International Journal of Sustainable Technology, Environmental Sciences and Conservation (IJSTESC)
Volume 1, Issue 1, 22 – 33.
www.nyenkemjournals.com

Health Risk Assessment of Exposure to Polycyclic Aromatic Hydrocarbons (PAHs) in Oruma River, Bayelsa State

James Bobby Yibatoro-iyela [1]*, Ugom Michael Kenneth [2], Nnaukwu Chimezie [2], Daniel Edu Kanu [2], Ikechukwu Gospel Chibuzor [2]

[1] Department of Environmental Management, University of Africa Toru-Orua, Bayelsa State, Nigeria.

[2] Centre for Environmental Management and Green Energy (CEMAGE), University of Nigeria, Enugu Campus, Nigeria.

***Correspondence:** yibatoro-iyela.james@uat.edu.ng

Received: 30 July 2025 / **Accepted:** 26 August 2025 / **Published:** 28 August 2025

Abstract

Polycyclic aromatic hydrocarbons (PAHs) are known hydrocarbon contaminants commonly found in our environment from both anthropogenic and natural activities. PAHs are very persistent group of compounds from petroleum hydrocarbon that can stay in the environment (both land and water) for a very long time. These PAHs are known to have carcinogenic properties that are dangerous to the health of plants and animals that come in contact with them. This study evaluated the carcinogenic health risk associated (exposure) with the known eight (8) PAHs with carcinogenic potentials beginning with the analysis of their concentrations from water samples collected from Oruma River, Bayelsa State during wet season. This study adopted liquid-liquid extraction method and Gas Chromatography and Mass Spectometry (GC-MS) to separate and analyse the concentrations of seven water samples collected from the study area, respectively. The carcinogenic risk of exposure (probability of developing cancer over a lifetime as a result of exposure to a contaminant) to the carcinogenic PAHs was evaluated using the equations; $CR = CDi \times SF$ and $CR = CDd \times SF$, for oral and dermal exposures, respectively for both adults and children. The results showed that benzo (a) pyrene values for carcinogenic risk via oral intake for adults went as high as 6.69E-02, 3.68E-02, 3.60E-02, 3.58E-02, 3.56E-02, 3.55E-02 and 3.57E-02, exceeding the acceptable limit of 1×10^{-6} and 1×10^{-4}. Similar high levels of carcinogenic risk from chrysene were recorded for oral intake children with 1.56E-01, 8.58E-02, 8.40E-02, 8.36E-02, 8.31E-02, 8.28E-02, and 8.32E-02, all exceeding the permissible limit. Dibenz (a, h) anthracene also recorded exceedingly high values for children via oral intake and dermal exposure. The study showed that children are more exposed to suffering from carcinogenic health issues than adults. Some PAHs had values higher than the acceptable limits of 1×10^{-6} and 1×10^{-4} with children showing higher vulnerability to carcinogenic risk than the adults. Therefore, all concerned stakeholders should work together to decontaminate the Oruma River for the use of the community. This study gives a detailed analysis of the concentration of the 16 priority polycyclic aromatic hydrocarbons (PAHs), and the evaluation of the carcinogenic health risk of exposure to the eight (8) polycyclic aromatic hydrocarbons for both adults and children via oral intake and dermal contact.

Keywords: Polycyclic Aromatic hydrocarbons, Health Risk of Exposure, Carcinogenic Risk, Risk Assessment, Incremental Lifetime Cancer Risk, Chronic Exposures.

1. Introduction

Petroleum resources gotten from beneath the earth have great value, and they have in no small measure helped many nations to address their energy need and boost the economic performance of their countries. This is more common with oil producing countries, which Nigeria is a common example, for over the last five (5) decades

(Ite et al., 2016). However, in many parts of the world with much emphasis on Nigeria, this supposed means for economic performance and addressing energy need has given rise to serious environmental and health issues which is well noticed in the very regions producing this resource. Studies have revealed that compounds like Polycyclic Aromatic Hydrocarbon (PAHs) from petroleum consisting fused benzene rings are serious contaminants that are dangerous to the environment. Studies have further revealed that these PAHs are widely common in the environment and are easily found in the air, water and soil. As a result of this problem plants, animals and humans are highly exposed to suffer from these contaminants (Smith et al., 2022). Studies have never supported the positive contribution of PAHs to the growth of plants and animals, even humans. More so, it has also revealed that PAHs have serious negative impact on different species of aquatic organisms (Horward et al., 2021).

