanitary pad samples (Table 5). Correlation coefficients generally exceeded 0.90, indicating that the congeners likely share common contamination sources or originate from similar manufacturing inputs. Particularly strong correlations were observed between PCB-138 and PCB-153, as well as between PCB-28 and PCB-52.

Table 5: Pearson Correlation Matrix of PCB Congeners Detected in Sanitary Pad Brands

Congener	PCB 28	PCB 52	PCB 101	PCB 118	PCB 138	PCB 153	PCB 180	PCB 77	PCB 126	PCB 169
PCB-28	1.00	0.99	0.98	0.95	0.99	0.99	0.98	0.96	0.97	0.98
PCB-52	0.99	1.00	0.97	0.94	0.99	0.98	0.98	0.95	0.96	0.97
PCB-101	0.98	0.97	1.00	0.93	0.97	0.98	0.96	0.94	0.95	0.96

Congener	PCB 28	PCB 52	PCB 101	PCB 118	PCB 138	PCB 153	PCB 180	PCB 77	PCB 126	PCB 169
PCB-118	0.95	0.94	0.93	1.00	0.95	0.94	0.92	0.91	0.92	0.93
PCB-138	0.99	0.99	0.97	0.95	1.00	0.99	0.98	0.96	0.97	0.98
PCB-153	0.99	0.98	0.98	0.94	0.99	1.00	0.97	0.95	0.96	0.97
PCB-180	0.98	0.98	0.96	0.92	0.98	0.97	1.00	0.93	0.95	0.96
PCB-77	0.96	0.95	0.94	0.91	0.96	0.95	0.93	1.00	0.92	0.94
PCB-126	0.97	0.96	0.95	0.92	0.97	0.96	0.95	0.92	1.00	0.94
PCB-169	0.98	0.97	0.96	0.93	0.98	0.97	0.96	0.94	0.94	1.00

Diagnostic PCB congener ratios were used to assess potential contamination sources among the sanitary pad brands (Table 6). The relatively consistent PCB-138/PCB-153 and PCB-28/PCB-52 ratios across samples suggest common contamination origins. The predominance of higher chlorinated congeners and PCB-138/PCB-153 ratios close to unity are indicative of weathered industrial PCB mixtures. Combined with the correlation and multivariate analyses, these results suggest that PCB contamination primarily originates from shared manufacturing inputs or recycled raw materials rather than distinct contamination sources.

Table 6: Diagnostic PCB Congener Ratios for Sanitary Pad Brands

Brand	PCB-28/PCB-52	PCB-138/PCB-153	PCB-101/PCB-153	PCB-180/PCB-153
A	2.00	1.50	0.50	0.50
B	2.00	1.33	0.50	0.67
C	2.00	1.50	0.30	0.80
D	1.25	1.33	0.33	0.50
E	1.33	1.25	0.50	0.50
F	2.50	1.60	0.80	0.40

CONCLUSION

This study provides a comprehensive assessment of polychlorinated biphenyl contamination in sanitary pad brands produced in Nigeria. PCB congeners were detected across all analysed samples, with concentrations varying considerably among brands. Higher chlorinated congeners, mainly PCB-138 and PCB-153, dominated the contamination profiles. This reflects their environmental persistence and affinity for organic materials. TEQ analysis indicated that dioxin-like congeners, especially PCB-126, contributed unequally to overall toxicity despite their relatively low concentrations.

Human health risk assessment showed that ADD and HQ values were below established safety thresholds. These suggest minimal non-carcinogenic risk under the assumed exposure conditions. Lifetime cancer risk estimates generally fell within acceptable regulatory ranges. However, elevated values were observed in certain brands, particularly Brand D. These elevated levels indicate the potential for increased risk under prolonged exposure scenarios.

Statistical analysis using two-way ANOVA demonstrated significant differences in PCB concentrations across both sanitary pad brands and congener types, with a significant interaction effect indicating variation in congener distribution among brands. Multivariate analyses, including PCA and HCA, revealed clear grouping patterns as most brands form low to moderate contamination clusters and one brand distinctly separated due to elevated PCB levels. Pearson correlation analysis and the corresponding heatmap further demonstrated strong positive relationships among several congeners, particularly higher chlorinated PCBs, thereby suggesting common contamination sources and similar physicochemical behaviour.

Evidently, the findings indicate that PCB contamination in sanitary pads is influenced by both manufacturing-related factors and inherent congener properties. While the general risk levels appear low, the consistent detection of persistent organic pollutants in products intended for prolonged dermal contact raises important public health considerations.

REFERENCES

Akinpelu, A. O., Oyewole, O. O., & Adekanla, B. A. (2015). Body size perceptions and weight status of adults in a Nigerian rural community. *Annals of Medical and Health Sciences Research*, *5*(5), 358–364. Doi: https://doi.org/10.4103/2141-9248.165253

Agency for Toxic Substances and Disease Registry. (2023). Calculating hazard quotients and cancer risk estimates. U.S. Department of Health and Human Services. https://atsdr.cdc.gov/pha-guidance/conducting_scientific_evaluations/epcs_and_exposure_calculations/hazardquotients_cancerrisk.html

DeVito, M., Bokkers, B., van Duursen, M. B. M., van Ede, K., Feeley, M., Gáspár, E. A. F., Haws, L., Kennedy, S., Peterson, R. E., Hoogenboom, R., Nohara, K., Petersen, K., Rider, C., Rose, M., Safe, S., Schrenk, D., Wheeler, M. W., Wikoff, D., Zhao, B., & van den Berg, M. (2024). *The 2022 World Health Organization reevaluation of human and mammalian toxic equivalency factors for polychlorinated dioxins, dibenzofurans and biphenyls*. *Regulatory Toxicology and Pharmacology*, 146, 105525. Doi: https://doi.org/10.1016/j.yrtph.2023.105525

