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Research Article

Determination of Polychlorinated Biphenyls in Soils and Industrial Effluents and Health Risks Assessment in Uyo, Akwa Ibom State, Nigeria

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About Article

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ABSTRACT

Polychlorinated biphenyls (PCBs) are persistent organic pollutants that are ubiquitous in nature and are available in all environmental components, and are implicated as being carcinogenic. In this study, the levels of PCBs were evaluated in soils and effluent water obtained from an industrial area in Uyo Local Government Area, Akwa Ibom State, Nigeria. The work also assessed the possible relationship between the parameters and risks posed by polychlorinated biphenyls via several pollution indices. A total of four (4) Soil and effluent samples were collected during the rainy season and analysed using USEPA Method 8082 and gas chromatography–mass spectrometry (GC–MS). The concentrations of total PCBs in the soil samples were: Soil1 (∑ PCBs 234.447 ug/kg), Soil 2 (∑ PCBs 216.000ug/kg), Soil 3 (∑ PCBs 195.375 ug/kg), and Soil 4 (∑ PCBs 197.948 ug/kg). The concentrations of total PCBs in the effluent water sample were ∑ 52.99 ug /L. These values were relatively low compared to the guideline limit of 500 µg/kg and those reported in the literature. The toxic equivalency quotient (TEQ) calculated for the samples was Soil1 (0.281 ug/kg), Soil 2 (0.231 ug/kg), Soil 3 (0.252 ug/kg) and Soil 4 (0.217 ug/kg). The toxic equivalency quotient (TEQ) for the water effluent was 0.176 ug/L. The TEQ values obtained were all less than 1, indicating that the levels of PCBs are not yet of toxicity concern to both biota and humans in the study area.

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1. INTRODUCTION

Persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs) are very ubiquitous in nature as a result of their volatility, increase in sources of production and mechanism of migration across the environmental components (Wania *et al.*, 2006; Ernesto *et al.*, 2021). More than three decades ago, there was a drastic increase in the sources of PCBs (Kallenborn *et al.*, 2015; Kosek & Ruman, 2021). Across the world, the use of PCBs has been banned in many countries, but their presence is still on the increase in the environment due to indiscriminate dumping of e-wastes (electronics wastes), burning of materials containing PCBs and accidental spillage of oil, which migrates into the water bodies via runoffs from rains into the dredged river (Okpoji *et al.*, 2025). In addition to their persistent nature, they are bioaccumulative across the food chain, which calls for the need for constant monitoring of the environment (Eyenubo *et al.*, 2024; Anarado *et al.*, 2023).

Polychlorinated biphenyls (PCBs) are a group of synthetic organic chemicals (Figure 1) that consist of 209 individual compounds known as congeners (Ekwere *et al.*, 2025). These chemicals gained widespread industrial use due to their chemical stability, high boiling points, and electrical insulating properties. Manufactured from the 1920s until their ban in many countries in the late 1970s and 1980s, PCBs were used in a variety of industrial applications, including as coolants and lubricants in transformers, capacitors, and other electrical equipment (John *et al.*, 2025; Aghanwa *et al.*, 2025).

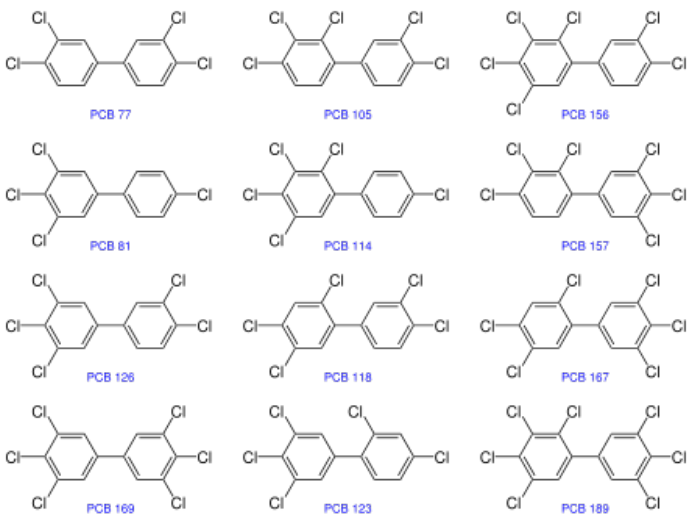

Figure 1. Polychlorinated biphenyls congeners.

