

The Bioaccumulation of BTEX and PCBs in *Gymnarchus niloticus* at Epe Lagoon, Nigeria

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Abstract. Aquatic ecosystems have become dumping grounds for human waste products, posing risks to food safety and integrity. This study evaluates the bioaccumulation of polychlorinated biphenyls (PCBs) and BTEX compounds (benzene, toluene, ethylbenzene, and xylene) in the tissues of *Gymnarchus niloticus* at Epe Lagoon. It assesses the integrity of the water and soil sediments. The researchers collected *Gymnarchus niloticus* fish, water, and soil samples from the study site (Epe Lagoon) and analysed them using gas chromatography–mass spectrometry (GC–MS) according to standard procedures. They also calculated the bioaccumulation factors (BAFs) to assess contaminant transfer from the aquatic environment into fish tissue. The study found that BTEX compounds occurred at generally low concentrations across all matrices (*Gymnarchus niloticus* fish tissue, water, and soil samples). However, the BAF value for benzene (4.7) was considerably high. In contrast, some PCB congeners were detected at concentrations above the regulatory threshold in the water sample. The BAF value also ascertains the bioaccumulation of PCB-70 (2,3',4,5-tetrachlorobiphenyl) in the tissue of *Gymnarchus niloticus*. These findings highlight the need for sustained environmental monitoring and effective pollution management strategies to protect aquatic ecosystems and public health in the Epe Lagoon system.

Keywords: Bioaccumulation; BTEX; Polychlorinated biphenyls; *Gymnarchus niloticus*; Epe Lagoon.

INTRODUCTION

Aquatic pollution remains one of the most critical environmental challenges of the 21st century, affecting both developed and developing nations through the continuous release of hazardous substances into freshwater and marine ecosystems, with these pollutants released at quantities, concentrations, and volumes that exceed the natural assimilative capacity of aquatic environments, resulting in ecological degradation and increased human health risks. Authors [1] identified major pollutants of the 21st century, including domestic sewage, agricultural pesticides and chemicals, oil spills, fuel and natural gas combustion, industrial metal discharges, nuclear radiation, pharmaceutical waste from textile industries, and electronic waste.

Among these contaminants, Polychlorinated biphenyls (PCBs) and BTEX (benzene, toluene,

ethylbenzene, and xylene) are of major concern due to their persistence in aquatic biota over long periods. Authors [2], as cited in [3], noted that these pollutants lack a natural mechanism for elimination, which exacerbates the challenges posed by PCBs. As such, these congeners move between sections of the aquatic biota and pose a significant health challenge to humans.

PCBs are synthetic organochlorine compounds characterised by high chemical stability and resistance to biodegradation - properties that have led to their classification as persistent organic pollutants (POPs) under the Stockholm Convention. Once introduced into aquatic systems, PCBs exhibit limited natural attenuation and are readily transferred among environmental compartments and trophic levels, thereby posing long-term ecological and human health risks [3].

BTEX compounds, although less persistent than PCBs, are widely distributed in aquatic environments as a result of petroleum exploration, refining, transportation, and improper disposal of industrial wastes. These monoaromatic hydrocarbons readily enter water bodies through oil spills, surface runoff, and effluent discharge, where they may exert acute and chronic toxic effects on aquatic organisms [4, 5]. Studies have documented elevated BTEX concentrations in sediments and biota in petroleum-impacted aquatic ecosystems, underscoring their relevance as indicators of anthropogenic contamination [6].

The bioaccumulation and biomagnification of these pollutants have been reported in aquatic biota. Organisms can retain higher concentrations of these pollutants within their systems than in the surrounding environment [7, 8]. Authors [9] noted that the primary route of human exposure to PCBs is through the consumption of contaminated food, particularly fish. Nigerians massively depend on fish for their nutritional needs. On average, 40% of the country's protein intake comes from fish, with consumption at 13.3 kg per person per year [10]. As such, the biomagnification of PCBs in fish tissues poses a greater danger to human health.