It is important to analyse the contamination of Polycyclic Aromatic Hydrocarbons (PAHs) because it would serve as a good source of information for regulators and other stakeholders. There has been numerous analysis of water, soil and air samples collected from different parts of African countries, and high levels of PAHs were seen in water, soil, indoor and outdoor air, and smoked food (Ofori et al., 2020). It is possible for hydrocarbons found in sediments to bioaccumulate and continue to exist in food chain, even affecting birds. One of the key causes of PAHs water contamination in Nigeria, especially in the Niger Delta region is from artisanal refining of crude oil. The process is illegal and unregulated using environmentally unfriendly local techniques to refine crude oil (Benson et al., 2022).

Studies also revealed that some polycyclic aromatic hydrocarbons (PAHs) such as Naphthalene and Phenanthrene are commonly found in water existing in dissolved form. PAHs have shown high levels of toxicity to animals, as it was reported that birds living in aquatic environments taking in considerable doses of oil suffer reproductive problems (Grau, Roudybush, Dobbs and Wathen, 1997). Studies have shown that PAHs in the environment (aquatic and terrestrial) are threat to the health of plants and animals because of their toxicity. Studies have also revealed that these PAHs have the potential of causing cancer and mutation. Because of this toxic potential of PAHs, the United States Environmental Protection Agency established certain PAHs as human carcinogens, they are Chrysene, benzo[b]fluoranthene, dibenzo[a,h]anthrcene, Benzo[a]anthracene, benzo[a]pyrene, benzo[k]fluoranthene, dibenzo[a,h]anthrcene and Indeno (1,2,3-cd) pyrene. High exposure to these PAHs during prenatal period by women leads to lower intelligent Quotient (IQ) (Lee, Liow, Tsai and Hsieh, 2002). Incremental lifetime cancer risks for children and adults via drinking groundwater and skin contact were from ND (not detected) to 7.44 × 10-3 and ND (not detected) to 1.83 × 10-3 , respectively in drinking water wells in Nsisioken community, Rivers State. From the reported risk index (RI), the risk for cancer was very high showing 1.5 × 10-2 and 2.5 × 10-2 for ingestion and dermal pathways, respectively (Chinemerem et al., 2024). Exposure to PAHs in contaminated water through ingestion and skin contact has led to high risks of cancer diseases, such as gastrointestinal diseases, lungs problems, skin diseases, and others. Children are considered to be more prone to suffering from this exposure than adults Akanimo et al., (2022). In a study, the expected lifetime cancer risk for water exposure shows that in a million (1,000,000) of people one person is at risk of suffering from cancer ailments. It further revealed that children would suffer from cancer ailments in every seven (7) out of 10,000,000 from ingestion of PAHs contaminated water in the study area (Ibrahim et al., 2024). Further studies on the incremental lifetime cancer risk (ILCR) revealed that children are more prone to suffering from cancer ailments than adults in their lifetime with values falling within the range of 10-2 and 10-3 (Ganiyu et al., 2024). Another study revealed that the carcinogenic risk via dermal contact had higher values than the acceptable risk levels for both adults and children, with children having higher chance of suffering cancer related diseases (Ekanem et al., 2022).

Due to the activities of artisanal refining of crude oil along the Kolo Creek River, and because of the health challenges that have been connected to exposures to

PAHs contaminated water bodies via oral intake and dermal contact; it became important to study the quality of the Oruma River to know the level of the 16 priority PAHs concentrations and the carcinogenic health risk of exposure to these PAHs because there was no related study by researchers on this issue.

2. Methodology

2.1. Study Area

The study area is Oruma River, an Ijaw speaking community in Ogbia Local Government Area of Bayelsa State, situated in the Niger Delta region of Nigeria. The community is located within longitudes 4^0 54' 54" N and 4^0 55' 15" N and lattitudes 6^0 25' 05" E and 6^0 25' 21" E (Google Earth, 2019). It is one of the communities upstream of the kolo creek. The Oruma River is one among several Rivers jointly cutting across some communities in Ogbia Local Government Area.

The population of the study area (Oruma community) has been estimated to be over 11,000 people (CENSUS, 2006).