The presence of PCBs in industrial areas is particularly of concern due to their persistence in the environment and their ability to accumulate in the food chain (Thompson, 2023; Kallenborn *et al.*, 2015; Megson *et al.*, 2024). In industrial settings, PCBs can be released into the environment through leaks and improper disposal of equipment containing PCBs. Additionally, the incineration of waste materials containing PCBs and the disposal in landfills can lead to further environmental contamination.

In response to their toxicity and persistence, strict regulations have been put in place to manage and reduce PCB contamination in industrial and other areas. These regulations include the management of existing PCB-containing equipment, the cleanup of contaminated sites, and restrictions on the disposal of PCBs to prevent further environmental contamination (Eyenubo *et al.*, 2024)

Despite these efforts, PCBs continue to pose a significant challenge in industrial areas due to their historic use and ongoing presence in older equipment and materials. Cleanup and mitigation efforts require careful management and ongoing monitoring to protect human health and the environment (Umueni *et al.*, 2025; Ekpe *et al.*, 2025). The toxicity of PCBs is well-documented, posing significant health risks to humans and wildlife. Exposure to PCBs is linked to several adverse health effects, including cancer, immune system suppression, liver damage, skin conditions like chloracne, and developmental problems in children (Okagbare *et al.*, 2025). The chemicals can affect the endocrine system and have been shown to act as endocrine disruptors, interfering with hormonal functions (USEPA, 2011).

PCBs are classified as probable human carcinogens by the International Agency for Research on Cancer (IARC). Long-term exposure to PCBs has been associated with increased risks of cancers, particularly melanoma, liver cancer, and gallbladder cancer. Studies have consistently shown a strong correlation between PCB exposure and elevated rates of certain cancers, especially among industrial workers who have handled these chemicals (Stewart *et al.*, 2000; ATSDR, 1997).

Exposure to PCBs can have adverse effects on the nervous system, including cognitive and motor function impairments. There is evidence to suggest that PCBs disrupt neurological function, potentially leading to learning disabilities and memory problems (World Bank, 2014; IARC, 2015).

The contamination level of PCBs in the aquatic environment is alarming, and it has become a global problem (Kosek & Ruman, 2021; Ekwere *et al.*, 2025). Despite the disastrous effect of PCB contamination in the ecosystem across the world, there has been little investigation of PCBs in dredged tributaries, creeks and industrial areas in Akwa Ibom State, Nigeria.

Across the globe, the use of PCBs has been banned in many countries, but their presence is still on the increase in the environment due to indiscriminate dumping of e-wastes (electronics wastes), burning of materials containing PCBs and accidental spillage of oil, which migrates into the water bodies via runoffs from rains into the dredged river (Onoja *et al.*, 2025). In addition to their persistent nature, they are bioaccumulative across the food chain, which calls for the need for constant monitoring of the environment (Eyenubo *et al.*, 2024; Lu *et al.*, 2016). This study, therefore, investigates the occurrence and distribution of PCB congeners in soils and industrial effluent from an industrial area during the rainy season in Uyo Local Government Area, Akwa Ibom State.

2. LITERATURE REVIEW

Polychlorinated biphenyls (PCBs) are synthetic chlorinated aromatic chemicals that are widely recognised as persistent organic pollutants (POPs) due to their hydrophobicity, chemical stability, and resistance to biotic and abiotic degradation (Ekpe

et al., 2025; Ekesiobi *et al.*, 2025). Despite global restrictions and bans initiated more than three decades ago, PCBs remain ubiquitous across environmental media, including soils, sediments, surface waters, and industrial effluents (John *et al.*, 2025; Ogbaji *et al.*, 2025). Their persistence is attributed to slow degradation rates, strong affinity for organic matter, and the capacity for long-range atmospheric and hydrological transport (Wania *et al.*, 2006; Ernesto *et al.*, 2021).