The negative impact of PCBs on human health includes liver disorder, endocrine dysfunction, neurological deficits, type 2 diabetes, obesity and cardiovascular disease. At the same time, other studies have shown that exposure to PCBs can affect the reproductive system and even compromise the immune system, thus enhancing the possibility of developing cancer [11-13]. Therefore, the current study seeks to evaluate the bioaccumulation of PCBs and BTEX in *Gymnarchus niloticus* at Epe Lagoon to assess the safety of the fauna and flora. The objectives of the study are;

1) Investigate the bioaccumulation of BTEX in the tissue of *Gymnarchus niloticus* obtained from Epe Lagoon.

2) To compare the PCB and BTEX concentration of *Gymnarchus niloticus*, water and soil sediment

Literature Review

General overview of PCBs. Polychlorinated biphenyls (PCBs) are Organic compounds with varying levels of chlorination and possess a biphenyl structure [14]. Scientists have long recognised this chemical compound as persistent in

the environment and associated with detrimental health effects, which led the Stockholm Convention on Persistent Organic Pollutants (2001) to list PCBs among persistent organic pollutants (POPs) [15]. Depending on the number of chlorine atoms and their position, there are over 209 congeners of PCB. Highly chlorinated PCBs with at least 4 chlorine atoms are more persistent. They are mostly contaminants in food due to their resistance to degradation, while low-chlorinated biphenyls are mostly found in indoor and outdoor environments in major urban cities [16].

Authors [17] reported that many industries widely use PCBs because their resistance to degradation, high heat capacity, and high flash point make them ideal for electrical components such as transformers, capacitors, and heat-transfer fluids, which industries mostly use for insulation. Authors [18] further noted that PCBs were used in other industries for the production of plastics, inks and dyes, oils, pesticides, wood preservatives, adhesives, and fluorescent light fixtures.

Researchers have recognised the widespread and prominent presence of PCBs despite the 1970s ban on their large-scale production. The persistence and bioaccumulation of PCBs in aquatic organisms and humans pose a threat to human life. In aquatic biota, PCBs exist in two phases: dissolved and suspended. In the suspended state, it can easily attach to sediment and suspended solids due to its hydrophobic properties [19]. Therefore, aquatic fauna that feed on sediments have greater exposure to PCBs.

Overview of BTEX. BTEX are naturally occurring compounds that are components of crude oil and its derivatives; thus, they are more frequently encountered in the sediments of aquatic biota worldwide [6]. These organic compounds include xylene isomers, ethylbenzene, toluene, and benzene, which are produced by petroleum refining, coal combustion, and factories during the manufacture of products such as rubber, inks, thinners, paints, pharmaceutical products, and cosmetics.

Authors [20] noted that BTEX can cause genetic aberrations, thereby leading to genotoxicity. Authors [21] reported that BTEX can cause both behavioural and cognitive effects and, as such, act as neuro- and hepatotoxins. BTEX are introduced into water bodies through industrial effluents, petroleum product spills, and atmospheric pollution [4, 5]. BTEX are abundant in aquatic biota,

though their presence is not readily apparent [22].

METHOD

The Epe lagoon located between longitudes 3° 23' and 3° 40' E, and latitudes 6° 22' and 6° 38' N stretches from Cotonou in the Republic of Benin and extends to the fringes of the Niger Delta in Nigeria [23], forming part of an intricate system of water ways made up of lagoons and creeks that are found along the coast line of Nigeria, Benin Republic, Togo and Cote d'Ivoire. It is the largest of the four lagoon systems, mainly of the Gulf of Guinea, covering an area of 257.49 km [24]. The Epe lagoon extends from the coast of Lagos to about 37 km north at Ikorodu and about 48 km east, where it narrows and continues as the Lekki lagoon. The lagoon supports major fishing activities in Nigeria, with several fishing villages along its shores. As a result of exponential population growth in this region, anthropogenic activities are increasing, including fishing, domestic waste disposal, and indiscriminate sand mining.

Collection of Specimens. The researchers collected *Gymnarchus niloticus* samples in April 2025 from Epe Lagoon in Nigeria. They procured the fish species directly from fishermen who used fishing traps, cast nets, and gill nets of various mesh sizes to catch them. The researchers then transported the freshly procured fish to the laboratory and examined the specimens for parasites. Before examining the parasites, they measured the fish morphometrically. The fish guts were dissected onto petri dishes containing physiological saline to recover parasites. The fish intestine was harvested and stored in a Teflon-lined, capped vial in a refrigerator before analysis for BTEX and PCBs.

