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# Evaluation of Polycyclic Aromatic Hydrocarbons (PAHs) Contents of Fishes, Waters and Sediments of Rivers Niger: Human Health Risk Assessment

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**ABSTRACT**
This study aimed to assess the levels of polycyclic Aromatic Hydrocarbon (PAHs) in fish, water and sediments samples collected from the confluence of the Niger Rivers in Lokoja, Kogi State. Random sampling technique was used to collect samples from twenty locations; resulting in five composite samples labeled A, B, C, D, and E. Fish samples A (Catfish) and B (Tilapias) were bought from fishermen along the riverbank. The samples were extracted using a liquid-liquid extraction (LLE) and solid-phase extraction (SPE) clean-up. Gas chromatography-mass spectrometry (GC-MS) was used for the determination of the sixteen priority PAHs. Only six out of the sixteen priority PAHs were identified. The PAH concentrations in water from various location ranged as follows: BaP (0.083 to 0.113), Nap (ND-0.543), Ant (ND-0.083), BbF (0.080-0.093), BkF (0.083-0.093) & Ph (ND-0.083) mg/L. Sediment concentrations across locations were as follows: Ant (ND-0.053), Nap (ND-2.210), Ph (ND-0.053), BaP (ND-0.053), BkF (0.053-0.110) & BbF (0.053-0.383) mg/kg. Average PAH concentrations in Catfish & Tilapia were as follows: BaP (0.050 & ND), Ph (0.050 & 0.057), Ant (0.057 & 0.057), BbF (0.043 & ND), BkF (0.043 & ND) & Nap (2.383 & 1.947). Hazard Quotient (HQ), & pollution index (PI) were used to evaluate the human risk from consuming water and fish. The findings indicated that water, fish & sediments contained high levels of PAH pollutants, with some measurements surpassing the permissible limits set by WHO. Strict pollution control measures are advised to adhere to, so as to protect both aquatic ecosystems and human health.

**Keywords:**
PAHs, Fish, sediment, Water,
River Niger Confluence, Lokoja.

## INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are defined as compounds that consist of two or more fused aromatic rings arranged in linear, angular, or clustered formations. Depending on their arrangement, PAHs can be categorized into three groups: Polyaryls PAHs, Ortho-fused PAHs, and Ortho and Peri-fused PAHs (Olatunde *et al*., 2012; Gorleku *et al*., 2014; Obruche *et al*., 2018). PAHs are widespread and are hydrophobic & lipophilic substances with low water solubility. Their hydrophobicity & lipophilicity increases with molecular weight, along with their persistence in the environment (Afshin & Farid, 2007). PAHs strongly adhere to the organic components of sediments and soil, indicating that these environments are typically viewed as the primary sinks for PAHs (Haiyuan, 2010; Aloysius *et al.*, 2014).



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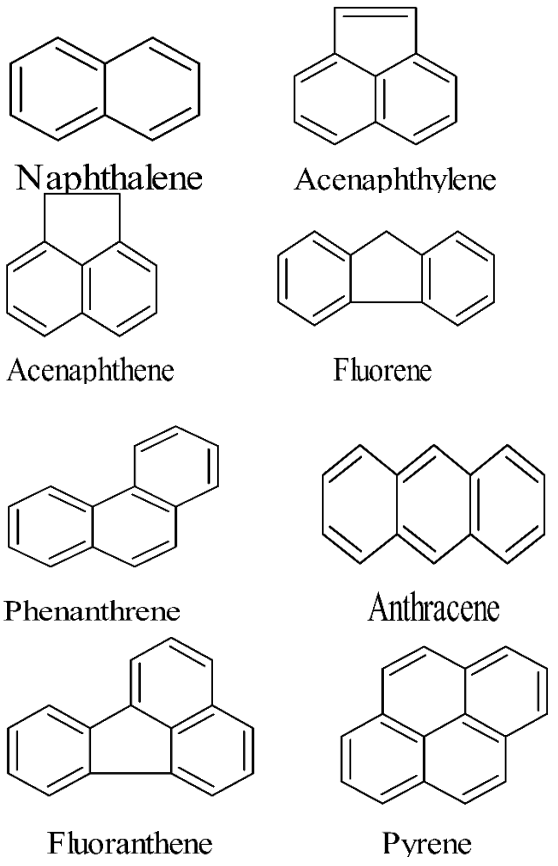
PAHs containing 4 or more aromatic rings are known to persist in the environment. Benzo[a] pyrene is the most recognized PAH and is often used as a representative example. Due to the variable mixtures of PAHs, the panel on pollutants in the food chain at the European Food Safety Authority, EFSA, criticized this choice in a 2008 report on PAHs in food products, stating that benzo[a] pyrene alone is not an adequate marker for PAHs in food. Instead, they identified four specific PAHs. However, the daily dietary intake of the contaminant from fish consumption raised public health concerns, as the PAH levels in some fish from various locations and seasons exceeded the limits set by Environment Canada for edible fish and shellfish (Mohanad, 2014). Continuous and effective monitoring of the river's quality is necessary and should be compared with baseline data to identify any quality changes, especially since crude oil production is expected to start in this sensitive area (Guobing *et al*., 2015). PAHs in the aquatic environment come from three main sources: Pyrogenic, Petrogenic, and Diagenic. Pyrogenic PAHs, which come from combustion, result from incomplete combustion of organic materials like fossil fuels and biomass at high temperatures for short periods, and these inputs are common in aquatic environments. Petrogenic PAHs, likely from petroleum, are associated with petroleum products such as oil spills and construction materials. Petrogenic PAHs are prevalent in oil-contaminated samples, whereas Pyrogenic PAHs are more common in samples from industrial regions (Abeer *et al*., 2012). Consequently, PAHs are generated from the incomplete burning of organic materials like coal, bones, wood, canes or animals. Generally, the lower the combustion temperature and the less oxygen present, the more incomplete the burning process is, leading to higher PAH production. These sources include rock weathering, wastewater, industrial discharges, and the incomplete burning of organic materials, fossil fuels, petroleum, and air pollution (Oyakhilome *et al*., 2013; Nzeve et al., 2014). People are exposed to PAH vapors or PAHs in dust and other particles both outdoors and indoors, such as at home or work. This exposure occurs through cigarette smoke, vehicle emissions, home heating, agricultural burning, waste incineration, and industrial emissions. PAHs can also enter the body through food and water or by skin contact. Once in the body, PAHs are distributed to all fat-containing tissues. They can accumulate in fat, the liver, and kidneys, especially with repeated and long-term exposure. Smaller amounts may also be found in the spleen, adrenal glands, and ovaries.