3. METHODOLOGY

3.1. The Study Area

The study was conducted in the Uyo Local Government Area of Akwa Ibom State, South South Nigeria. The geographical location of the study area across the industrial area of Uyo is Latitude 50 47′17′′ N. Longitude 60 4 ′49′′ E, Latitude 50 47′11′′ (Figure 2). Much rainfall is observed in the study area, which ranges from 1600 – 2300 mm and covers from April – September (wet season) with a temperature range of 30 – 35 °C (maximum) and 20 – 23 °C (minimum) in the dry season which covers October – March in most cases. There are several economic activities like fishing, wildlife hunting, industrial activities and agriculture in the study area, as shown in Figure 2.

Figure 2. Map of sampling locations.

3.2. Materials and Reagents

The materials and reagents required for the study were deionised water, 250 ml volumetric flask (10 pieces), 100 ml volumetric flask (10 pieces), 250 ml glass beakers (10 pieces) 100 ml glass beakers (10 pieces), Rotary Evaporator: BUCHI Rotavapor R-215 (Switzerland), dichloromethane, Separatory Funnel [500mL], Microwave Assisted Extractor [with Florisil SPE Cleanup], anhydrous sodium sulfate,100mL disposable glass vials (20 pieces), hexane (analar grade), acetone (analar grade), Agilent 7890B Gas chromatograph, Agilent 5977B Mass Spectrometer and Agilent 7693 Automatic Liquid Sampler.

3.3. Collection of Samples and Preparation

Four soil samples were collected in black glass bottles from the designated locations within the study area during the rainy season (July – September, 2024). One wastewater sample as effluent was collected from an industrial establishment located within the study area in a dark glass bottle during the rainy season (July – September, 2024). The samples were transported to the Laboratory in ice-cooled coolers for analysis. The soil samples were air dried, ground, and sieved with a 2 mm mesh sieve according to a previous method (Montour *et al.*, 2020) and stored in vialed bottles.

3.4. Extraction of Soil Samples and Cleanup for PCBs

Extraction was carried out with Milestone Ethos X Microwave Extractor fitted with a fastEX-24 rotor. 5g of each sample was weighed and thoroughly mixed with anhydrous sodium sulfate. Samples were then transferred into 100 mL disposable glass vials of the fastEX-24 rotor. 20 mL of acetone-hexane (1:1) solvent mixture was mixed with the samples (Andrianova & Quimby, 2019). The microwave extraction programme consisted of 15 minutes at up to 1600 W and 110 °C, followed by an additional 10 minutes at the same conditions. The extracts were cooled and filtered before cleanup. Cleanup was performed using Florisil SPE cartridges. Each cartridge was preconditioned with 4 mL n-hexane. Two millilitres of concentrated extract were loaded onto the cartridge. PCBs were eluted using 4 mL n-hexane, and the eluate was concentrated to 2 mL using nitrogen blowdown or rotary evaporation.

3.5. Extraction of PCBs from Effluent Water

Measured 250 ml of the effluent water sample was transferred to a separatory funnel, 15 ml of dichloromethane was added, and the lid was closed with a stopper. The separatory funnel was shaken vigorously for about 5 minutes and periodically vent the funnel to release built-up pressure. The mixture was allowed to settle until two clear layers were formed: The aqueous layer (upper) and the organic layer (lower) containing the extracted analytes. The stopcock was carefully ed to drain the bottom (organic) layer into a clean beaker. The extraction process was repeated two more times with fresh solvent (10 mL dichloromethane each time) to maximise recovery. The extracts were collected into the same beaker and concentrated to 2 ml using a rotary evaporator.

3.6. Determination of PCB congener

PCBs determination was done on soils and effluent samples with the help of an Agilent 7890B Gas chromatograph with an Agilent 5977B Mass Spectrometer D System equipped with a split/splitless inlet and an Agilent 7693 Automatic Liquid Sampler for the analysis. The column was made up of a fused silica capillary, a 30 m DB–1 ms (100% dimethyl siloxane) (Cj & W Scientific, CA, USA) (0.25 mm i.d. x 0.25 µm of the thickness of film). The temperature of the oven was initially programmed at 100 °C (standing for 1 min) – 325 °C at the ratio of 15 o C/min for 5 min. The conditions under which the gas chromatograph was carried out were 250 °C injection temperature and 280 °C transfer line temperature.