Physicochemical analysis. The physicochemical parameters were measured on-site at three locations in the lagoon using a Horiba water checker. The physicochemical parameters evaluated included pH, surface water temperature (°C), dissolved oxygen, salinity, conductivity (µS), and total suspended solids.

Extraction and Analysis of PCBs in Fish Tissue. PCB extraction from *Gymnarchus niloticus* tissue was carried out using alkaline digestion followed by solvent extraction in accordance with USEPA Method 3611C. The researchers macerated and homogenised the fish tissue samples and trans-

ferred approximately 5 g of the homogenate into a 50 ml centrifuge tube. They then added 15 ml of 6 N potassium hydroxide (KOH), sealed the tubes tightly, and incubated them in a 35 °C water bath for 18 hours. During the first four hours of incubation, the researchers vigorously shook the samples for 30 seconds at 30-minute intervals.

After digestion, the researchers added 15 ml of methylene chloride and centrifuged the mixture at 2000 rpm for 5 minutes. They transferred the organic layer to a round-bottom flask, washed it with deionised water, dried it over anhydrous sodium sulfate, and concentrated it to 5–10 ml under reduced pressure using a rotary evaporator. The researchers solvent-exchanged the extract to n-hexane, transferred it into amber glass vials, and stored it at 4 °C before analysis. They then quantified PCB congeners using gas chromatography–mass spectrometry (GC–MS) [8].

For PCB analysis in soil sediments, samples were lyophilised (freeze-dried) and ground to a fine powder. The researchers extracted the dried samples using dichloromethane through Soxhlet extraction. The extracts were concentrated using a rotary evaporator and transferred into amber glass vials for analysis. PCB congeners were determined using GC–MS [25].

Extraction and Analysis of BTEX in Gymnarchus niloticus, Soil and Water Samples. BTEX compounds in fish tissue, soil, and water samples were analysed using gas chromatography–mass spectrometry (GC–MS) in accordance with USEPA Method 8260B. A sample introduction was achieved using a purge-and-trap system suitable for volatile organic compounds.

The researchers performed chromatographic separation using a DB-5 capillary column (95% dimethyl-5% diphenyl polysiloxane; 30 m × 0.32 mm × 1.0 µm). They injected 1 µL in split mode (100:1) at an injector temperature of 125 °C. They programmed the oven temperature at 35 °C (2 min), ramped it at 4 °C min⁻¹ to 50 °C, and then increased it at 10 °C min⁻¹ to 220 °C. They used helium as the carrier gas at a flow rate of 1.5 ml min⁻¹.

The mass spectrometer was operated in electron impact mode at 70 eV, with a scan range of 35–260 amu. Identification and quantification were based on comparison with certified analytical standards and calibration curves [8].

The bioaccumulation factor was calculated using the formula below and also summarised in the table.

$$\text{BAF} = \frac{\text{Concentration of Pollutant in Fish (mg/kg)}}{\text{Concentration of Pollutant in water (mg/l)}}$$

RESULTS AND DISCUSSION

Physicochemical parameters of the water sample in Epe lagoon. The physicochemical characteristics of surface water collected from Epe Lagoon are summarised in Table 1. The mean pH of the lagoon water was 7.1 ± 0.4 , and the Surface water temperature was relatively high, with a mean value of 31.52 ± 0.31 °C. Electrical conductivity recorded a mean value of 0.137 ± 0.006 mS/cm, suggesting moderate ionic content in the lagoon water. Total dissolved solids (TDS) showed a mean concentration of 105.4 ± 3.1 mg/l.

Table 1 – Physicochemical parameters of the water sample in Epe lagoon

| Parameter | Mean \pm SD |
|---------------------------------|------------------|
| pH | 7.1 ± 0.4 |
| Electrical conductivity (mS/cm) | $0.137 \pm .006$ |
| Total Dissolved Solids (mg/l) | 105.4 ± 3.1 |
| Temperature | 31.52 ± 0.31 |

*Mean concentration of BTEX bioaccumulation in *Gymnarchus niloticus* tissue.* The analysis of the mean concentration of BTEX bioaccumulation in the tissue of *Gymnarchus niloticus*, popularly known as the knife fish, is presented in Table 2.