Lokoja is a community situated on the banks of the Niger River, where the Niger and Benue rivers meet in Kogi State, central Nigeria. The local inhabitants of Lokoja mainly engage in farming and fishing. The primary sources of PAHs in the confluence of the Niger and Benue rivers in Lokoja, as well as in nearby lakes, are rainfall and urban runoff, which carry these pollutants from both natural and human-made sources into the water (Itodo et al., 2021; Obruche et al., 2025). Reports indicate that the high volume of untreated waste released into the Benue River at Makurdi is concerning, and rural residents use this river as a toilet and for disposing of solid waste. This water serves as a primary drinking source for some and provides fish for their consumption and export, contributing to their income. The decline in water quality poses a serious issue for the Niger River, especially due to the expansion of large cities along its banks, which has not been matched by the establishment of wastewater collection and treatment facilities for either domestic or industrial waste. Thus, it is essential to investigate the pollution effects on the Niger and Benue rivers in Lokoja and their aquatic ecosystems to mitigate negative impacts on the environment and the people who depend on the river's fish for sustenance (Michael, 2012; Obiakor et al., 2014; Obruche et al., 2019). This research will, for the first time, provide baseline data on PAHs for this region. The data generated will be utilized to evaluate the effects of PAHs on water and the fish-eating population in the study area.



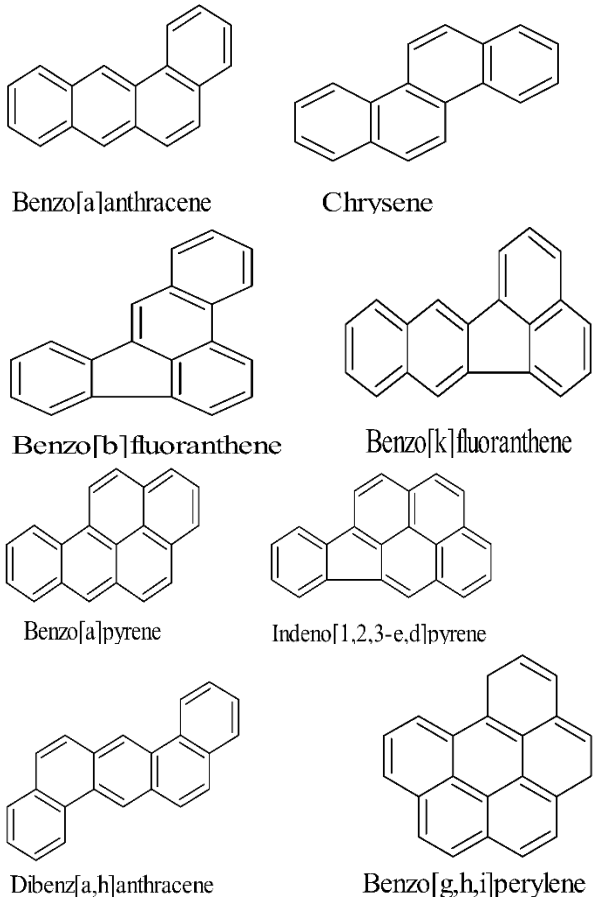



Figure 1. Names of PAHs and their structures

## MATERIALS AND METHODS

### Description of Study Area

This study covered the area where river Niger and river Benue meet in lokoja, Kogi State. The state is located at the coordinates of latitude 7°30'N/6°42'E and longitude 7.500°N/6.700°E, while Lokoja is situated between 7°45'N and 7°52'N of the equator and longitude 6°45'E of the Greenwich meridian. The river Niger bounds Lokoja to the west, at an elevation of 45 m - 125 m above sea level. The region experiences a tropical wet and dry climate, with a rainy season from May to October and a dry season from December to April, receiving approximately 1000 mm of annual rainfall. Lokoja serves as the headquarters of Lokoja L.G.A. and is the capital of Kogi State, covering an area of 3180 $km^2$ and having a population of 196,643 according to the 2006 census, with most locals engaging in farming and fishing (Obruche *et al*., 2019).

All chemicals used in this study were of reagent grade and required no further treatment. (65%) Nitric acid ($HNO_3$), Dichloromethane ($CH_2Cl_2$), anhydrous sodium sulphate ($Na_2SO_4$), and standards of the sixteen priority compounds were provided by Merck. Distilled water was sourced from the Chemistry Laboratory at the Federal University of Petroleum Resources, Delta State, Nigeria.

### Pretreatment

The method of pretreatment used was done by adopting the process that was described by (WHO, 2010; Obruche *et al*., 2019) with some amendment. All polyethylene containers for collecting fish samples were cleaned with detergent and treated with dilute nitric acid (10% $HNO_3$), and properly rinsed with deionized water, then properly labeled.