3.7. Calibration and Quantification

PCB standard, 100 ppm (Catalogue Number: 8082), containing 19 PCB components, was purchased from AccuStandard. A three-point serial dilution calibration standard (0, 1, 10, 20 ug/L) was prepared from the stock and used to calibrate the GC-MS.

3.8. Quality Assurance and Quality Control

All glassware was solvent-rinsed and oven-dried before use. Procedural blanks and solvent blanks were analysed alongside samples. Recoveries for surrogate standards ranged between 80 % and 120 %. Calibration verification standards were analysed intermittently to ensure instrument stability. All results were corrected for blank values.

4. RESULTS AND DISCUSSION

4.1. Results

The results of PCB analysis in soils of the study area are presented in Table 1, and represented in Figures 3– 6. Table 2 is the statistical analysis of the concentrations of PCBs obtained from soil samples from the study area. The mean of ΣPCBs levels in soil 1 is 234.447 µg/kg, soil 2 is 216.001 µg/kg, soil 3 is 195.375 µg/kg, and soil 4 is 197.948 µg/kg, which were below the 500 µg/kg PCB guideline of the Environmental Protection Agency (Victor *et al.*, 2023).

Table 1. Concentrations of PCB Congeners in Soil Samples (µg/kg)

PCB	Soil 1	Soil 2	Soil 3	Soil 4
PCB1	18.1398	16.2150	12.6543	15.4327
PCB5	24.6522	20.6712	22.1346	21.5623
PCB18	ND	<0.001	<0.001	<0.001
PCB29	29.9886	31.0852	25.4523	20.9156
PCB44	3.5526	2.1753	5.6320	1.8734
PCB52	4.6230	6.1008	2.6589	7.1126
PCB66	11.1223	9.1034	8.6651	14.0776
PCB87	ND	<0.001	<0.001	<0.001
PCB101	25.2545	23.2713	21.7540	23.1146
PCB110	15.8934	17.6581	12.0976	11.9067
PCB138	4.4257	6.9913	3.1652	2.2276
PCB141	5.4729	5.1456	3.9017	7.0674
PCB151	6.5398	3.9087	2.6752	5.2472
PCB153	6.3267	5.3215	4.5319	8.9913
PCB170	49.6130	40.4518	45.1461	38.0127
PCB180	6.8998	6.1724	4.7554	2.9635
PCB183	9.0956	11.0765	7.1428	7.6412
PCB187	12.8469	10.6521	13.0076	9.8017
PCB206	ND	<0.001	<0.001	<0.001
ΣPCBs	234.447	216.000	195.375	197.948