Table 2 – Mean concentration of BTEX bioaccumulation in *Gymnarchus niloticus* tissue

| Compound | Mean \pm SD (mg/kg ww) | BAF |
|----------------|--------------------------|------|
| Toluene | $0.00051 \pm .00027$ | 0.72 |
| Benzene | $0.00061 \pm .00082$ | 4.70 |
| p-Xylene | $0.00037 \pm .00035$ | 1.40 |
| Ethylbenzene | $0.00320 \pm .00287$ | 0.35 |
| benzene propyl | $0.04057 \pm .06351$ | 0.97 |

The results indicate that Toluene, Benzene, and Parabenzene were present at trace levels, with means ranging from 0.00037 to 0.00061. However, higher levels were observed for 1-methyl ethyl (0.00320) and Benzene propyl (0.04057). The standard deviations for these samples indi-

cate low variability for most compounds, except Benzene propyl, which showed greater fluctuation. The majority of the BTEX pollutants are less than 1, except Benzene and P-Xylene, which record BAF values of 4.70 and 1.40, respectively.

Mean concentration of BTEX in water and soil sediment. Table 3 reveals the presence and abundance of BTEX pollutants within the environment of *Gymnarchus niloticus* (water and soil sediments). The analysis indicates that the concentrations recorded were generally higher for 1-methyl ethyl (9.15 μ g/l) and Benzene propyl (41.7 μ g/l) in the water sample. However, Toluene, Benzene, and Parabenzene remained low but detectable. Whereas, for the soil sediment, the concentrations of 1-methyl ethyl (0.00343 mg/kg) and Benzene propyl (0.01805 mg/kg) are moderate, while Toluene, Benzene, and Parabenzene remained at low levels.

Table 3 – Mean concentration of BTEX bioaccumulation in water and soil sediment

| Compound | Water (μ g/l) | Sediment (mg/kg dw) |
|----------------|--------------------|---------------------|
| Toluene | 0.71 | 0.00068 |
| Benzene | 0.13 | 0.00021 |
| parabenzene | 0.27 | 0.00016 |
| 1-methyl ethyl | 9.15 | 0.00343 |
| benzene propyl | 41.74 | 0.01805 |

*Mean concentration of PCB in *Gymnarchus* Tissue.* The concentrations of individual polychlorinated biphenyl (PCB) congeners detected in *Gymnarchus* tissue are presented in Table 3. Detectable PCB congeners showed variable accumulation patterns, with mean concentrations ranging from 0.050 to 0.394 mg/kg (wet weight). Among the quantified congeners, 2,3',4,5-Tetrachlorobiphenyl exhibited the highest mean concentration in tissue (0.394 ± 0.283 mg/kg), followed by 1,1'-Biphenyl, 2,3,4'-trichloro- (0.350 ± 0.218 mg/kg) and 1,1'-Biphenyl, 2,3-dichloro- (0.200 ± 0.104 mg/kg). 1,1'-Biphenyl, 4-chloro- was present at a moderate level (0.134 ± 0.160 mg/kg), while 1,1'-Biphenyl, 2,2',4-trichloro- showed the lowest detectable concentration (0.050 mg/kg). All the PCB values are also lower than 1, except for Congener 70, which has a BAF value of 4.38.

Table 4 – Mean concentration of PCB in *Gymnarchus niloticus* fish

| PCB congeners | Mean ± SD (mg/kg ww) | BAF |
|--|----------------------|------|
| PCB-4 (4-chlorobiphenyl) | 0.134±0.160 | 0.14 |
| PCB-5 (2,3-dichlorobiphenyl) | 0.200±0.104 | 0.22 |
| PCB-18 (2,2',4-trichlorobiphenyl) | ND | ND |
| PCB-31 (2,4',5-trichlorobiphenyl) | ND | ND |
| PCB-33 (2,3,4'-trichlorobiphenyl) | 0.350±0.218 | - |
| PCB-70 (2,3',4,5-tetrachlorobiphenyl) | 0.394±0.283 | 4.38 |
| PCB-52 (2,2',5,5'-tetrachlorobiphenyl) | 0.050 | - |
| PCB-101 (1,1'-Biphenyl, 2,2',3) | 0.120±0.014 | 0.86 |