The Kolo Creek area as defined by this study includes all the communities around the Kolo Creek where oil exploration and exploitation activities are ongoing in the Ogbia Local Government Area. It is located within longitudes 4^0 55' 52.25" N and 4^0 55' 31.92" N and latitudes 6^0 20' 11.94" E and 6^0 24' 50.70" E including the towns of Imiringi, Otuasega, Elebele, Oruma and Ibelebiri (Ezekwe, 2018). The Niger Delta area is situated in the southern part of Nigeria. Numerous creeks, rivers are found in this area, and it possesses the world's largest wetland with significant biological diversity. The Niger Delta Basin, which lies within latitudes 3° and 6° N and longitudes 5° and 8° E, occupies the Gulf of Guinea continental margin in equatorial West Africa (Adegoke, 2017).

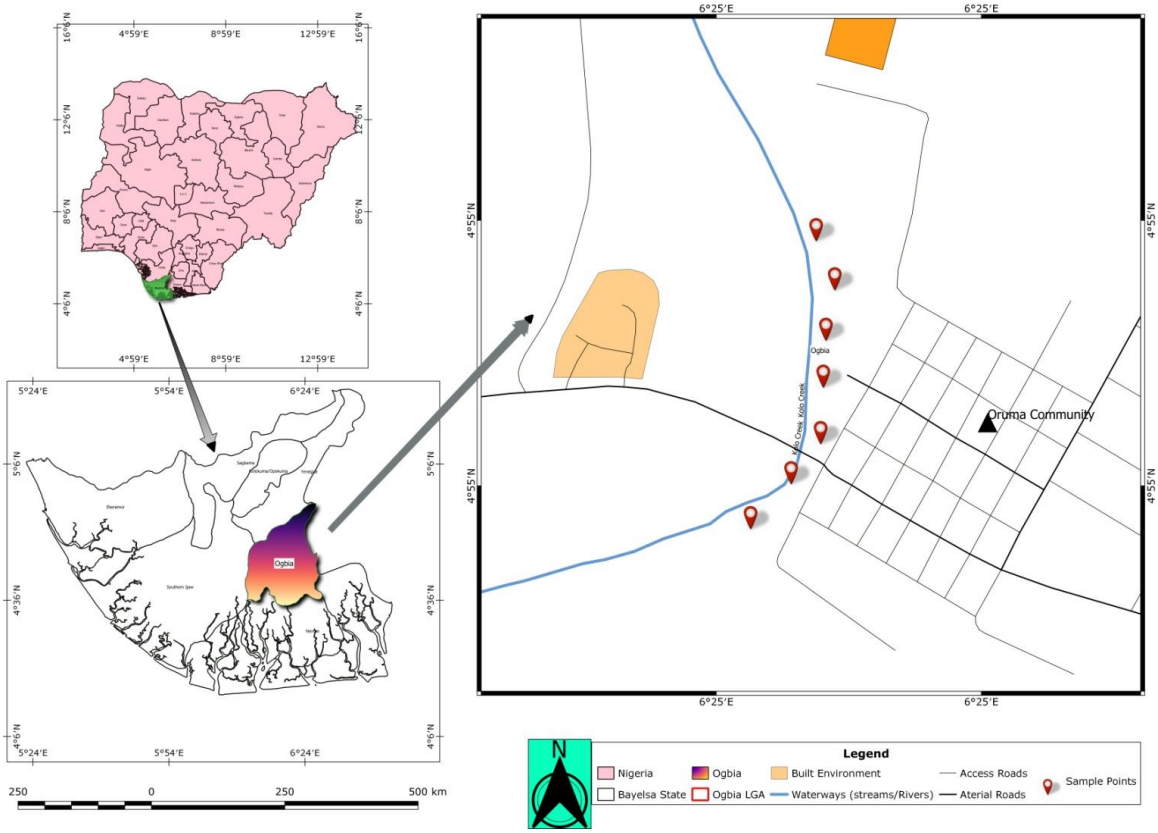

Figure 1: Map of Nigeria showing Bayelsa State, different Local Government Areas and the study area showing the kolo creek.
(Source: Digitized Google Earth Map, 2023)

2.2. Sample Collection and Preparation

A total of fourteen (14) water samples were collected from the study area during the rainy season. The samples were collected from seven selected points along the Oruma River twice during the wet season. The water samples were collected in clean, dry pretreated amber bottles equipped with Teflon cap. The samples were quickly moved to the laboratory in an ice chest cooler below 4 °C for analysis. On arrival at the lab, the samples were stored in a refrigerator at 4^{o}C or lower.