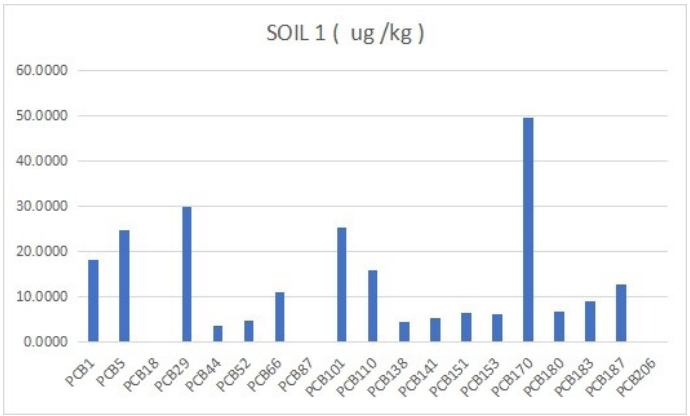

Figure 3. Results of PCBs analysis in Soil sample 1

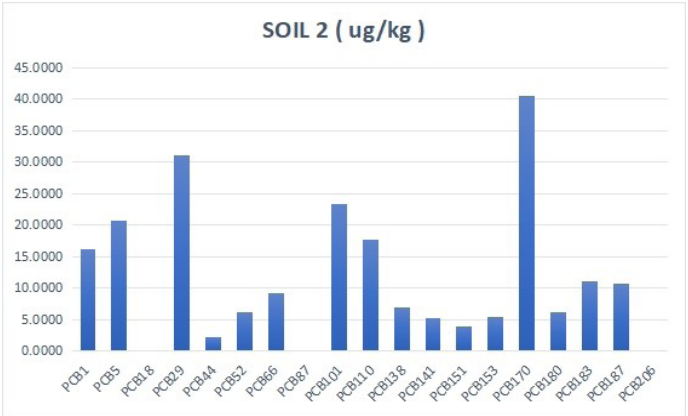

Figure 4. Results of PCBs analysis in Soil sample 2

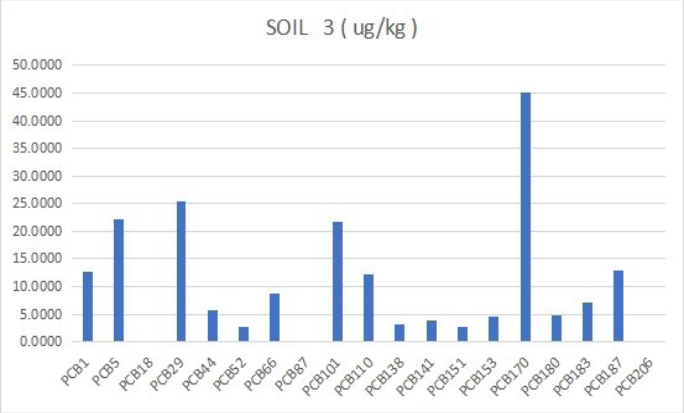

Figure 5. Results of PCBs analysis in Soil sample 3

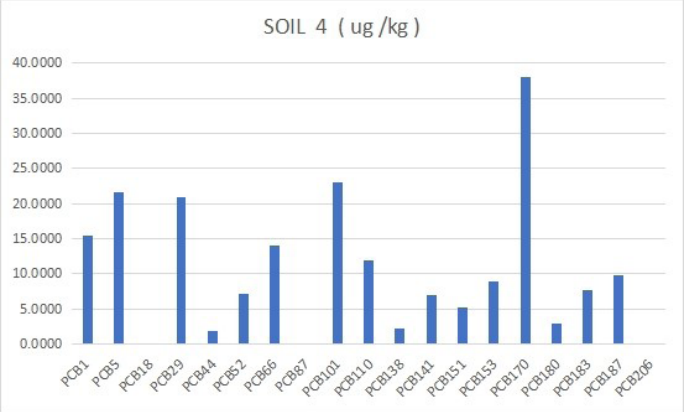

Figure 6. Results of PCBs analysis in Soil sample 4

The effluent water sample displayed a distinct PCB congener profile with ΣPCBs measured at a moderate concentration, as shown in Table 2.

Table 2. Concentrations of PCB Congeners in Effluent Water (µg/L)

PCB	Water (µg/L)
PCB1	1.2207
PCB5	ND
PCB18	ND
PCB29	3.3116
PCB44	ND
PCB52	1.0258
PCB66	ND
PCB87	19.0667
PCB101	1.6320
PCB110	0.9919
PCB138	0.1106
PCB141	2.3081
PCB151	1.4209
PCB153	1.8124
PCB170	12.0112
PCB180	1.4702
PCB183	2.8682
PCB187	3.7397
PCB206	ND
ΣPCBs	52.99