Mean concentration of PCBs in water and soil sediment. PCB concentrations measured in water and soil sediment are summarised in Table 4. Overall, PCB levels in water ranged from non-detectable to 990 µg/l, while soil sediment concentrations ranged from 0.050 to 0.230 mg/kg, demonstrating environmental compartmentalisation of PCB congeners. In water samples, 1,1'-Biphenyl, 4-chloro Biphenyl recorded the highest concentration (990 µg/l), followed by 1,1'-Biphenyl, 2,3-dichloro- Biphenyl (930 µg/l). Lower concentrations were observed for 2,3',4,5-Tetrachlorobiphenyl (90 µg/l) and 1,1'-Biphenyl, 2,2',3-trichloro- Biphenyl (140 µg/l). Several congeners were not detected in water, suggesting heterogeneous distribution among PCB congeners.

Soil sediment samples showed comparatively lower but more consistent PCB levels. The analysis showed that 1,1'-Biphenyl, 2,3-dichloro- and 1,1'-Biphenyl, 2,2',3-trichloro- had the highest sediment concentrations (0.230 mg/kg each), while 1,1'-Biphenyl, 2,3,4'-trichloro- and another trichlorinated congener reached 0.120 mg/kg. The analysis also showed that 2,3',4,5-Tetrachlorobiphenyl had the lowest sediment concentration (0.050 mg/kg).

Table 5 – Mean concentration of PCBs in water and soil sediment

| PCB Congeners | Water (µg/l) | Soil Sediment (mg/kg dw) |
|----------------------------------|--------------|--------------------------|
| PCB-4 (1,1'-Biphenyl, 4-chloro-) | 990 | 060 |
| PCB-5 (1,1'-Biphenyl, 2,3-dic) | 930 | 0.230 |
| PCB-33 (1,1'-Biphenyl, 2,3,4'-) | ND | 0.120 |
| PCB-70(2,3',4,5-Tetrachloro-1) | 90 | 0.050 |
| PCB-52 (1,1'-Biphenyl, 2,2',4) | ND | 0.060 |
| PCB-101 (1,1'-Biphenyl, 2,2',3,) | 140 | 0.230 |
| PCB-110 (1,1'-Biphenyl, 2,2',3,) | ND | 0.120 |

Environmental Distribution of PCBs across Water and Sediment. The results demonstrate the widespread presence of polychlorinated biphenyls (PCBs) across aquatic environmental compartments, with clear differences in concentration profiles between water and soil sediment. The result is consistent with the study by authors [2], which reported the persistence of PCBs in Lagos Lagoon. Higher PCB concentrations recorded in water for lower-chlorinated congeners (e.g., 1,1'-Biphenyl, 4-chloro- and 1,1'-Biphenyl, 2,3-dichloro-) suggest recent or ongoing inputs into the aquatic system, as these congeners are more soluble and mobile in water than higher-chlorinated analogues that are not easily soluble in water and have been reported to be more persistent due to the extent of their chlorination [9]. It is imperative to note that the quantity of the previously mentioned PCB congeners in water is beyond the standard regulatory threshold, bearing in mind that the World Health Organisation (WHO) recommend extremely low guideline values for PCBs in surface waters, typically less than 0.5 u/l due to their carcinogenicity, endocrine-disrupting properties, and strong bioaccumulative behaviour.

In contrast, soil sediment showed relatively lower but more stable concentrations, reflecting the well-documented tendency of PCBs to adsorb onto organic matter and fine particles over time. The persistence of detectable PCB levels in sediment indicates historical contamination and long-term environmental retention, consistent with PCBs' physicochemical stability and hydrophobic nature. Similar sediment-dominated PCB reservoirs have been reported in contaminated freshwater ecosystems worldwide, where sediments act as both sinks and secondary sources of contamination through resuspension. The result differs slightly from that of the authors [26], who observed an increase in PCB concentrations in the sediments of Lagos Lagoon.

