Innovations

Polychlorinated Biphenyls in Stored Plastic Bottle Water Exposed to Sunlight

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Abstract: *Over the years, the challenge of availability and access to improved drinking water sources has necessitated water storage for short- and long-term uses in Africa and most developing countries. Plastic containers of different volumes are usually used for long- or short-term storage of water or sold as plastic bottle water for immediate use by individuals. These stored plastic bottles are mostly stored in the sun for long period of time before they are sold and consumed. This study investigates the likely impact and health risk associated with polychlorinated biphenyls in stored plastic bottle water exposed to sunlight. The study involved the collection of water samples from functional pipe borne water sources in Lagos state, Nigeria using PET bottles after which the samples were exposed to sunlight for a period of 3 months and analyzed for 27 PCB congeners using EPA Method 8082A using Agilent 7820A GC equipped with Electron-Capture detector. Analysis of plastic bottled water exposed to sunlight at 28.65°C–30.24°C for three months detected 20 out of 27 PCB congeners. Before exposure, only PCB 8, PCB 18, PCB 28, PCB 44, PCB 52, PCB 60, and PCB 81 were present in the water. The study reported PCB 28, 44 and 18 as the most predominant PCB observed in the water, however, PCB 81, PCB 28 and PCB 44 had concentrations above the USEPA permissible limit of 0.0005mg/L with mean difference of 0.010015 mg/l (t = 16.754, df = 49, p <0.001), 0.002607 mg/l (t = 16.645, df = 49, p <0.001) and 0.001718 mg/l (t = 14.106, df = 49, p <0.001) respectively. However, the health risk assessment showed a low risk of cancer and non-cancer related diseases, however the estimated risk seemed to be higher for children. The study highlights the paucity of data for PCB in water media, especially drinking water in most developing countries, thus there is a need for more research and monitoring for PCB in drinking water sources exposed to climate conditions. The study findings highlight the need for storing bottle water in cool places while emphasizing the role sunlight could play in remediating PCBs in other sample media such as surface water and air.* ***Competing interests****: The authors declare no competing financial interests*

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1. Introduction

The accessibility of clean water for use is important for long-term development, good health, food production, and poverty alleviation (Nagendrappa, 2022; Shehu et al. 2022). Twenty-nine percent of the world's population (2.5 billion people) requires available clean potable water. Eight hundred and forty-four million people in Africa lack access to clean, safe water, with 37% living in Sub-Saharan Africa (Just One Africa, 2020). Historically, studies have shown that in Africa, the production and storage of plastic bottle water is more affordable and easier way to get available clean water for drinking which can easily be accessed by the consumers (Adedire et al. 2020) either through retail/wholesale or by purchasing them on the road while on transit.Despite the fact that plastics have been reported to be suitable for storing liquids because they are transparent and durable (Plastics Europe, 2020), various researchers have highlighted those exposing plastics to sunlight causes microplastic contamination through photochemical reactions (Lambert et al. 2018; Danopoulos et al. 2020). The byproducts of the reaction are of great concern considering that most consumers are unaware of the composition of the ingested water post exposure to sunlight, which could be organic and toxic, hence the by products are usually classified as non-intentionally added substances such as persistent organic pollutants (POPs) like Polychlorinated biphenyls (PCBs) (UNEP, 2023; WHO, 2019).

PCBs classified as one of the persistent organic compounds are a group of 209 compounds identified as one of the world's most harmful substances to human health and the environment (UNEP, 2009). Thes 209 compounds known as PCB congeners are suspected endocrine disruptors, that are linked to various health impacts, including cancer (Buha et al., 2019) and non-cancer health diseases such as thyroid effects (Zhuo et al., 2022).

PCBs have been banned by most countries including countries in Africa, but emerging research have shown the prevalence of PCBs in different environmental media, even though PCBs are not produced or imported in these areas (Gioia et al. 2014). Emerging research have consistently reported the presence of PCBs in water sources in south west, Nigeria, indicating contaminated water (Eze et al., 2023; Unyimadu et al., 2023; Ibigbami et al., 2020). UNEP (2023) in their technical report suggested that PCBs and other chemicals are released during the use of plastics, and as a result emphasizing the need for more research and monitoring of these chemicals to understand the contamination pathway and the hazard they pose (UNEP, 2023). Maraveas, C. et al. (2023) in their study, emphasized on the risk associated with the use and reuse of plastics, which can be attributed to the release of chemicals such as PCBs, especially when the plastics are exposed to heat from sunlight.Salinas et al. (2010) in their study on plastic bottle water kept under room temperature for a period of 1 year in Mexico state, observed PCB levels in the bottle water, although the study did not highlight the role of sunlight in the release of the PCB and did not also look at the baseline PCB content in the water before exposing to room temperature (Salinas et al. 2010). Building on the above research gaps, this study shifts the focus to Lagos state, Nigeria with over twenty-five (25) million population 2100 (World Bank, 2023; Lagos State Government, 2022), where about 10% of residents have access to treated water (NBS, 2023). Given Lagos State's projected demand for potable water, accounting for 30.3% of the total residential requirement by 2022, this study investigates the impact of sunlight on PCB photodegradation in stored bottled water exposed to sunlight in Lagos State, providing a novel perspective on this critical issue (Lagos State Government, 2022).