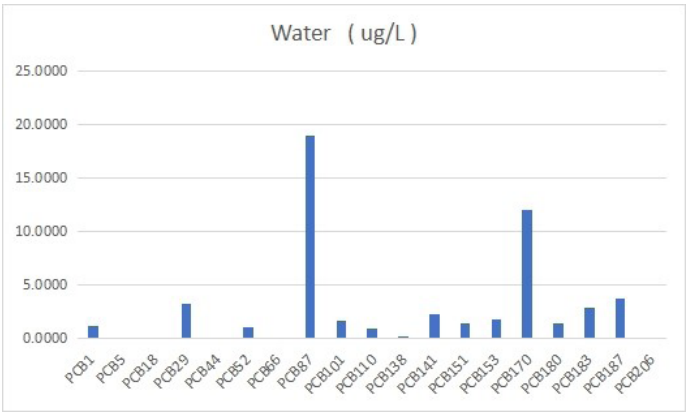

Figure 7. Results of PCBs analysis in Effluent Water

The toxic equivalency assessment of PCBs in the effluent water shows that only a subset of congeners contributed measurable TEQ values, with the majority of low-chlorinated congeners either not detected or producing negligible toxicity contributions due to their very low toxic equivalency factors. The TEQ was overwhelmingly driven by two congeners PCB87 and PCB170 which have higher TEFs and occurred at relatively elevated concentrations. Together, these congeners accounted for the dominant share of the total TEQ. The cumulative TEQ of 0.176 µg/L falls well below the WHO and USEPA toxicity threshold of 1 µg/L, indicating low immediate dioxin-like toxicity in the effluent. However, the presence of persistent, high-chlorinated congeners underscores the potential for long-term accumulation in aquatic systems and eventual transfer into the food chain, warranting ongoing monitoring and improved industrial waste management.

Table 3. Toxic Equivalency (TEQ) of PCBs in Effluent Water

PCB Congener	PCB Concentration in Water (µg/L)	WHO TEF (2022)	TEQ (µg/L)
PCB1	1.2207	0.0003	0.00037
PCB5	ND	–	–
PCB18	ND	–	–
PCB29	3.3116	0.0003	0.00099
PCB44	ND	0.0003	–
PCB52	1.0258	0.0003	0.00031
PCB66	ND	0.0003	–

PCB87	19.0667	0.0060	0.11440
PCB101	1.6320	0.00003	0.000049
PCB110	0.9919	0.00003	0.000030
PCB138	0.1106	0.00003	0.0000033
PCB141	2.3081	0.00003	0.000070
PCB151	1.4209	0.00003	0.000043
PCB153	1.8124	0.00003	0.000054
PCB170	12.0112	0.0050	0.06010
PCB180	1.4702	0.00003	0.000044
PCB183	2.8682	0.00003	0.000086
PCB187	3.7397	0.00003	0.000110
PCB206	ND	–	–
ΣTEQ	–	–	0.176

4.2. Discussion

The concentrations of PCBs detected in soils from the industrial area in Uyo indicate moderate contamination typical of environments exposed to long-term mechanical, electrical, and industrial activities. The ΣPCBs values of 195.375–234.447 µg/kg do not reach the severe contamination levels reported for heavily industrialised Niger Delta ecosystems but nevertheless reflect notable pollutant loading. Such concentrations are characteristic of aged contamination, as has been reported in other Nigerian and international studies of industrial landscapes (Oghenekohwiroro & Osaro, 2017; Ernesto *et al.*, 2021). The dominance of high-chlorinated congeners particularly PCB170, PCB187, and PCB183 across all sampled soils is consistent with patterns observed in regions affected by historical PCB usage and delayed degradation. These congeners are more resistant to volatilisation and microbial breakdown due to their higher molecular weight and lower vapour pressure, a behaviour well described in PCB fate and transport models (Wania *et al.*, 2006). This congener pattern aligns with findings from the Qua Iboe River estuary, where Okpoji *et al.* (2025a) reported the persistence of refractory contaminants with strong sorption affinity to organic-rich matrices. Similar persistence was also observed in the Forcados River by Umueni *et al.* (2025), who documented slow environmental turnover of heavier PCB congeners due to limited microbial degradation and reduced volatility. The uniform dominance of these congener groups in Uyo soils therefore suggests that the contamination has persisted over time, rather than resulting from recent or acute discharges.

The nondetection or very low detection of lighter congeners including PCB18, PCB52, PCB87, and PCB206 in several locations is indicative of volatilisation losses, atmospheric dispersion, or enhanced biodegradation. Low-molecular-weight PCBs degrade more rapidly, especially in tropical climates where high temperatures accelerate volatilisation (Kallenborn *et al.*, 2015). This supports the hypothesis of aged contamination, corroborated by atmospheric transport studies in Ogoniland by Okpoji *et al.* (2025d), who demonstrated that volatile organic pollutants can disperse widely via atmospheric currents, leaving behind more persistent congeners in soils. Similar processes were documented in Ebocha by Aghanwa *et al.* (2025), where atmospheric deposition from combustion and industrial emissions contributed to accumulations of persistent pollutants in local soils and water bodies.