2.3. Reagents Used

The following reagents were used: series of PAH Primary Standards (AccuStandards), n-Hexane for separation of aliphatic from total petroleum hydrocarbon, Dichloromethane (DCM), HPLC grade, Sodium Sulphate - Analar grade, anhydrous, concentrated chromic acid prepared by quantitatively mixing Potassium dichromate salt with concentrated sulphuric acid.

2.4. Testing Procedure and Analysis of PAHs in Water Samples

Liquid- Liquid Extraction method was used for the water sample. The polycyclic aromatic hydrocarbons were determined using a Gas Chromatograph (Hewlet Parkard HP 5890) equipped with chem workstation software, capillary column.

The samples were extracted after acclimatization to room temperature. The entire volume of samples was carefully transferred into hydrocarbon free 1000ml separating funnel, and then spiked with 0.1ml of internal standard (d8 Naphthalene). A known volume of a mixture of n-hexane and dichloromethane in the ratio of 3:1 was added. The water sample was then extracted only by very gentle shaking for about five minutes. The mixture was re-clamped and allowed the aqueous – organic phase in the funnel to separate out. These steps were repeated twice. The total sample to extractant ratio was 10:1.The water sample was re-extracted with the same volume of extractant as described above. The extract was then cleansed using neutral alumina column. The extract was stored in a dried organic free and chromic acid pre – clean vial.1.0 µl of the extract was withdrawn with an automated gas-tight syringe of the autosampler and analyzed by direct injection into the GC preset at a specific condition. The analysis was allowed to run and data was quantified at the end of the analysis.

2.5. Equipment/Apparatus

Gas Chromatograph (Hewlet Parkard HP 5890) equipped with chem workstation software, Capillary column, Filter Paper (Ashless, Quantitative), Clean, Dry Amber Bottles equipped with Teflon cap (extraction bottle), Vials for storing extracts (2ml), Glass funnel, Sonicator, Separatory funnel (2000ml), 50ml volumetric flask, 100ml clean and dried conical flask, 100ml sintered glass funnel, Clamp and stand, Refrigerator (specially designated for storage of standards at 4^{o}C), and Refrigerator for the storage of extracts (at 4^{o}C).

2.6. Statistical Analysis of Data

Data obtained from the laboratory were made to undergo descriptive statistics for mean, charts, and tables etc., using Microsoft excel version 2016 software.

3. Results and Discussion

Table 1 below shows the average results of laboratory analysis of the water samples collected for all the two times sampling in the wet season to achieve the first objective of the research. From the table, the 16 priority polycyclic aromatic hydrocarbons (PAHs) were all detected in the analysis. In the table, sample point A had its highest concentration from chrysene with 1.58E+00 (mg/l), followed by the concentration of anthracene with 1.29E+00 (mg/l). The lowest and highest values for sample B were from Benzo (b) fluoranthene and pyrene. In sample C, pyrene had 8.75E-01 (mg/l) as highest concentration with the lowest of 2.89E-02 (mg/l) from benzo (b) fluoranthene. Same with sample D and E, were pyrene recorded the highest concentrations with 3.20E-01 (mg/l) and 4.10E-01 (mg/L), respectively. This similar trend occurred in sample F for pyrene having the highest of concentration with 4.10E-01 (mg/l). Sample G had a range of values from 2.60E-02 to 3.41E-01 (mg/l) where benzo(b)

fluoranthene and pyrene recorded the lowest and highest concentrations.

Table 1: Concentrations of the 16 priority polycyclic aromatic hydrocarbons (PAHs) (mg/l)