2. Study Objectives

The aim of this study was to identify the PCB Congeners associated with plastic bottled water and their potential health effects. The specific objectives were to:

(i) determine the difference in the PCB concentrations in stored bottled water before and after exposure to sunlight in Lagos State;

(ii) compare the difference between the PCB concentrations in stored packaged bottled water exposed to sunlight in Lagos State and the United States Environmental Protection Agency (USEPA) observable limit for PCBs in water.

(iii) estimate the health risk assessment of the PCB congeners observed in the plastic bottle water during the study.

3. Methodology

The study adopted an experimental research design. It was conducted in Lagos East and Lagos West senatorial zones, selected for their functional pipe-borne water supply. Fifty water samples were collected in 750 mL and 1500 mL PET bottles, stored in a cooler, and transported to the Central Laboratory at the Nigerian Institute of Oceanography and Maritime Research (NIOMR) for analysis. Baseline PCB analysis was conducted before exposing the bottled water to sunlight for three months. Monthly subsamples (100 mL) were taken from April to June 2024. Each was mixed with 50 mL Dichloromethane (DCM), homogenized in an ultrasonic bath, and subjected to Liquid-Liquid extraction (USEPA 3510c). The extracts were dried in a fume box, reconstituted with 5 mL acetone, and cleaned using a Silica gel column (USEPA 3535a). PCBs were eluted with 15 mL acetone, concentrated to 1.5 mL, and analyzed using Agilent 7820A Gas Chromatography (GC) with an Electron Capture Detector. Temperature readings were recorded using a HOBO Weather Station at NIOMR. Data were analyzed using IBM SPSS statistics 27 descriptive statistics, while inferential analyses included Paired Sample T-Test, Linear Regression, Pearson

Correlation, and One-Sample T-Test. Hypotheses were tested at a 95% confidence interval.