### Collection of samples

The sample collection methods were similar to the one of Ogwuche and Obruche (2020) with a few minor modifications. All polyethylene containers for collecting water samples, along with polyethylene bags for fish and sediment samples analyzed for PAHs, were washed with detergent, treated with dilute Nitric acid (10% $HNO_3$), and thoroughly rinsed with distilled-deionized water. Sediment and water samples were collected from locations 2 km downstream and upstream during both the dry and rainy seasons (March and August). Randomly sampling technique was employed to collect samples from twenty locations, resulting in five composite samples labeled A, B, C, D, and E. the fish samples A (Catfish) & B (Tilapias) were bought from fishermen along the riverbank, transported in an ice-cooler box along with other samples to the laboratory for analysis.

### Fish, Water and Sediment Samples Preparation for PAHs Quantification

The sample preparation method was similar to Ogwuche and Obruche (2020) with a few minor modifications. The samples were extracted using a liquid-liquid extraction (LLE) and solid-phase extraction (SPE) clean-up as described by (USEPA, 2006).

For the preparation of the fish sample. Exactly 10 g of gill and muscle samples from the dissected fish were blended with 100 grams of anhydrous sodium sulfate using a mortar and pestle. This mixture was placed into the thimble of the Soxhlet apparatus and extracted with 300 mL of a 1:1 mixture of acetone and n-hexane in a water bath for 8 hrs.

For the sediment, the method of preparation was adopting the process that was described by (WHO, 2010; Enuneku et al., 2013; Obruche et al., 2019) with some amendment. Exactly 10 g of sediment samples were mixed with 100 g of NaSO4.

For the water sample analysis (USEPA, 2006; Ekpo *et al*., 2023) Method employed. Exactly 1.0 L of water sample was extracted three times using 100 mL of dichloromethane. The dichloromethane extracts (lower layer) were combined and drained into a funnel with anhydrous sodium sulfate. Each sample was extracted using a Soxhlet extractor for 8 hrs with a 1:1 V/V mixture of acetone and hexane. The extracts were then rotary evaporated to 5 mL. The sediment, fish and water extracts were cleaned using solid-phase extraction (SPE) method. All PAH analyses were performed using GC-MS.

**GC-MC Analysis**

According to the USEPA (2006) and Abdulrasheed et al. (2025), both HPLC and GC/MS methods are seen as equally valid for analyzing PAHs, although GC/MS is more commonly used. In this research, a GC/MS method was utilized. The PAHs extracts were analyzed using a 3800 Varian gas chromatography linked to a Varian Saturn 2200 mass spectrometer, which had a 30 m× 0.25 mm id. WCOT CP-Sil 8 CB column. The GC/MS functioned under these conditions: the starting column temperature was set at 70 °C. After holding for 1 minute, the temperature was programmed to increase to 300 °C at a rate of 10 °C/min over 30 minutes. The injector and detector temperatures were maintained at 250 °C and 300 °C, respectively. Helium served as the carrier gas at a flow rate of 2 mL/min. The concentrations of PAHs were identified by their retention times and verified by comparing their mass spectra with a reference library. Calibration curves were created at seven concentration levels ranging from 2 to 2000 ng/L using standard solutions that included all the PAHs studied. The detection limit (DL) for individual PAHs, with a signal to noise ratio of 3, varied from 0.8 to 2 ng/L.

**Risk Assessment models for Carcinogenic and Non-Carcinogenic Risk factors**

Hazard Quotient (HQ), also referred to as non-carcinogenic risk, carcinogenic risk (CR), and pollution index (PI) for PAHs were employed to evaluate the human risk from consuming water and fish. The risk assessment model adheres to the methodology suggested by the USEPA (2006), which classifies risk into non-carcinogenic and carcinogenic effects. Non-carcinogenic risk relates to long-term exposure to contaminants in food, such as fish and water, while carcinogenic risk uses a slope factor to estimate the upper-bound lifetime probability of an individual developing cancer due to exposure to a specific level of potential carcinogen (PAHs). If the HQ value is below 1, the exposed population (consumers) is considered safe. However, if the HQ is 1 or higher, it indicates that human health is at risk, necessitating protective measures. It is important to note that the HQ parameter does not quantify risks; it merely indicates the risk level associated with exposure to pollutants. The non-carcinogenic risk was calculated using equation 1:

Health Hazard Quotient (HQ) = $HQ = \frac{EDI}{RfD}$ (1)

In this context, EDI refers to the daily intake exposure dose, while RfD stands for the oral reference dose. The oral reference dose is the amount of a substance that can be safely consumed daily without any identifiable risk over a lifetime. It represents the daily oral exposure for the human population that does not lead to harmful effects throughout life 41, 155. To determine EDIf and EDIw, which are the estimated daily intake or exposure doses from consuming fish and water (mg/kg/day), refer to equations 2 and 3 respectively.

$$EDI_f = \frac{CMf\ X\ IRf\ X\ CfX\ EF\ X\ ED}{BW\ X\ AT} \quad (2)$$

$$EDI_w = \frac{CMw\ X\ IRw\ X\ EF\ X\ ED}{BW\ X\ AT} \quad (3)$$

The carcinogenic health effect refers to the likelihood of an individual developing cancer over their lifetime due to exposure to a contaminant. This risk is estimated by multiplying the pollutant's oral slope factor (SF) by EDI, which represents daily exposure doses averaged over a lifetime, as shown in equation 4.

Cancer risk = EDI X SF (4)

Here, SF is the oral slope factor, indicating the percentage increase in cancer risk associated with daily exposure to a toxin (in mg of toxin per kg of body weight) over a lifetime.

Consequently, the PAHs Cancer Risk from consuming water or fish was estimated using equations 5 and 6.

$$\text{Cancer Risk} = \frac{CMw\ X\ IRw\ X\ EF\ XED}{BW\ X\ AT}\ X\ SF \quad (5)$$

$$\text{Cancer Risk} = \frac{CMf\ X\ IRf\ X\ EF\ XED}{BW\ XAT}\ X\ SF \quad (6)$$

In these equations, SF represents the oral slope factor for the PAHs. The USEPA has established that a carcinogenic health risk level of 1.0E-6 for any individual toxic metal or pollutant corresponds to a negligible cancer risk for one person out of a million.