Effluent water from the industrial facility recorded ΣPCBs of 52.99 µg/L, with PCB87 and PCB170 being the dominant congeners. Although these concentrations are lower than those reported in severely contaminated aquatic systems such as the Bonny and Andoni Rivers (Okpoji *et al.*, 2025a; Okpoji *et al.*, 2025c), the values remain environmentally relevant because industrial effluent channels interact directly with surface drainage systems and may infiltrate unconfined aquifers. Medium- and high-chlorinated congeners in the effluent suggest inputs from industrial materials such as lubricants, hydraulic oils, and electrical components sources that mirror observations in Forcados River sediments by Umueni *et al.* (2025). Related hydrocarbon transport studies in Yenagoa further show that contaminants introduced at industrial sites can migrate via shallow groundwater and surface runoff, leading to diffuse pollution (Okagbare *et al.*, 2025).

The TEQ values obtained for soils (0.217–0.281 µg/kg) and effluent water (0.176 µg/L) fall well below the WHO threshold of 1 µg/kg, indicating low acute toxic equivalence. However, PCBs are bioaccumulative, and chronic exposure even at sub-threshold concentrations can lead to adverse ecological and human health outcomes (IARC, 2015; ATSDR, 1997). Similar bioaccumulation tendencies were demonstrated in the Iko River, where Okpoji *et al.* (2025b) found significant tissue accumulation of low-level contaminants in Callinectes sapidus, increasing dietary risks. Studies on PAHs in smoked and dried fish (John *et al.*, 2025; Onoja *et al.*, 2025) also highlight that low environmental contaminant levels can translate to disproportionately higher exposure in food webs, especially in communities with high dependence on aquatic foods.

A comparative assessment shows that PCB concentrations in Uyo soils exceed those in the Ethiope River sediments (Eyenubo *et al.*, 2024) but remain lower than those documented in heavily industrialised water systems such as Andoni and Bonny Rivers (Okpoji *et al.*, 2025e). This positioning suggests that Uyo may be undergoing moderate but progressive PCB accumulation. Seasonal hydrological processes similar to those reported in the Andoni–Isiokwan District (Okpoji *et al.*, 2025 could further influence pollutant mobility, particularly during heavy rainfall when runoff facilitates contaminant redistribution into receiving soils and surface waters.

The resilience of high-molecular-weight congeners observed in this study underscores the chemical stability and long-term persistence of PCBs in the environment. Hydrocarbon and contaminant transport research, including Ekpe *et al.* (2025), shows that pollutants derived from industrial activities rarely remain confined and can migrate through infiltration, runoff, and atmospheric pathways. This broader regional evidence suggests that without intervention, Uyo's contamination profile could intensify, following the progressive patterns observed in many Niger Delta industrial corridors.

The results indicate that PCB contamination in Uyo's industrial

area is moderate, chronic, and predominantly associated with long-term anthropogenic sources especially those involving industrial wastes, electrical equipment residues, and mechanical operations. Although TEQ values suggest low immediate toxicity, the persistence and bioaccumulative properties of PCBs imply that continued accumulation may lead to ecological degradation and potential human health risks over time.

5. CONCLUSION

The levels of PCB congeners were determined in soils and effluent water from the industrial area in Uyo, Akwa Ibom State. Most PCBs were not indicated in the soils, like PCB 18, PCB 87, and PCB 206, while other congeners indicated varied levels, which could be a result of the contribution of the PCBs from various industrial and domestic sources.

Most PCBs were not indicated in the water effluents, like PCB 5, PCB 18, PCB 44, PCB 60, and PCB 206, but showed various levels of other congeners. The total PCBs determined for the soils and the water effluents were lower than the EPA guideline limit of 500 µg/kg and were also lower than values reported in other works. The toxicity equivalency quotient (TEQ) reveals from the study that the soils and the effluent do not yet raise a serious environmental concern to the biota and humans based on the less than 1 ug/kg TEQ values determined in samples from the study area.

Although the toxic equivalency quotient (TEQ) assessments indicate low immediate dioxin-like toxicity, the persistence, mobility, and bioaccumulative nature of PCBs highlight the potential for gradual environmental buildup. This accumulation may facilitate the transfer of PCBs into groundwater, aquatic ecosystems, and food chains, presenting possible ecological and public health concerns. Continuous monitoring, stricter industrial waste management, and proactive environmental regulation are therefore essential to mitigate future risks and maintain environmental safety in the area.

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