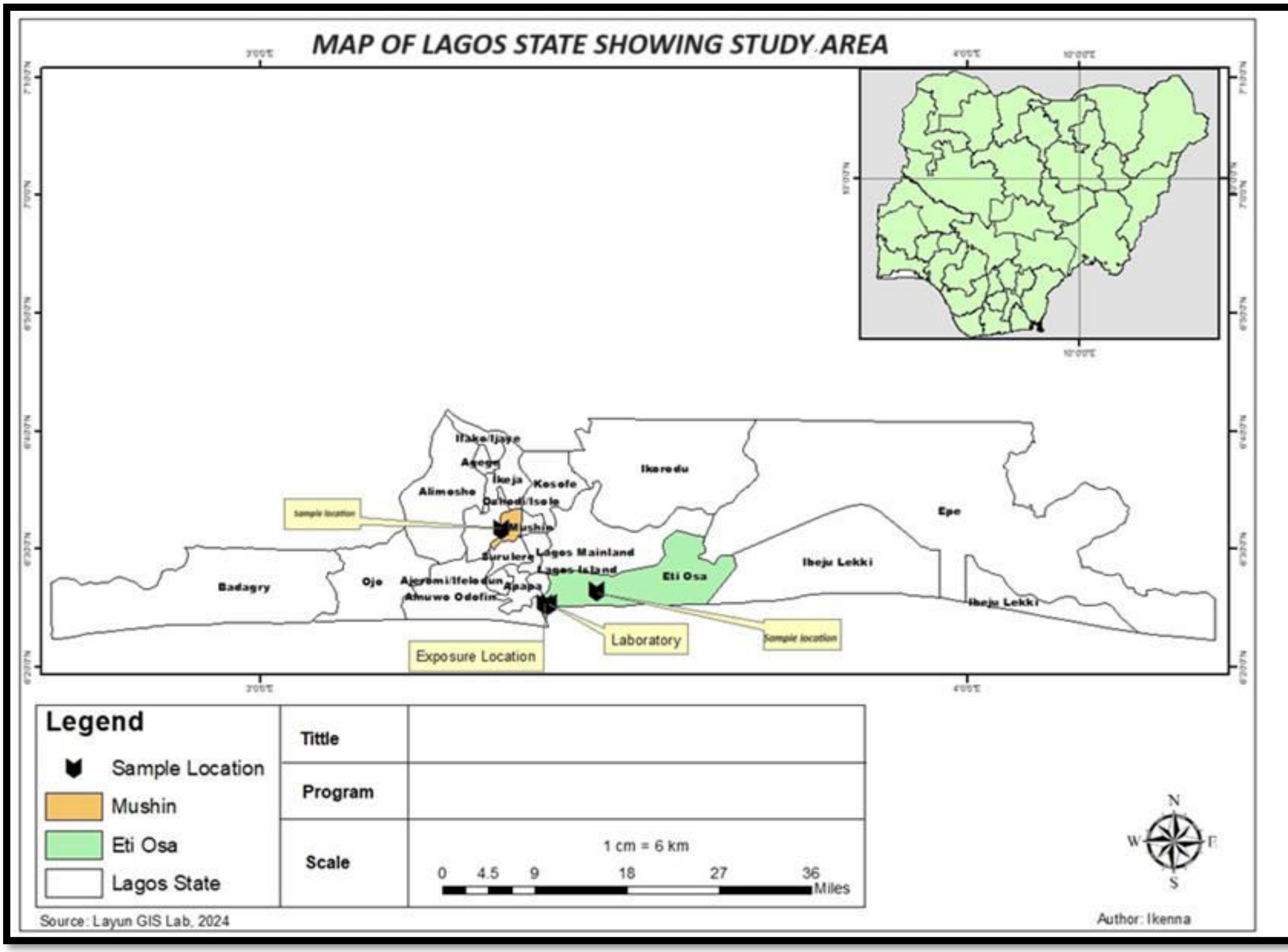

Figure 1: Map showing Study area

Source: ArcGIS(2024)

3.1 Calculation of PCB concentration from the Chromatogram

PCB Result(ng/ml) = (Final GC Result x Volume Factor) / (Volume of Result x 1000) (1)

Volume factor = 1500 uL
Volume of samples = 100ml
Final GC Result in ng/ ul

To convert to PCB Result (ng/ml) to mg/l
1 ng/ml = 0.001 mg/l, the final result will be divided by 1000

3.2 Estimation of Health Risk Assessment of PCBs in Water samples

The carcinogenic and Non carcinogenic risk of the PCB concentration observed in the water samples was calculated based on the formular in equations 2 and 3 respectively (USEPA, 2005 and Cui, 2020). The results and interpretation are also shown in Table 5 and 6.

CR = Cancer risk
HQ= Hazard Quotient
HI = Hazard Index = ∑HQ = non-cancer risk
CR= (C x IR x EF x SF/BW x AT) (2)
HI = (C x IR x EF x ED/ BW x AT x RfD) (3)

C = PCB Concentration in mg/L
IR = daily drinking volume in L/day(1.85L for Adult and 1.5 for Children)
SF = carcinogenic slope factor(2kg d/mg)
ED = Exposure duration in years(70 for Adult and 12 for Children)
EF = Exposure Frequency in days/years(365 days/year)
BW = Body Weight in kg(60kg for Adult and 35 for Children)
AT = Average Time (70 x 365 = 25550days for adults and 12 x 365 = 4380days)
RFD = Exposure dose (0.02mg/day kg)

3.3 Reagents

(a) Analar grade Acetone and Dichloromethane (DCM) were purchase from Fisher Scientific U.K Limited
(b) Accustandard Certified PCBs External Standard Mix: 1mL ×10μg/mL in Isooctane was purchased from Accustandard Inc USA and constituted of PCB 8, PCB 18. PCB 28, PCB 44, PCB 52, PCB 60, PCB 77, PCB 101, PCB 81, PCB 105, PCB 118, PCB 123, PCB 126, PCB 138, PCB 153, PCB 156, PCB 157, PCB 167, PCB 169, PCB 170, PCB 180, PCB 185, PCB 189, PCB 195 and PCB 206

3.4 Quality Control and Data Analysis

Method blanks were prepared and analyzed to measure the response of the Gas Chromatograph to the analyte at a theoretical concentration of zero. Statistical Package for Social Sciences (IBM SPSS Statistics 27) was employed for the statistical analyses while Microsoft Excel and Words 2021 were also used for collation and arrangement of data.

4. Results and Discussion

The matrix in Table 1 shows an overview of the PCBs reported during this study of plastic bottle water exposed to sunlight over the period of 3 months. Interestingly, out of the 20 PCB congeners observed during the study period, only PCB 8, 18, 28, 44, 52, 60 and PCB 81 were detected in the water samples prior to exposure (baseline) to sunlight while the other congeners, PCB 77, 101, 105, 118, 123, 126, 138, 156, 157, 170, 180, 185 and 206 were formed during the exposure period. The PCBs observed were similar to the congeners detected in the study by Okoh et al(2022) where 28 PCB congeners were analyzed and 8 PCBs 28, 44, 52, 180, 187, 189, 206 and 209 were not detected in water source in Wupa river in Abuja unlike the study by Eze et al. (2023) were 28 PCBs were studied and all were detected. This result shows that PCBs are becoming more prevalent in the environmental media which supports the findings of various researches especially that of UNEP (2023). Also on the other hand, PCBs 114, 153, 167, 169, 189, 195, and 209 were not detected in any of the samples after exposure. Additionally, the detected PCBs observed in the baseline samples were all lower chlorinated PCBs, the presence of the PCBs in the baseline samples could be attributed to the water source, storage of the water collected (which are mostly stored in Plastic Tanks) and PCBs at the surface of the plastic bottle before collection. Moreover, the presence of dl-PCB PCB 81, raises some concerns due to the risk of cancer.