PAHs	A	B	C	D	E	F	G	MEAN
Napthalene	1.63E-01	1.48E-01	1.45E-01	1.46E-01	1.49E-01	1.47E-01	1.47E-01	1.49E-01
Acenaphthylene	2.41E-01	2.76E-01	2.38E-01	2.32E-01	2.48E-01	2.35E-01	2.32E-01	2.43E-01
Acenaphthene	2.72E-01	2.49E-01	2.48E-01	2.53E-01	2.51E-01	2.50E-01	2.49E-01	2.53E-01
Fluorene	2.07E-01	1.65E-01	1.59E-01	1.56E-01	1.74E-01	1.57E-01	1.60E-01	1.68E-01
Phenanthrene	1.94E-01	1.85E-01	1.91E-01	1.88E-01	3.47E-01	1.88E-01	1.85E-01	2.11E-01
Anthracene	1.29E+00	1.39E-01	1.34E-01	1.33E-01	1.70E-01	1.57E-01	1.60E-01	3.12E-01
Fluoranthene	2.26E-01	2.32E-01	2.34E-01	2.26E-01	2.40E-01	2.26E-01	2.25E-01	2.30E-01
Pyrene	2.91E-01	1.99E+00	8.75E-01	3.20E-01	4.10E-01	4.10E-01	3.41E-01	6.62E-01
Chrysene	1.58E+00	1.29E-01	1.57E-01	1.15E-01	1.22E-01	1.14E-01	1.13E-01	3.32E-01
Benz (a) anthracene	1.60E-01	1.55E-01	1.39E-01	1.40E-01	1.45E-01	1.38E-01	1.38E-01	1.45E-01
Benzo (b) fluoranthene	5.43E-02	2.92E-02	2.89E-02	2.59E-02	2.71E-02	2.66E-02	2.60E-02	3.11E-02
Benzo (k) fluoranthene	5.80E-02	4.72E-02	4.55E-02	4.61E-02	4.85E-02	4.55E-02	4.77E-02	4.84E-02
Benzo (a) pyrene	3.21E-01	1.76E-01	1.73E-01	1.72E-01	1.71E-01	1.70E-01	1.71E-01	1.93E-01
Indeno (1,2,3-cd) pyrene	5.07E-02	4.64E-02	4.97E-02	4.79E-02	7.28E-02	4.57E-02	5.16E-02	5.21E-02
Benzo (g, h, i) perylene	1.22E-01	1.22E-01	1.30E-01	1.22E-01	3.20E-01	1.19E-01	1.21E-01	1.51E-01
Dibenz (a, h) anthracene	3.60E-02	4.10E-02	3.37E-02	3.27E-02	3.36E-02	3.39E-02	3.31E-02	3.49E-02
Total in ppm	5.26E+00	4.13E+00	2.98E+00	2.36E+00	2.93E+00	2.46E+00	2.40E+00	3.22E+00

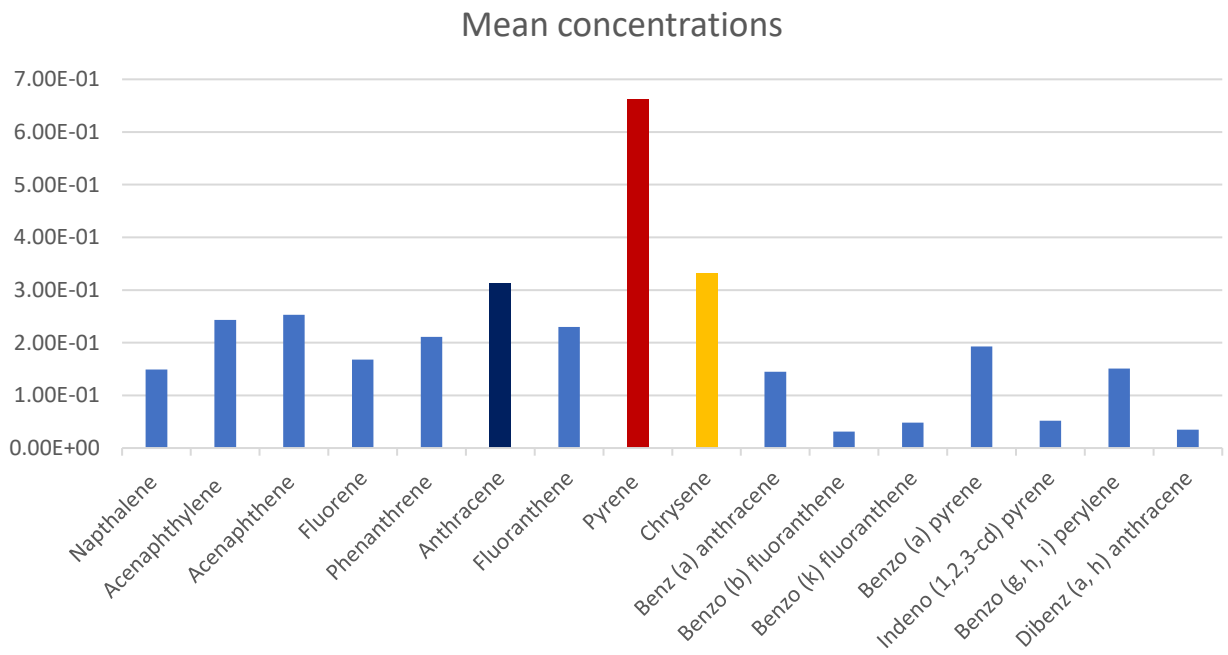

Figure 2: Mean concentrations of individual PAHs.