The PAHs pollution index (PPI) is used to compare the total PAHs content at various sampling sites. The PPI serves as a valuable tool for evaluating PAHs pollution; a PPI value greater than 1 indicates pollution, while a value less than 1 suggests no pollution has occurred.

PAHs Pollution Index (PPI) $= (Ch_1\ X\ Ch_2 \ldots Ch_K)^{1/k}$

where,

$Ch_1$ = concentration value of the first PAH.

$Ch_2$ = concentration value of the second PAH.

$Ch_k$ = concentration value of the kth PAH.

Statistical Data Analysis and Precision

All determinations of PAHs were performed in triplicate, and the results were reported as mean and standard deviation to assess the precision of the equipment. This precision indicates how close the results of replicate samples are to each other or reflects the reproducibility of results from samples measured under identical conditions.

**Statistical Analysis**

The SPSS version 20 software package was utilized to calculate the mean values from the triplicate results, estimate the standard deviation, and conduct analysis of variance (ANOVA) at a significance level of less than 0.05 ($P<0.05$). Additionally, Principal Component Analysis (PCA) based on the Pearson Correlation matrix analysis and component plot in rotated space statistics were performed.

## RESULTS AND DISCUSSION

Tables 1-3 present six out of the sixteen priority PAHs identified by (USEPA, 2016; Ekpo et al., 2025) in the three media (Sediment, water & Fish) during this study. These compounds were detected and quantified. The other PAHs may not have been detected but not necessarily due to their absence but possibly because they were present at concentrations below the detection limit of the gas chromatography (GC). The PAHs that were detected and quantified include Benzo [b] fluoranthene, Naphthalene, Anthracene, Benzo [k] fluoranthene, Phenanthrene and Benzo [a] pyrene.

**Table 1**. Results of PAHs concentration in water (µg/L) reported as mean & standard deviation

| | LOCATIONS | | | | |
|---|---|---|---|---|---|
| **PAHs** | **A** | **B** | **C** | **D** | **E** |
| Naphthalene | ND | 0.380-0.040<br>0.420 ± 0.035 | ND | 0.190-0.080<br>0.543 ± 0.316 | ND |
| Phenanthrene | ND | ND | ND | 0.08-.009<br>0.083 ± 0.006 | ND |
| Anthracene | ND | ND | ND | 0.08-0.09<br>0.083 ± 0.006 | ND |
| Benzo[b]flouranthene | 0.080-0.100<br>0.093 ± 0.012 | 0.070-0.090<br>0.080± 0.010 | 0.060-0.110<br>0.087 ± 0.025 | 0.040-0.13<br>0.083 ± 0.045 | 0.060-012<br>0.090 ± 0.030 |
| Benzo[k]fluoranthene | 0.080-0.100<br>0.093 ± 0.012 | 0.080-0.090<br>0.087 ± 0.006 | 0.060-0.110<br>0.087 ± 0.025 | 0.040-0.130<br>0.083 ± 0.045 | 0.060-0.120<br>0.090 ± 0.030 |
| Benzo[a]pyrene | 0.08-0.100<br>0.090 ± 0.010 | 0.07-0.130<br>0.097 ± 0.031 | 0.100-0.110<br>0.103 ± 0.006 | 0.050-0.110<br>0.083 ± 0.031 | 0.100-0.120<br>0.113 ± 0.012 |

The average concentration of PAHs in water, measured in µg/L from stations A to E showed Naphthalene levels ranging from 0.420 to 0.543 µg/L, with no detection at stations A, C, and E. The concentrations for Phenanthrene and Anthracene were both 0.083, detected only at station D. The concentration of Benzo[b]fluoranthene and Benzo[k]fluoranthene varied from 0.080 to 0.093 across stations A to E, while Benzo[a]pyrene ranged from 0.083 to 0.113 µg/L, with the highest concentration found at station E. The mean concentration values of PAHs in sediment (see table 2) ranged from not detected at station D to 2.210 µg/kg at location A for Naphthalene across stations A to E, and from not detected at stations B, D, and E to 0.053 µg/kg at location C for Phenanthrene across the same stations. The mean concentration for Anthracene ranged from not detected to 0.053 µg/kg, while Benzo[b]fluoranthene ranged from not detected to 0.050 µg/kg. Benzo[k]fluoranthene had mean concentrations from not detected to 0.110 µg/kg, and Benzo[a]pyrene showed mean concentrations from not detected to 0.053 µg/kg, these results are in agreement with the work of (Obruche et al., 2022)

**Table 2**. PAHs concentration results for Sediments (µg/kg) presented as mean & standard deviation

| | | STATIONS | | | | |
|---|---|---|---|---|---|---|
| | **PAHs** | **A** | **B** | **C** | **D** | **E** |
| | Naphthalene | 2.120-2.270<br>2.210 ± 0.079 | 0.050-0.060<br>0.053 ± 0.006 | 1.740-1.960<br>1.850 ± 0.110 | ND | 1.580-1.640<br>1.610 ± 0.030 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Phenanthrene | 0.040-0.050<br>0.047 ±<br>0.006 | ND | 0.050-0.060<br>0.053 ±<br>0.006 | ND | ND |
| | Anthracene | 0.050-0.060<br>0.053 ±<br>0.006 | ND | 0.050-0.060<br>0.053 ±<br>0.006 | ND | ND |
| | Benzo[b]flouranthene | 0.040-0.110<br>0.100 ±<br>0.056 | 0.040-0.96<br>0.383 ±<br>0.494 | 0.050-0.060<br>0.053 ±<br>0.006 | 0.04-0.060<br>0.053 ±<br>0.011 | ND |
| | Benzo[k]fluoranthene | 0.040-0.150<br>0.093 ±<br>0.055 | 0.050-0.160<br>0.110 ±<br>0.056 | 0.050-0.070<br>0.057 ±<br>0.012 | 0.04-0.060<br>0.053 ±<br>0.011 | ND |
| | Benzo[a]pyrene | ND | 0.020-0.080<br>0.047 ±<br>0.031 | 0.050-0.060<br>0.053 ±<br>0.006 | 0.050-0.060<br>0.053 ±<br>0.006 | ND |