Table1: Photodegradation Matrix of PCB congeners during the 3 months of exposure (2024)

Chemical	**Number**	**Name**	**Comments**	**0 (Baseline)**	**20 days**	**50 days**	**80 days**
PCB	8	2,4'-Dichlorobiphenyl		D	D	D	D
PCB	18	2,2',5-Trichlorobiphenyl		D	D	D	D
PCB	28	2,4,4'-Trichlorobiphenyl		D	D	D	D
PCB	44	2,2',3,5'-Tetrachlorobiphenyl		D	D	D	D
PCB	52	2,2',5,5'-Tetrachlorobiphenyl		D	D	D	D
PCB	60	2,3,4,4'-Tetrachlorobiphenyl		D	D	D	D
PCB	77	3,3',4,4'-Tetrachlorobiphenyl	Dioxin-like substance	ND	ND	ND	D
PCB	101	2,2',4,5,5'-Pentachlorobiphenyl		ND	D	D	ND

Chemical	Number	Name	Comments	0 (Baseline)	20 days	50 days	80 days
PCB	81	3,4,4',5-Tetrachlorobiphenyl	Dioxin-like substance	D	D	D	D
PCB	105	2,3,3',4,4'-Pentachlorobiphenyl	Dioxin-like substance	ND	ND	ND	D
PCB	114	2,3,4,4',5-Pentachlorobiphenyl	Dioxin-like substance	ND	ND	ND	ND
PCB	118	2,3',4,4',5-Pentachlorobiphenyl	Dioxin-like substance	ND	ND	ND	D
PCB	123	2,3',4,4',5'-Pentachlorobiphenyl	Dioxin-like substance	ND	ND	ND	D
PCB	126	3,3',4,4',5-Pentachlorobiphenyl	Dioxin-like substance	ND	ND	ND	D
PCB	138	2,2',3,4,4',5'-Hexachlorobiphenyl		ND	ND	ND	D
PCB	153	2,2',4,4',5,5'-Hexachlorobiphenyl		ND	ND	ND	ND
PCB	156	2,3,3',4,4',5-Hexachlorobiphenyl	Dioxin-like substance	ND	D	D	D
PCB	157	2,3,3',4,4',5'-Hexachlorobiphenyl	Dioxin-like substance	ND	ND	ND	D
PCB	167	2,3',4,4',5,5'-Hexachlorobiphenyl	Dioxin-like substance	ND	ND	ND	ND
PCB	169	3,3',4,4',5,5'-Hexachlorobiphenyl	Dioxin-like substance	ND	ND	ND	ND
PCB	170	2,2',3,3',4,4',5-Heptachlorobiphenyl		ND	ND	D	D
PCB	180	2,2',3,4,4',5,5'-Heptachlorobiphenyl		ND	D	D	D
PCB	185	2,2',3,4,5,5',6-Heptachlorobiphenyl		ND	ND	ND	D
PCB	189	2,3,3',4,4',5,5'-Heptachlorobiphenyl	Dioxin-like substance	ND	ND	ND	ND
PCB	195	2,2',3,3',4,4',5,6-Octachlorobiphenyl		ND	ND	ND	ND
PCB	206	2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl		ND	ND	D	ND

Chemical	Number	Name	Comments	0 (Baseline)	20 days	50 days	80 days
PCB	209	Decachlorobiphenyl		ND	ND	ND	ND

D - Detected, ND – Non detected

Furthermore, from a toxicity perspective, Table 2shows the percentage of dl-PCBs compared with the Total PCB concentration measured while highlighting the mean concentration of PCBs observed in the water samples over a period of 3 months. The results show that while the Total PCB in the baseline samples constituted of 42% of dl-PCBs, the Total PCB concentration observed during the 3 months of exposure in April, May and June constituted of 58%, 72%, and 9% of the dl-PCBs respectively. The comparison further highlights the complexity and persistence of PCBs in the environment while spotlighting the likely risk of exposure to sunlight. the mean concentration of PCBs observed in the water samples over a period of 3 months.