3.1. Carcinogenic Risk Assessment

The CR was used to calculate or estimate the probability of a person developing cancer after being exposed to a contaminant over a lifetime. The probability of developing cancer over a lifetime as a result of exposure to a contaminant. The CDi and CDd are the chronic exposures through ingestion and dermal absorption and SF is the corresponding slope factor.

$$CR = CDi \times SF \qquad (1)$$

$$CR = CDd \times SF \qquad (2)$$

where, the CR = probability of developing cancer over a lifetime as a result of exposure to a contaminant. The CDi and CDd = chronic exposures through ingestion and dermal absorption and SF = corresponding slope factor of the PAH (mg/kg/day) (Olayinka *et al*. 2018).

This is because of the exposure to a potential carcinogen, and it means a person may have cancer in 70 years' lifetime. The value $\leq 1 \times 10^{-6}$ is accepted as the standard limit of cancer risk set by USEPA which is taken on average. The cancer risk values ranging between 1×10^{-6} and 1×10^{-4} are accepted. Therefore, by acceptable standard, any value higher than 1×10^{-4} is not accepted and could cause cancer over a period of time (USEPA 1999).

Table 2 below shows the readily available values of oral slope factor (OSF) and dermal slope factor (CSF) used to estimate the carcinogenic risk of the PAHs in the study season.

Table 2: The Slope factors and toxicity response (dose- response) of polycyclic aromatic hydrocarbons (PAHs).

PAH	Ingestion OSF (mg/kg/day)$^{-1}$	Ingestion RfD (mg/kg/day)		Dermal CSF	Dermal RfD
Napthalene	NA	0.04		NA	0.02
Acenaphthylene	0.0073	0.06		0.0073	0.06
Acenaphthene	0.073	0.006		0.073	0.02
Fluorene	NA	0.04		NA	0.04
Phenanthrene	NA	0.04		NA	NA
Anthracene	NA	0.3		NA	0.3
Fluoranthene	0.073	0.04		0.073	0.04
Pyrene	0.73	0.03		0.73	0.03
Chrysene	0.0073	0.03		0.0073	0.03
Benz (a) anthracene	0.73	0.03		0.73	0.03
Benzo (b) fluoranthene	0.73	0.03		0.73	0.03
Benzo (k) fluoranthene	0.0073	0.03	0.03	0.0073	0.03
Benzo (a) pyrene	7.3	0.03		7.3	0.03
Indeno (1,2,3-cd) pyrene	0.73	0.03	0.03	0.73	0.73
Benzo (g, h, i) perylene	0.073	0.03	0.03*	0.073	0.03
Dibenz (a, h) anthracene	7.3	0.03	0.03	7.3	0.03

USEPA (2005), USEPA (2017).

Table 3 below shows the carcinogenic risk levels of the PAHs after estimating for the two sample times in wet season. CR levels of PAHs with established carcinogenic potentials were estimated. From the table, CR levels from Benzo (a) pyrene for ELCRi Adult (carcinogenic risk via oral intake) exceeded the acceptable limit of 1×10^{-6} and 1×10^{-4} having values as high as 6.69E-02, 3.68E-02, 3.60E-02, 3.58E-02, 3.56E-02, 3.55E-02 and 3.57E-02 in all the samples. Higher levels were recorded from chrysene for carcinogenic risk via oral intake for children (ELCRi children) with 1.56E-01, 8.58E-02, 8.40E-02, 8.36E-02, 8.31E-02, 8.28E-02 and 8.32E-02, all exceeding the permissible limit. High levels of total carcinogenic risk was recorded from children via oral intake and dermal exposure which were seen in Dibenz (a, h) anthracene with values 1.21E-01, 1.37E-01, 1.13E-01, 1.10E-01, 1.13E-01, 1.14E-01 and 1.11E-01, all exceeding the permissible limit. Levels recorded for dermal exposure for both adults and children were low compared to the levels for children. These high values exceeding the permissible limits show that children are more at higher risk of suffering from cancer related ailments over a period of time.