The average concentration of Naphthalene in catfish was 2.383 µg/kg (refer to table 3), which is higher than the 1.947 µg/kg found in Tilapia. The average concentrations for Phenanthrene in Catfish and Tilapia were 0.050 and 0.057, respectively, while both fish had an Anthracene concentration of 0.057 µg/kg, as indicated in table 3. For Catfish, the average concentrations of Benzo[b] fluoranthene and Benzo[k]fluoranthene were 0.043 µg/kg, and Benzo[a]pyrene was 0.05 µg/kg. In contrast, these compounds were not detected in Tilapia, as illustrated in figure 3. In summary, the PAH concentrations in water from various locations varied as follows: BbF (0.080 to 0.093), Ph (ND to 0.083), BkF (0.083 to 0.093), Nap (ND to 0.543), BaP (0.083 to 0.113), and Ant (ND to 0.083) mg/L with a distribution pattern of Nap > BaP > BbF = BkF > Ant = Ph, as shown in table 1. The PAH concentrations in sediment across locations were as follows: BbF (0.053 to 0.383), Nap (ND to 2.210), BkF (0.053 to 0.110), Ant (ND to 0.053), BaP (ND to 0.053) and Ph (ND to 0.053), mg/kg, with a distribution pattern of Nap > BbF > BkF > Ph = Ant = BaP, as shown in table 2. The average PAH concentrations in Catfish and Tilapia were as follows: Ant (0.057 and 0.057), Ph (0.050 and 0.057), BbF (0.043 and ND), BkF (0.043 and ND), BaP (0.050 and ND), and Nap (2.383 and 1.947), as detailed in table 3. This gives excellent agreement with the previously reported by Umanah et al. (2025), who reported similar results.

**Table 3**. PAHs concentration results in Fish (µg/kg) presented as mean & standard deviation

| PAHs | Catfish | Tilapia |
|---|---|---|
| Naphthalene | 2.340-2.420<br>2.383 ± 0.040 | 1.200-2.310<br>1.947 ± 0.647 |
| Phenanthrene | 0.040-0.060<br>0.050 ± 0.010 | 0.050-0.070<br>0.057 ± 0.012 |
| Anthracene | 0.040-0.080<br>0.057 ± 0.021 | 0.050-0.070<br>0.057 ± 0.012 |
| Benzo[b]flouranthene | 0.040-.0.050<br>0.043 ± 0.006 | ND |
| Benzo[k]fluoranthene | 0.040-0.050<br>0.043 ± 0.006 | ND |
| Benzo[a]pyrene | 0.040-0.060<br>0.050 ± 0.010 | ND |

The results for the estimated daily intake (EDI) of PAHs from drinking water and fish, along with the cancer risk (CR) for adults and children during both dry and rainy seasons, are presented. Tables 4-6 show the estimated daily intake (EDI) of PAHs from water consumption, calculated using the parameters from tables 1-3 for hazard quotients and cancer risk. The estimated daily intake (EDI) of polycyclic aromatic hydrocarbons from water and fish, as well as the associated cancer risk, are detailed in tables 1-3. Cancer risk calculations were only performed for Catfish, as no carcinogenic PAHs Benzo[a]pyrene), (Benzo[k]fluoranthene, and Benzo[b] fluoranthene were detected in Tilapia. These results agreed with the work of Abeokuta *et al*., (2025) he carried out in same river.