Table 2: Mean concentration of PCBs in plastic bottle water exposed to sunlight in Lagos state (2024)

Concentrations mg/l				
PCB Congener	**Baseline**	**April**	**May**	**June**
PCB 8	0.000514	0.000456	0.000178	0.000344
PCB 18	0.001415	0.000780	0.000521	0.000484
PCB 28	0.002107	0.003209	0.003473	0.002639
PCB 44	0.001979	0.002886	0.003318	0.000450
PCB 52	0.001240	0.000476	0.000296	0.000411
PCB 60	0.000262	0.000078	0.000105	0.000462
PCB 77	0.000000	0.000000	0.000000	0.000015
PCB 101	0.000000	0.000761	0.000124	0.000000
PCB 81	0.005516	0.011358	0.020066	0.000122
PCB 105	0.000000	0.000000	0.000000	0.000050
PCB 114	0.000000	0.000000	0.000000	0.000000
PCB 118	0.000000	0.000000	0.000000	0.000044
PCB 123	0.000000	0.000000	0.000000	0.000074
PCB 126	0.000000	0.000000	0.000000	0.000174
PCB 138	0.000000	0.000000	0.000000	0.000005
PCB 153	0.000000	0.000000	0.000000	0.000000
PCB 156	0.000000	0.000434	0.000682	0.000006
PCB 157	0.000000	0.000000	0.000000	0.000003
PCB 167	0.000000	0.000000	0.000000	0.000000
PCB 169	0.000000	0.000000	0.000000	0.000000
PCB 170	0.000000	0.000000	0.000041	0.000103
PCB 180	0.000000	0.000007	0.000032	0.000079
PCB 185	0.000000	0.000000	0.000000	0.000005
PCB 189	0.000000	0.000000	0.000000	0.000000
PCB 195	0.000000	0.000000	0.000000	0.000000
PCB 206	0.000000	0.000000	0.000139	0.000000
PCB 209	0.000000	0.000000	0.000000	0.000000
Total PCB	0.013033423	0.020164966	0.028975373	0.005468
Total DL PCB	0.005516404	0.011791935	0.020747919	0.000488389
% DL PCB in samples	42%	58%	72%	9%

4.1PCB concentration after exposure to Sunlight

The paired samples t- test result in Table 3showed statistically significant changes in several PCB congeners after sunlight exposure. Specifically, Total PCB, PCB 28,

PCB 44, PCB 101, PCB 81, PCB 156, PCB 170, and PCB 180 show significant reductions, indicating that sunlight exposure effectively reduces the concentrations of these congeners in water samples, likely through photodegradation. Conversely, PCB 8, PCB 52, and PCB 18 exhibit significant increases, suggesting that these congeners may be formed or released during exposure, potentially due to the breakdown of more complex PCBs or possible leaching from the plastic bottles. Other congeners such as PCB 60, PCB 77, PCB 105, PCB 118, PCB 123, PCB 126, PCB 138, PCB 157, PCB 185, and PCB 206 do not show statistically significant changes, indicating that sunlight exposure does not significantly impact their concentrations. These findings highlight the complexity of PCB behavior under sunlight exposure, with some congeners being reduced while others are increased.

Additionally, the complexity of PCB congeners existence in environmental media cannot be overlooked with several research reporting emergence of both low and high chlorinated PCBs in environmental media. For instance, Iniaghe (2022) reported PCB 167 as the most abundant PCB congener with a concentration of 0.0018mg/l in Niger Delta water source, compared to this research where PCB 167 was not detected during exposure and analysis of the samples. Also, Salinas et al (2010) in their study where they investigated the presence of 7 PCB concentration in plastoc bottle water in Mexico reported range of PCB 28, 52 and 101 as the most dominant which is similar to the current study where PCB 28 and 44 were the most dominant PCB observed followed by PCB 18, 8 and 52. This assertion corroborates with that reported in the study in Mexico (Salinas et. 2010). The findings align with the findings of Megson et al. (2024) and UNEP (2023) which highlighted the emergence of newly or unintentional produced PCBs rather than the previous assumption that PCBs in the environment were legacy PCBs.

Table 3: Result of Paired Samples T-Test of PCB concentration in the water samples prior to exposure to sunlight and after exposure to sunlight in Lagos

PCB(mg/l)	Paired Sample T-test Paired Differences					T	Df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Total PCB (Before) - Total PCB (After)	-0.005169	0.006185	0.000875	-0.006927	-0.003412	-5.9100	49	<0.001

PCB(mg/l)	Paired Sample T-test Paired Differences					T	Df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
PCB 8 (Before) - PCB 8 (After)	0.000188	0.000153	0.000022	0.000144	0.000231	8.6820	49	<0.001
PCB 18 (Before) - PCB 18(After)	0.000932	0.001303	0.000184	0.000561	0.001302	5.0570	49	<0.001
PCB 28 (Before) - PCB 28 (After)	-0.001000	0.001128	0.000160	-0.001320	-0.000679	-6.2660	49	<0.001
PCB 44 (Before) - PCB 44 (After)	-0.000239	0.000820	0.000116	-0.000472	-0.000006	-2.0620	49	0.05
PCB 52 (Before) - PCB 52 (After)	0.000846	0.000853	0.000121	0.000604	0.001088	7.0140	49	<0.001
PCB 60 (Before) - PCB 60 (After)	0.000047	0.000374	0.000053	-0.000060	0.000153	0.8840	49	0.38
PCB 77 (Before) - PCB 77 (After)	-0.000005	0.000027	0.000004	-0.000013	0.000003	-1.3220	49	0.19
PCB 101 (Before) - PCB 101 (After)	-0.000295	0.000896	0.000127	-0.000549	-0.000040	-2.3270	49	0.02
PCB 81 (Before) - PCB 81 (After)	-0.004999	0.004089	0.000578	-0.006161	-0.003837	-8.6440	49	<0.001