Table 3: Carcinogenic risk (CR) for adults and children via oral ingestion and dermal absorption in the wet season.

Chrysene	ELCRi Adult	ELCRd Adult	ELCR total	ELCRi children	ELCRd children	ELCR total
A	3.29E-04	2.15E-07	3.29E-04	7.67E-04	4.85E-07	7.68E-04
B	2.69E-05	1.76E-08	2.69E-05	6.28E-05	3.97E-08	6.29E-05
C	3.27E-05	2.13E-08	3.27E-05	7.63E-05	4.82E-08	7.63E-05
D	2.39E-05	1.56E-08	2.39E-05	5.57E-05	3.52E-08	5.58E-05
E	2.54E-05	1.66E-08	2.54E-05	5.92E-05	3.74E-08	5.93E-05
F	2.38E-05	1.55E-08	2.38E-05	5.55E-05	3.51E-08	5.55E-05
G	2.35E-05	1.54E-08	2.36E-05	5.49E-05	3.47E-08	5.50E-05
Benz (a) anthracene						
A	3.34E-03	1.13E-06	3.34E-03	7.79E-03	2.55E-06	7.80E-03
B	3.24E-03	1.09E-06	3.24E-03	7.57E-03	2.47E-06	7.57E-03
C	2.90E-03	9.79E-07	2.90E-03	6.77E-03	2.21E-06	6.77E-03
D	2.91E-03	9.82E-07	2.91E-03	6.79E-03	2.22E-06	6.79E-03
E	3.02E-03	1.02E-06	3.02E-03	7.04E-03	2.30E-06	7.04E-03
F	2.89E-03	9.74E-07	2.89E-03	6.73E-03	2.20E-06	6.74E-03
G	2.87E-03	9.69E-07	2.87E-03	6.70E-03	2.19E-06	6.70E-03
Benzo (b) fluoranthene						
A	1.13E-03	3.06E-03	4.19E-03	2.64E-03	6.91E-03	9.56E-03
B	6.10E-04	1.65E-03	2.26E-03	1.42E-03	3.72E-03	5.14E-03
C	6.03E-04	1.63E-03	2.23E-03	1.41E-03	3.67E-03	5.08E-03
D	5.40E-04	1.46E-03	2.00E-03	1.26E-03	3.29E-03	4.55E-03
E	5.64E-04	1.52E-03	2.09E-03	1.32E-03	3.44E-03	4.76E-03
F	5.55E-04	1.50E-03	2.05E-03	1.29E-03	3.38E-03	4.68E-03
G	5.43E-04	1.46E-03	2.01E-03	1.27E-03	3.31E-03	4.57E-03
Benzo (k) fluoranthene						
A	1.21E-05	1.91E-06	1.40E-05	2.82E-05	4.30E-06	3.25E-05
B	9.84E-06	1.55E-06	1.14E-05	2.30E-05	3.50E-06	2.65E-05
C	9.49E-06	1.49E-06	1.10E-05	2.21E-05	3.38E-06	2.55E-05
D	9.61E-06	1.51E-06	1.11E-05	2.24E-05	3.42E-06	2.58E-05
E	1.01E-05	1.59E-06	1.17E-05	2.36E-05	3.60E-06	2.72E-05
F	9.49E-06	1.50E-06	1.10E-05	2.21E-05	3.38E-06	2.55E-05
G	9.95E-06	1.57E-06	1.15E-05	2.32E-05	3.54E-06	2.68E-05