**Table 4**. Estimated daily intake (EDI) and cancer risk (CR) of PAHs from water ingestion for adults and children.

| Location | Nap | Ph | Ant | B[b]F | B[k]F | B[a]P |
|---|---|---|---|---|---|---|
| **A** | ND | ND | ND | $EDI_{Adult}$ 6.6E-8 $EDI_{Child}$ 3.1E-7 $CR_{Adult}$ 4.8E-8 $CR_{Child}$ 2.3E-7 $RI_{Adult}$ 0.05 $RI_{Child}$ 0.23 | $EDI_{Adult}$ 6.6E-8 $EDI_{Child}$ 3.1E-7 $CR_{Adult}$ 4.8E-9 $CR_{Child}$ 2.3E-8 $RI_{Adult}$ 0.005 $RI_{Child}$ 0.02 | $EDI_{Adult}$ 6.4E-8 $EDI_{Child}$ 3.0E-7 $CR_{Adult}$ 4.8E-7 **$CR_{Child}$ 2.2E-6** $RI_{Adult}$ 0.48 **$RI_{Child}$ 2.2** |
| **B** | $EDI_{Adult}$ 3.0E-7 $EDI_{Child}$ 1.4E-6 $HQ_{Adult}$ 1.5E-5 $HQ_{Child}$ 7.0E-5 | ND | ND | $EDI_{Adult}$ 5.7E-8 $EDI_{Child}$ 2.7E-6 $CR_{Adult}$ 4.2E-8 **$CR_{Child}$ 1.9E-6** $RI_{Adult}$ 0.04 **$RI_{Child}$ 1.9** | $EDI_{Adult}$ 6.2E-8 $EDI_{Child}$ 2.9E-7 $CR_{Adult}$ 4.5E-9 $CR_{Child}$ 2.1E-8 $RI_{Adult}$ 0.05 $RI_{Child}$ 0.02 | $EDI_{Adult}$ 6.9E-8 $EDI_{Child}$ 3.2E-7 $CR_{Adult}$ 5.1E-7 **$CR_{Child}$ 2.4E-6** $RI_{Adult}$ 0.51 **$RI_{Child}$ 2.4** |
| **C** | ND | ND | ND | $EDI_{Adult}$6.2E-8 $EDI_{Child}$ 2.9E-7 $CR_{Adult}$ 4.5E-8 $CR_{Child}$ 2.1E-7 $RI_{Adult}$ 0.05 $RI_{Child}$ 0.21 | $EDI_{Adult}$ 6.2E-8 $EDI_{Child}$ 2.9E-7 $CR_{Adult}$ 4.5E-9 $CR_{Child}$ 2.1E-8 $RI_{Adult}$ 0.005 $RI_{Child}$ 0.02 | $EDI_{Adult}$ 7.4E-8 $EDI_{Child}$ 3.4E-7 $CR_{Adult}$ 5.4E-7 **$CR_{Child}$ 2.5E-6** $RI_{Adult}$ 0.54 **$RI_{Child}$ 2.5** |
| **D** | $EDI_{Adult}$ 3.9E-7 $EDI_{Child}$ 1.8E-6 $HQ_{Adult}$ 1.9E-5 $HQ_{Child}$ 9.1E-5 | $EDI_{Adult}$ 5.9E-8 $EDI_{Child}$ 2.8E-7 $HQ_{Adult1}$ 2.0E-7 $HQ_{Child}$ 9.2E-7 | $EDI_{Adult}$ 5.9E-8 $EDI_{Child}$ 2.8E-7 $HQ_{Adult1}$ 2.0E-7 $HQ_{Child}$ 9.2E-7 | $EDI_{Adult}$ 5.9E-8 $EDI_{Child}$ 2.8E-7 $CR_{Adult}$ 4.3E-8 $CR_{Child}$ 2.0E-7 $RI_{Adult}$ 0.04 $RI_{Child}$ 0.2 | $EDI_{Adult}$ 5.9E-8 $EDI_{Child}$ 2.8E-7 $CR_{Adult}$ 4.3E-9 $CR_{Child}$ 2.0E-8 $RI_{Adult}$ 0.004 $RI_{Child}$ 0.02 | $EDI_{Adult}$ 5.9E-8 $EDI_{Child}$ 2.8E-7 $CR_{Adult}$ 4.3E-7 **$CR_{Child}$ 2.0E6** $RI_{Adult}$ 0.43 **$RI_{Child}$ 2.0** |
| **E** | ND | ND | ND | $EDI_{Adult}$ 6.4E-8 $EDI_{Child}$ 3.0E-7 $CR_{Adult}$ 4.7E-8 $CR_{Child}$ 2.2E-7 $RI_{Adult}$ 0.05 $RI_{Child}$ 0.22 | $EDI_{Adult}$ 6.4E-8 $EDI_{Child}$ 3.0E-7 $CR_{Adult}$ 4.7E-9 $CR_{Child}$ 2.2E-8 $RI_{Adult}$ 0.005 $RI_{Child}$ 0.02 | $EDI_{Adult}$ 8.1E-8 $EDI_{Child}$ 3.8E-7 $CR_{Adult}$ 5.9E-7 **$CR_{Child}$ 2.7E-6** $RI_{Adult}$ 0.59 **$RI_{Child}$ 2.7** |

**Table 5**. Estimated daily intake (EDI), Hazard Quotient (HQ) and Cancer risk (CR) of PAHs in Catfish via ingestion for Adult and a Child

| Location | Nap | Ph | Ant | B[b]F | B[k]F | B[a]P |
|---|---|---|---|---|---|---|
| Catfish | $EDI_{Adult}$ 3.5E-7<br>$EDI_{Child}$ 5.4E-7<br>$HQ_{Adult}$ 1.7E-5<br>$HQ_{Child}$ 2.7-5 | $EDI_{Adult}$ 7.3E-9<br>$EDI_{Child}$ 1.1E-8<br>$HQ_{Adult}$ 2.4E-8<br>$HQ_{Child}$ 3.8E-8 | $EDI_{Adult}$ 8.3E-9<br>$EDI_{Child}$ 1.3E-8<br>$HQ_{Adult}$ 2.8E-8<br>$HQ_{Child}$ 4.3E-8 | $EDI_{Adult}$ 3.0E-8<br>$EDI_{Child}$ 4.7E-8<br>$CR_{Adult}$ 2.2E-8<br>$CR_{Child}$ 3.4E-8<br>$RI_{Adult}$ 0.02<br>$RI_{Child}$ 0.03 | $EDI_{Adult}$ 3.0E-8<br>$EDI_{Child}$ 4.7E-8<br>$CR_{Adult}$ 2.2E-9<br>$CR_{Child}$ 3.4E-9<br>$RI_{Adult}$ 0.002<br>$RI_{Child}$ 0.003 | $EDI_{Adult}$ 3.5E-8<br>$EDI_{Child}$ 5.4E-8<br>$CR_{Adult}$ 2.6E-7<br>$CR_{Child}$ 3.9E-7<br>$RI_{Adult}$ 0.26<br>$RI_{Child}$ 0.39 |

**Table 6**. Estimated daily intake (EDI), Hazard Quotient (HQ) and Cancer risk (CR) of PAHs in Tilapia via ingestion for Adult and Child

| Location | Nap | Ph | Ant | B[b]F | B[k]F | B[a]P |
|---|---|---|---|---|---|---|
| Tilapia | $EDI_{Adult}$ 2.8E-7<br>$EDI_{Child}$ 4.4E-7<br>$HQ_{Adult}$ 1.4E-5<br>$HQ_{Child}$ 2.2E-5 | $EDI_{Adult}$ 8.3E-9<br>$EDI_{Child}$ 2.8E-9<br>$HQ_{Adult\times}$ 2.8E-8<br>$HQ_{Child}$ 9.3E-9 | $EDI_{Adult}$ 8.3E-9<br>$EDI_{Child}$ 2.8E-9<br>$HQ_{Adult\times}$ 2.8E-8<br>$HQ_{Child}$ 9.3E-9 | ND | ND | ND |

The Outcomes of the Ecological Risk Assessment of PAHs in Water, Sediment, and Fish.