PCB(mg/l)	Paired Sample T-test Paired Differences					T	Df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
PCB 105 (Before) - PCB 105 (After)	-0.000017	0.000119	0.000017	-0.000051	0.000017	-1.0000	49	0.32
PCB 118 (Before) - PCB 118 (After)	-0.000015	0.000104	0.000015	-0.000044	0.000015	-1.0000	49	0.32
PCB 123 (Before) - PCB 123 (After)	-0.000025	0.000168	0.000024	-0.000072	0.000023	-1.0350	49	0.31
PCB 126 (Before) - PCB 126 (After)	-0.000058	0.000392	0.000055	-0.000169	0.000054	-1.0430	49	0.30
PCB 138 (Before) - PCB 138 (After)	-0.000002	0.000012	0.000002	-0.000005	0.000002	-1.0000	49	0.32
PCB 156 (Before) - PCB 156 (After)	-0.000374	0.000246	0.000035	-0.000444	-0.000304	-10.7400	49	<0.001
PCB 157 (Before) - PCB 157 (After)	-0.000001	0.000008	0.000001	-0.000003	0.000001	-1.0000	49	0.32
PCB 170 (Before) - PCB 170 (After)	-0.000048	0.000113	0.000016	-0.000080	-0.000016	-3.0000	49	0.00
PCB 180 (Before) - PCB 180 (After)	-0.000039	0.000126	0.000018	-0.000075	-0.000003	-2.1950	49	0.03

PCB(mg/l)	Paired Sample T-test Paired Differences					T	Df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
PCB 185 (Before) - PCB 185 (After)	-0.000002	0.000011	0.000002	-0.000005	0.000002	-1.0000	49	0.32
PCB 206 (Before) - PCB 206 (After)	-0.000046	0.000230	0.000033	-0.000112	0.000019	-1.4280	49	0.16

4.2 Comparison with USEPA recommended limit for PCB in water

The result (Table 4) suggests that the mean concentrations of several PCB congeners in bottled water exposed to sunlight in Lagos State differ significantly from the USEPA permissible limit of 0.0005 mg/l. Specifically, the total PCB levels and most individual congeners showed a significant decrease below the USEPA permissible limit, indicating effective degradation under sunlight exposure. This supports the hypothesis that sunlight can serve as a natural remediation method for PCB-contaminated water bodies.

However, certain congeners like PCB 28, PCB 44, and PCB 81 exhibited mean concentrations exceeding the USEPA permissible limit post-exposure, suggesting persistence or even an increase in concentration. It is good to note that from the analysis, PCB 18 had concentrations slightly above the USEPA permissible limit after exposure, however at $p=0.057$, the result is marginally non-significant. Interestingly, PCB 52, PCB 101, and PCB 156 showed no significant difference from the USEPA permissible limit, indicating possible stability under sunlight exposure. Eze et al. (2023) reported PCB 118 with the highest concentration of 0.00008858mg/L and PCB 157 with the lowest concentration in their study on surface water in Imo state while in the present study PCB 118 and 157 were only observed after 3 months of exposures (in June 2024). Both studies recorded both PCB congeners to be below USEPA permissible limit.

During the research, there was an expectation that PCB levels in the water samples collected before exposure(baseline) to sunlight will be 0mg/l or non-detected, which was not the case and even if there were traces it was not expected that PCB 81 which is a dioxin like PCB, would be observed in the baseline water sample. The concentration observed in the baseline samples could be an indication of contamination from water source, storage or treatment of water at the Water Corporation Facility. Especially the fact that most of the pipelines are made from plastic materials such as PVC. PCB 8, 18, 28, 44, 52, 60 and 81 were observed across the samples throughout the exposure period and according to the Salina et al(2010), PCB 28 is usually found in significant concentrations due to its lower chlorination, making it more soluble in water, which corroborates with what was observed in this study where PCB 28 was observed in all the samples with mean concentration 0.00311 ± 0.00111mg/l as well as PCB 44 with mean concentration of 0.00222 ± 0.00087mg/l. Eze et al.(2023) reported PCB 118 with the highest concentration of 0.00008858mg/L and PCB 157 with the lowest concentration in their study on surface water in Imo state while in the present study PCB 118 and 157 were only observed after 3 months of exposures(in June 2024). Both studies recorded both PCB congeners to be below USEPA permissible limit.