European Food Safety Authority (EFSA). (2018). Risk for animal and human health related to the presence of dioxins and dioxin-like PCBs in feed and food. *EFSA Journal, 16*(11), e05333. Doi: https://doi.org/10.2903/j.efsa.2018.5333

Farage, M. A., Miller, K. W., Sobel, J. D., & Ledger, W. J. (2021). *Vulvar and vaginal health: Current perspectives and future challenges*. *International Journal of Women's Dermatology*, *7*(3), 267–275. Doi: https://doi.org/10.1016/j.ijwd.2020.09.003

Gao, C. J., Wang, F., Shen, H. M., Kannan, K., & Guo, Y. (2020). Feminine hygiene products—A neglected source of phthalate exposure in women. *Environmental Science &*

Technology, *54*(2), 930–937. Doi: https://doi.org/10.1021/acs.est.9b04356

Gao, C. J., & Kannan, K. (2020). Phthalates, bisphenols, parabens, and triclocarban in feminine hygiene products from the United States and their implications for human exposure. *Environment International*, *136*, 105465. Doi: https://doi.org/10.1016/j.envint.2019.105465

Gore, A. C., Chappell, V. A., Fenton, S. E., Flaws, J. A., Nadal, A., Prins, G. S., Toppari, J., & Zoeller, R. T. (2015). EDC-2: The Endocrine Society's second scientific statement on endocrine-disrupting chemicals. *Endocrine Reviews*, *36*(6), E1–E150. Doi: https://doi.org/10.1210/er.2015-1010

International Agency for Research on Cancer. (2016). *Polychlorinated Biphenyls and Polybrominated Biphenyls (IARC Monographs, Vol. 107)*. IARC.

Ishii, S., Katagiri, R., Minobe, Y., Kuribara, I., Wada, T., Wada, M., & Imai, S. (2015). Investigation of the amount of transdermal exposure of newborn babies to phthalates in paper diapers and certification of the safety of paper diapers. *Regulatory Toxicology and Pharmacology*, *73*(1), 85–92. Doi: https://doi.org/10.1016/j.yrtph.2015.06.012

Kumar, B., Singh, J., Mittal, S., & Singh, H. (2024). The Indian perspective on the harmful substances found in sanitary napkins and their effects on the environment and human health. *Environmental Science and Pollution Research*, *31*(25), 36217–36229. Doi: https://doi.org/10.1007/s11356-023-26739-2

Li, X., Yan, M., Yang, J., Chen, T., Lu, S., Yan, J., Cen, K., & Li, X. (2020). Polychlorinated dibenzo-*p*-dioxins, dibenzofurans and dioxin-like PCBs emitted from municipal solid waste incinerators: Characteristics, environmental impact and control technologies. *Environmental Pollution*, *263*, 114500. Doi: https://doi.org/10.1016/j.envpol.2020.114500

Ma, J., Chai, M., Li, J., Wang, S., & Tang, Z. (2024). Occurrence of heavy metals in sanitary napkins from seven countries: implication for risk management of female hygiene products. *Environmental Technology & Innovation*, *34*, 103606. Doi: https://doi.org/10.1016/j.eti.2024.103606

Santa Marina, L., Irizar, A., Barroeta-Legarreta, Z., Abad, E., et al. (2023). Serum levels of PCDDs, PCDFs and dl-PCBs in general population residing far and near from an urban waste treatment plant under construction in Gipuzkoa, Basque Country (Spain). *Environmental Research*, *236*(Part 1), 116721. Doi: https://doi.org/10.1016/j.envres.2023.116721

United Nations Environment Programme. (2023). *Global Monitoring Plan on Persistent Organic Pollutants: Regional Monitoring Reports under the Stockholm Convention*. UNEP

United States Environmental Protection Agency. (2024). *Dioxin and dioxin-like compounds: Health and environmental effects*. U.S. EPA.

Upson, K., Shearston, J. A., & Kioumourtzoglou, M. A. (2022). Menstrual products as a source of environmental chemical exposure: A review from the epidemiologic perspective. *Current Environmental Health Reports*, *9*(1), 38–52. Doi: https://doi.org/10.1007/s40572-022-00346-7

Van den Berg, M., Birnbaum, L. S., Denison, M., De Vito, M., Farland, W., Feeley, M., Fiedler, H., Håkansson, H., Hanberg, A., Haws, L., Rose, M., Safe, S., Schrenk, D., Tohyama, C., Tritscher, A., Tuomisto, J., Tysklind, M., Walker, N., & Peterson, R. E. (2006). The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicological Sciences*, *93*(2), 223–241. Doi: https://doi.org/10.1093/toxsci/kfl055

Weber, R., Watson, A., Forter, M., & Oliaei, F. (2018). Persistent organic pollutants and landfills: A review of past experiences and future challenges. *Waste Management & Research*, *36*(5), 417–431. Doi: https://doi.org/10.1177/0734242X18756144

World Health Organization. (2023). *Dioxins*. WHO

Xu, P., Zheng, Y., Wang, X., Shen, H., Wu, L., Chen, Y., Xu, D., Xiang, J., Cheng, P., Chen, Z., & Lou, X. (2022). *Breastfed infants' exposure to polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins and dibenzofurans, and per- and polyfluoroalkyl substances: A cross-sectional study of a municipal waste incinerator in China*. *Chemosphere*, *309*(Part 2), 136639. Doi: https://doi.org/10.1016/j.chemosphere.2022.136639

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