Bioaccumulation of PCBs in Gymnarchus Tissue. The detection of multiple PCB congeners in *Gymnarchus* tissue confirms active bioaccumulation and trophic transfer within the aquatic food web. Notably, 2,3',4,5-Tetrachlorobiphenyl exhibited the highest tissue concentration, despite comparatively lower levels in water and sediment, with a BAF of 4.38, indicating greater bioaccumulation. This pattern underscores the importance of lipophilicity and chlorination degree in governing PCB bioaccumulation rather than environmental concentration alone. The higher the

chlorine content, the higher the lipophilicity and the less soluble they are in water; as such, this PCB compound can persist for a long time and even increase bioaccumulation and biomagnification.

Moderately to highly chlorinated congeners are known to resist metabolic breakdown and preferentially partition into lipid-rich tissues of aquatic organisms. The absence or low detection of some congeners in tissues, despite their presence in environmental matrices, further suggests selective uptake, metabolism, or elimination. These findings align with established bioaccumulation models, indicating that PCB congeners with higher octanol-water partition coefficients (K_{ow}) exhibit stronger bioconcentration in fish tissues. Some PCB congeners in the study exceeded the recommended levels set by the FAO and WHO, which range from 0.02 to 0.1 mg/kg. For instance, the 3',4,5-Tetrachlorobiphenyl value of 0.394 mg/kg exceeds this limit, highlighting the relevance of biomagnification pathways.

BTEX Concentration in Water and Soil Sediment. BTEX compounds (benzene, toluene, ethylbenzene derivatives, and propylbenzene) were generally detected at lower concentrations than PCBs, reflecting their greater volatility and lower persistence. However, propylbenzene and 1-methyl ethyl benzene showed comparatively elevated concentrations in both water and sediment, indicating possible localised petroleum-related inputs such as fuel leakage, runoff, or improper waste disposal—the bioaccumulation. BTEX levels were generally below the WHO threshold; however, continuous input can maintain environmentally relevant concentrations, posing chronic exposure risks to aquatic organisms.

BTEX accumulation in Gymnarchus Tissue. BTEX concentrations in *Gymnarchus* tissue were generally low, with relatively high variability, indicating transient exposure and rapid metabolic processing. Unlike PCBs, BTEX compounds are more readily biotransformed and eliminated by fish, which explains their lower tissue accumulation despite measurable environmental concentrations. Although benzene and p-xylene showed high BAF values, it may be more a transient uptake than true biomagnification.

Nevertheless, the presence of propylbenzene at higher mean concentrations and with wide variability suggests episodic exposure events or spatial heterogeneity in contamination sources.

Chronic exposure to BTEX compounds, even at low tissue concentrations, has been associated with sublethal effects such as oxidative stress, enzyme disruption, and behavioural changes in fish, which may not be immediately evident from concentration data alone.

Ecological and Human Health Implications. Exceedance of international guideline values for PCBs across all environmental matrices assessed underscores a high ecological risk and potential human health concern. Persistent PCB contamination in sediment acts as a long-term source of exposure for aquatic organisms. At the same time, bioaccumulation in fish tissue represents a direct pathway for human exposure through dietary intake. Vulnerable populations, including children and pregnant women, are particularly at risk due to the neurodevelopmental and endocrine-disrupting effects of PCBs. In contrast, while BTEX compounds showed lower bioaccumulation potential, their detection across all matrices indicates active contamination inputs, likely linked to petroleum-related activities. Combined exposure to both persistent (PCBs) and non-persistent (BTEX) contaminants may produce synergistic toxic effects that single-compound regulatory thresholds do not fully capture.

CONCLUSIONS

This study provides compelling evidence of multi-contaminant pollution in the aquatic environment, characterised by elevated PCB concentrations and persistent BTEX inputs. The distribution patterns observed across water, sediment, and *Gymnarchus* tissue highlight the contrasting environmental behaviour of these compound classes: PCBs demonstrate strong persistence and bioaccumulation. In contrast, BTEX compounds reflect ongoing, likely anthropogenic inputs.

Exceeding international safety limits for PCBs in fish tissue raises serious concerns about food safety and public health, particularly for communities reliant on local fish resources. These findings underscore the urgent need for routine environmental monitoring, sediment remediation strategies, and public health risk communication.

Ethical Approval

The researchers conducted all procedures involving sample collection in accordance with institutional and national guidelines for environ-

mental research. The study did not involve any endangered or protected species.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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