Table 4: One-Sample Test of the difference in the mean concentration of PCBs leached in stored packaged bottled water exposed to sunlight in Lagos State with USEPA's permissible limit for PCBs in drinking water

One-Sample Test						
	Test Value = 0.0005mg/l					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
PCB 8 (After)	-8.053	49	<0.001	-0.000174	-0.000217	-0.000130
PCB 18 (After)	1.948	49	0.057	0.000095	-0.000003	0.000193
PCB 28 (After)	16.645	49	<0.001	0.002607	0.002292	0.002922
PCB 44 (After)	14.106	49	<0.001	0.001718	0.001473	0.001963
PCB 52 (After)	-1.641	49	0.107	-0.000106	-0.000235	0.000024
PCB 60 (After)	-6.996	49	<0.001	-0.000285	-0.000367	-0.000203
PCB 77 (After)	-131.2	49	<0.001	-0.000495	-0.000503	-0.000487
PCB 101 (After)	-1.620	49	0.112	-0.000205	-0.000460	0.000049
PCB 81	16.75	49	<0.001	0.010015	0.008814	0.011217

One-Sample Test						
	Test Value = 0.0005mg/l					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
(After)	4					
PCB 105 (After)	-28.71	49	<0.001	-0.000483	-0.000517	-0.000449
PCB 118 (After)	-32.96	49	<0.001	-0.000485	-0.000515	-0.000456
PCB 123 (After)	-19.96	49	<0.001	-0.000475	-0.000523	-0.000428
PCB 126 (After)	-7.967	49	<0.001	-0.000442	-0.000554	-0.000331
PCB 138 (After)	-304.3	49	<0.001	-0.000498	-0.000502	-0.000495
PCB 156 (After)	-3.619	49	0.001	-0.000130	-0.000200	-0.000100
PCB 157 (After)	-450.9	49	<0.001	-0.000499	-0.000501	-0.000497
PCB 170 (After)	-28.35	49	<0.001	-0.000452	-0.000484	-0.000420
PCB 180 (After)	-25.80	49	<0.001	-0.000461	-0.000497	-0.000425
PCB 185 (After)	-308.1	49	<0.001	-0.000498	-0.000502	-0.000495
PCB 206 (After)	-13.93	49	<0.001	-0.000454	-0.000519	-0.000388

5. Human Health Risk Assessment

The results of the Non-Cancer health risk assessment for adults was estimated at 0.01379 as shown in Table 5. The Health Index(HI) results were below 1 which shows that there is a low risk of non-cancer health risk if the water is ingested by both adult while a Lifetime Cancer Risk of 0.00001for adult was estimated based on the PCB concentrations as shown in Table 5.

Table 5: Cancer (CR) and Non-Cancer Risk (HI) for adults exposed to the PCB concentrations in this study

PCB Congeners	Name	CR	HI
PCB 77	3,3',4,4'-Tetrachlorobiphenyl	0.00000	0.00001

PCB Congeners	Name	CR	HI
PCB 81	3,4,4',5-Tetrachlorobiphenyl	0.00001	0.01314
PCB 105	2,3,3',4,4'-Pentachlorobiphenyl	0.00000	0.00002
PCB 114	2,3,4,4',5-Pentachlorobiphenyl	0.00000	0.00000
PCB 118	2,3',4,4',5-Pentachlorobiphenyl	0.00000	0.00002
PCB 123	2,3',4,4',5'-Pentachlorobiphenyl	0.00000	0.00003
PCB 126	3,3',4,4',5-Pentachlorobiphenyl	0.00000	0.00007
PCB 156	2,3,3',4,4',5-Hexachlorobiphenyl	0.00000	0.00050
PCB 157	2,3,3',4,4',5'-Hexachlorobiphenyl	0.00000	0.00000
PCB 167	2,3',4,4',5,5'-Hexachlorobiphenyl	0.00000	0.00000
PCB 169	3,3',4,4',5,5'-Hexachlorobiphenyl	0.00000	0.00000
PCB 189	2,3,3',4,4',5,5'-Heptachlorobiphenyl	0.00000	0.00000
	Total	0.00001	0.01379

The results of the Non-Cancer health risk assessment for the children was estimated at 0.02365 as shown in Table 6.The Health Index(HI) results was below 1 which shows that there is a low risk of non-cancer health risk if the water is ingested by children while the Lifetime Cancer Risk of 0.00008 for children was estimated based on the PCB concentrations as shown in Table 6.