The pollution index assessment results for PAHs in rivers, sediments, and fish were calculated and presented in table 7. The parameters generated in tables 1-3 were utilized to evaluate the pollution condition of the sediments and water. The findings regarding the polycyclic aromatic hydrocarbons pollution index (PPI) are illustrated in table 7.

**Table 7**. PAHs Pollution Index (PPI) for Water, Sediment, and Fish.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| PPI of Water | 0.10 | 0.13 | 0.10 | 0.11 | 0.10 |
| PPI of Sediment | 0.14 | 0.10 | 0.10 | 0.05 | - |
| PPI of Catfish | 0.10 | | | | |
| PPI of Tilapia | 0.10 | | | | |

**Source Identification and Statistical Correlation of PAHs.**

The data collected for PAHs underwent Principal Component Analysis (PCA) using the correlation matrix to analyze the relationships and trends among pollutants, helping to determine if these pollutants originate from multiple sources. Table 8 shows the Correlation Matrix of PAHs found in water, sediment, and fish samples

**Table 8.** Correlation Matrix of PAHs in water, Sediment and Fish samples

| | NapW | PhW | ANw | BbFw | BkFw | BaPw | Naps | PHs | ANs | BbFs | BkFs | Baps | NaPf | PHf | ANf | BbFf | BkFf | BaPf |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NapW | 1 | | | | | | | | | | | | | | | | | |
| PhW | .632* | 1 | | | | | | | | | | | | | | | | |
| ANw | .632* | 1.000** | 1 | | | | | | | | | | | | | | | |
| BbFw | .143 | -.110 | -.110 | 1 | | | | | | | | | . | | | | | |
| BkFw | .201 | -.142 | -.142 | .976** | 1 | | | | | | | | | | | | | |
| BaPw | -.076 | -.386 | -.386 | .478 | .465 | 1 | | | | | | | | | | | | |
| Naps | -.870** | -.611* | -.611* | .202 | .137 | .233 | 1 | | | | | | | | | | | |
| PHs | -.585* | -.403 | -.403 | .094 | .048 | .000 | .758** | 1 | | | | | | | | | | |
| ANs | -.588* | -.405 | -.405 | .107 | .061 | -.044 | .763** | .972** | 1 | | | | | | | | | |
| BbFs | .265 | -.148 | -.148 | .044 | .025 | .328 | -.313 | -.152 | -.144 | 1 | | | | | | | | |
| BkFs | .206 | -.125 | -.125 | .054 | .041 | -.316 | -.163 | .196 | .214 | .509 | 1 | | | | | | | |
| Baps | .[a] | .[a] | .[a] | .[a] | .[a] | .[a] | .[a] | .[a] | .[a] | .[a] | .[a] | .[a] | | | | | | |
| NaPf | -.420 | .[a] | .[a] | .327 | .598 | .529 | .507 | .506 | .494 | .064 | -.578 | .[a] | 1 | | | | | |
| PHf | .285 | .[a] | .[a] | -.213 | -.433 | -.531 | -.349 | -.350 | -.351 | -.029 | .872* | .[a] | -.800 | 1 | | | | |
| ANf | -.046 | .[a] | .[a] | .146 | .000 | -.407 | .016 | .034 | -.030 | -.090 | .853* | .[a] | -.423 | .857* | 1 | | | |
| BbFf | -.984** | .[a] | .[a] | .642 | .466 | -.175 | .992** | .989** | .971** | -.425 | -.085 | .[a] | .499 | -.269 | .129 | 1 | | |
| BkFf | -.984** | .[a] | .[a] | .642 | .466 | -.175 | .992** | .989** | .971** | -.425 | -.085 | .[a] | .499 | -.269 | .129 | 1.000** | 1 | |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BaPf | -.970** | .[a] | .[a] | .470 | .239 | -.241 | .966** | .937** | .991** | -.417 | -.106 | .[a] | .479 | -.276 | .047 | .963** | .963** | 1 |

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

**Correlation Analysis and Source Identification**

The average concentration levels of PAHs in water, sediment, and fish (see tables 1-3) underwent correlation analysis to streamline the data without any loss, aiming to uncover any hidden trends. Correlation is useful for identifying and highlighting any concealed relationships within the data. This method employs a multivariate technique known as Principal Component Analysis (PCA), which identifies different groups of polycyclic aromatic hydrocarbons that are correlated. When PAHs are correlated, it suggests they may behave similarly and could share a common source. Consequently, the correlation matrix of the PAHs illustrates the relationships among the data variables, as presented in table 8. Table 8 of the correlation matrix revealed varying correlations among the different PAHs in water, sediment, and fish, ranging from -0.970 to 1.000 at significance levels of 0.05 and 0.01. At the 0.05 significance level, there is a correlation between Naphthalene and Phenanthrene in water (0.632), as well as between Naphthalene and Anthracene in water (0.632). Additionally, there is a strong, positive & perfect correlation with Phenanthrene in water (1.000). At the 0.01 significance level, a very strong positive correlation exists between Benzo[b]fluoranthene and Benzo[k]fluoranthene in water (0.976). Naphthalene in sediment exhibited a strong negative correlation with Naphthalene in water (-0.870) at the 0.01 significance level, and with Anthracene and Phenanthrene in water (-0.611) at the 0.05 significance level. Furthermore, Phenanthrene in sediment showed a moderate negative correlation with Naphthalene in water (-0.585) at the 0.05 significance level, while it had a positive correlation with Naphthalene in sediment (0.758) at the 0.01 significance level. Ugochukwu et al., (2025) had similar view in their findings in the analysis of PAH in fish, sediment and water in Warri River.