Table 6: Cancer (CR) and Non-Cancer Risk/Hazard Index (HI) for Children (Ages 1 -12 years) exposed to the PCB concentrations in this study

PCB Congeners	Name	CR	HI
PCB 77	3,3',4,4'-Tetrachlorobiphenyl	0.00000	0.00001
PCB 81	3,4,4',5-Tetrachlorobiphenyl	0.00008	0.02253
PCB 105	2,3,3',4,4'-Pentachlorobiphenyl	0.00000	0.00004
PCB 114	2,3,4,4',5-Pentachlorobiphenyl	0.00000	0.00000
PCB 118	2,3',4,4',5-Pentachlorobiphenyl	0.00000	0.00003
PCB 123	2,3',4,4',5'-Pentachlorobiphenyl	0.00000	0.00005
PCB 126	3,3',4,4',5-Pentachlorobiphenyl	0.00000	0.00012
PCB 156	2,3,3',4,4',5-Hexachlorobiphenyl	0.00000	0.00086
PCB 157	2,3,3',4,4',5'-Hexachlorobiphenyl	0.00000	0.00000
PCB 167	2,3',4,4',5,5'-Hexachlorobiphenyl	0.00000	0.00000
PCB 169	3,3',4,4',5,5'-Hexachlorobiphenyl	0.00000	0.00000
PCB 189	2,3,3',4,4',5,5'-Heptachlorobiphenyl	0.00000	0.00000
	Total	0.00008	0.02365

However, it is good to note that the HI for the children was higher than that of the adult which is expected as children are more prone to more impact when they are exposed to contaminants as a result of their developing immune system and organs. The health risk assessment results also show that for an adult, there is an estimated 1 in 100,000 chances of developing cancer through ingestion of the water over a lifetime while there is 1 in 12,5000 chances of health impact due to cancer for the children when the water contaminated with the concentrations observed in this study, is ingested. The cancer risk for the adult seems to be negligible/non -significant. when compared with the recommended limit by US EPA(1996) of range 0.0001 – 0.000001, however, when compared with the cancer risk estimated for the children, the result shows that children are more likely to develop cancer when the water is ingested when compared with the adults. Several studies have recently reported the prevalence of PCBs in water sources and have highlighted the cancer and non-cancer health risk associated with ingestion of water contaminated with PCBs while also spotlighting the increased risk in children (Ibor et al.2023; Folarin et al. 2024; Eze et al. 2023

The health risk assessment of the PCB concentrations recorded in this study indicates a low cancer risk for both adult and children which aligns with previous studies in addition to the study by Liu et al. (2024) which also highlighted the health risk associated with exposing plastic bottle to sunlight, however, considering the elevated risk in children, there is a need to carry out further study and continuous monitoring of drinking water sources and water sold/stored in plastic bottles.

6. Conclusion

Notwithstanding the limitations of the study which include but not limited to funding, limitations in the sample size due to pipe borne water source in most locations being under maintenance, this study highlights the significant impact of sunlight in the degradation of PCB congeners in plastic bottle water exposed to sunlight in Lagos, Nigeria, the findings demonstrate the persistence and complexity of different PCB congeners present in water samples, where the congeners reacted differently in water after exposure to sunlight.

The purpose of this study was to investigate whether PCBs were present in bottle water before and after exposure to sunlight and if there were traces, whether the concentrations will be above USEPA permissible limit of 0.0005mg/l. The study reported PCB concentration in both baseline samples and samples exposed to sunlight while some of the samples also recorded concentrations higher than USEPA permissible limit.

This study highlights the significant impact of sunlight in the degradation of PCB congeners in plastic bottle water exposed to sunlight in Lagos, Nigeria, the findings demonstrate the persistence and complexity of different PCB congeners present in water samples, where the congeners reacted differently in water after exposure to sunlight. While some congeners degraded when exposed to sunlight some were stable after sunlight exposure. Furthermore, the study showed the presence of PCBs in pipe borne water samples collected in plastic bottle water before the samples were exposed to sunlight. The presence of PCB in the water sample before exposure to sunlight can be attributed to the source of the pipe borne water and the plastic. The observations in the study suggests that asides the degradation of the 7 PCB congeners observed in the baseline samples, the increase in their concentration and the quantitative evidence of the formation of 13 more PCBs during exposure to sunlight links to possible leaching from the plastic PET bottles. The findings in particular highlighted that the mean concentrations of PCB 28, PCB 44 and PCB 81(a dl-PCB) were above USEPA permissible limit of 0.0005mg/l for water. Moreover, the health risk assessment of the concentrations observed showed a low risk for cancer or non-cancer related diseases, however, based on the CR and HQ, the children are more at risk than the adults.

The results of this study underscore the importance of proper storage practices for bottled water, particularly in regions with high solar radiation, to ensure consumer safety. Additionally, the study provides valuable insights into the natural remediation processes of PCBs, contributing to the broader understanding of environmental remediation strategies. Future research should focus on investigating the actual temperatures at which degradations occur for the different PCB congeners while examining PCB degradation on other types of plastics. Overall, this research offers a foundation for developing guidelines and policies aimed at reducing PCB contamination in drinking water, ultimately protecting public health and the environment.

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