Anthracene found in sediment had a negative correlation with Naphthalene in water (-0.588) at a significance level of 0.05. It showed a positive correlation with Naphthalene in sediment (0.763) and a strong positive correlation with Phenanthrene in sediment (0.972) at a significance level of 0.01. Meanwhile, Benzo[k]fluoranthene in sediment was positively correlated with Phenanthrene in fish (0.872). Anthracene in fish also had a positive correlation with Benzo[k]fluoranthene in sediment (0.853) and with Phenanthrene in fish (0.857) at a significance level of 0.05. Benzo[b]fluoranthene, Benzo[k]fluoranthene, and Benzo[a]pyrene in fish exhibited strong negative correlations with Naphthalene in water (-0.984, -0.984, and -0.970), but showed strong positive correlations with Naphthalene in sediment (0.992, 0.992, and 0.966), Phenanthrene in sediment (0.989, 0.989, and 0.937), and Anthracene in sediment (0.971, 0.971, and 0.991) at a significance level of 0.01. Additionally, Benzo[a]pyrene in fish had a strong positive correlation with both Benzo[b]fluoranthene and Benzo[k]fluoranthene in fish (0.963). Benzo[k]fluoranthene was strongly positively and perfectly correlated with Benzo[b]fluoranthene at a significance level of 0.01. All these correlations presented in table 8 indicate that these PAHs behave similarly and are likely derived from the same source. Benzo[a]pyrene is often used as a marker for PAHs from combustion, and its correlation with other PAHs supports the idea that combustion is the main source of PAHs that have leached into the water through runoff. However, examining the mean concentration values of the PAHs shows no significant differences in the concentration levels of the PAHs across the three media (water, sediment, and fish). The observed results are in tandem with the PAHs synthesized by Festus-Amadi et al., (2021). Concentration of PAHs in sediment samples regarding ecological risk assessment.

The ecological risk posed by polycyclic aromatic hydrocarbons (PAHs) to organisms, including plants and animals, was evaluated due to sediment contamination by PAHs. This was done by calculating the Pollution Load Index, contamination factor, and the Polycyclic Aromatic Pollution Index (PPI). The sediments underwent testing with the PPI, which indicated that they were not contaminated with PAHs, as all PPI values were below 1 (PPI<1). Polycyclic aromatic hydrocarbons in water, fish, and sediment samples concerning health and ecological risk assessment. A cancer risk model was utilized to estimate the health risks associated with the ingestion of carcinogenic PAHs, which the USEPA classifies as probable human carcinogens. The carcinogenic PAHs identified in the water, fish, and sediments in this study included Benzo[b]fluoranthene (BbF), Benzo[k]fluoranthene (BkF), and Benzo[a]pyrene (BaP). Additionally, a hazard quotient model was applied to estimate non-carcinogenic health risks for other PAHs, such as Naphthalene, Phenanthrene, and Anthracene, found in this research.

The estimated daily intakes of PAHs were calculated, and cancer risks were assessed for water and fish consumption. The carcinogenic PAHs were evaluated for cancer risk and cancer risk index. It was found that the cancer risk and carcinogenic cancer risk for Benzo[b]fluoranthene, Benzo[k]fluoranthene, and Benzo[a]pyrene were within or below acceptable limits,

except for Benzo[a]pyrene at location E, which had a cancer risk value of 3 per one million people and a cancer risk index of 2.7, exceeding the limit of 1 per million individuals.

The level of PAHs in catfish indicated a cancer risk and a cancer risk index that remained within acceptable limits. The three carcinogenic PAHs (Benzo[b]fluoranthene, Benzo[k]fluoranthene, and Benzo[a]pyrene) were not found in Tilapia fish. It was evident that pollution was significantly noted at locations D and E, which are below location C. This could be due to the presence of a mini or local port between locations C and D on the Lokoja bank, opposite the Shintaku bank. People from Shintaku in the Bassa local government area and nearby areas frequently travel to and from Lokoja, resulting in increased vehicle and boat traffic. Additionally, the use of petroleum products at these banks for boat engines, along with the spillage of engine oil and other petroleum products during repairs and maintenance, contributes to the pollution. This finding aligns with a study of Obruche et al., (2029) in ughelli river that claimed canoe landing sites are more polluted than inner fishing harbors due to various human activities, including fishmongers smoking fish at these sites, which adds more PAHs. The concentration of Benzo[a]pyrene in water and catfish is notably high compared to the concentration limit of 0.01 µg/L in water set by Environment Canada. As a common marker for PAHs from combustion, its presence above the limit suggests a risk of PAHs for the confluence of the Niger and Benue rivers.

## CONCLUSION

Health is often referred to as wealth, so people have always sought to understand how to avoid anything that could harm their health. Among the substances that can negatively impact human health through various issues are PAHs, which this research study aims to evaluate for the first time in this field. The study was designed to investigate and estimate the concentration of PAHs in the confluence of the Niger River's water, fish, and sediment, as well as to assess the human health and ecological risks involved. The findings indicate that the levels of PAHs in the fish, sediment and water pose a moderate risk that requires immediate attention. The fish samples (cat fish and tilapia fish) have the highest concentration of PAHs. This is due to the fact that both fishes feed from both the sediment and water and also come in contact with both the sediment and water regularly. Sediment is the second most contaminated of PAHs, this due to the fact that PAHs do settle at the base of the oil. Therefore, it is essential to promote good hygiene practices, prevent indiscriminate waste dumping in water bodies, and curb the burning of tires, organic materials, and petroleum products, which are the primary sources of PAHs. Additionally, stricter laws should be established and enforced to regulate bush burning and waste disposal. Regular monitoring should also be conducted to prevent the unintentional consumption of excessive pollutants (PAHs) if their levels in the environment rise to dangerous levels.

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