Continuation of table

Benzo (a) pyrene	ELCRi Adult	ELCRd Adult	ELCR total	ELCRi children	ELCRd children	ELCR total
A	6.69E-02	2.86E-05	6.69E-02	1.56E-01	6.46E-05	1.56E-01
B	3.68E-02	1.57E-05	3.68E-02	8.58E-02	3.55E-05	8.58E-02
C	3.60E-02	1.54E-05	3.60E-02	8.40E-02	3.48E-05	8.41E-02
D	3.58E-02	1.53E-05	3.58E-02	8.36E-02	3.46E-05	8.36E-02
E	3.56E-02	1.52E-05	3.56E-02	8.31E-02	3.44E-05	8.31E-02
F	3.55E-02	1.52E-05	3.55E-02	8.28E-02	3.43E-05	8.29E-02
G	3.57E-02	1.52E-05	3.57E-02	8.32E-02	3.44E-05	8.32E-02
Indeno (1,2,3-cd) pyrene						
A	1.06E-03	4.52E-03	5.58E-03	2.47E-03	1.02E-02	1.27E-02
B	9.67E-04	4.13E-03	5.10E-03	2.26E-03	9.34E-03	1.16E-02
C	1.04E-03	4.43E-03	5.47E-03	2.42E-03	1.00E-02	1.24E-02
D	9.99E-04	4.27E-03	5.27E-03	2.33E-03	9.64E-03	1.20E-02
E	1.52E-03	6.49E-03	8.01E-03	3.54E-03	1.47E-02	1.82E-02
F	9.54E-04	4.08E-03	5.03E-03	2.22E-03	9.21E-03	1.14E-02
G	1.08E-03	4.60E-03	5.68E-03	2.51E-03	1.04E-02	1.29E-02
Benzo (g, h, i) perylene						
A	2.54E-04	0.00E+00	2.54E-04	5.92E-04	0.00E+00	5.92E-04
B	2.54E-04	0.00E+00	2.54E-04	5.94E-04	0.00E+00	5.94E-04
C	2.72E-04	0.00E+00	2.72E-04	6.34E-04	0.00E+00	6.34E-04
D	2.55E-04	0.00E+00	2.55E-04	5.95E-04	0.00E+00	5.95E-04
E	6.68E-04	0.00E+00	6.68E-04	1.56E-03	0.00E+00	1.56E-03
F	2.49E-04	0.00E+00	2.49E-04	5.80E-04	0.00E+00	5.80E-04
G	2.53E-04	0.00E+00	2.53E-04	5.90E-04	0.00E+00	5.90E-04
Dibenz (a, h) anthracene						
A	7.52E-03	4.57E-02	5.32E-02	1.75E-02	1.03E-01	1.21E-01
B	8.55E-03	5.19E-02	6.05E-02	1.99E-02	1.17E-01	1.37E-01
C	7.02E-03	4.27E-02	4.97E-02	1.64E-02	9.64E-02	1.13E-01
D	6.82E-03	4.14E-02	4.83E-02	1.59E-02	9.36E-02	1.10E-01
E	7.01E-03	4.26E-02	4.96E-02	1.64E-02	9.62E-02	1.13E-01
F	7.08E-03	4.30E-02	5.01E-02	1.65E-02	9.71E-02	1.14E-01
G	6.90E-03	4.19E-02	4.88E-02	1.61E-02	9.47E-02	1.11E-01

The carcinogenic risk levels of the PAHs with established carcinogenic potentials were estimated for the wet season. From the table, CR levels from Benzo (a) pyrene for ELCRi Adult (carcinogenic risk via oral intake) had values as high as 6.69E-02, 3.68E-02, 3.60E-02, 3.58E-02, 3.56E-02, 3.55E-02 and 3.57E-02, exceeding the acceptable limit of 1×10^{-6} and 1×10^{-4} in all the samples. Higher levels from chrysene were recorded for carcinogenic risk via oral intake for children (ELCRi children) with 1.56E-01, 8.58E-02, 8.40E-02, 8.36E-02, 8.31E-02, 8.28E-02, and 8.32E-02, all exceeding the permissible limit. High levels of total carcinogenic risk for children via oral intake and dermal exposure were seen from Dibenz (a, h) anthracene with values 1.21E-01, 1.37E-01, 1.13E-01, 1.10E-01, 1.13E-01, 1.14E-01, and 1.11E-01, all exceeding the permissible limit. Levels recorded for dermal exposure for both adults and children were low compared to the levels for children. These values exceeded the standard limit and are therefore a threat to the health of children and adults.

4. Conclusion

The evaluation of the health risk of exposure to the carcinogenic PAHs through oral intake and dermal (skin) exposure for adults and children in Oruma River was very important because of the known contamination of the River from artisanal refining of crude oil. Until the contamination of the River from crude oil related activities; it served the community members for drinking, swimming, and other household and individual needs. The probability of adults and children developing cancer over a lifetime as a result of exposure to PAHs contamination in the River revealed the high risk involved when the water is ingested and contacted via skin. As revealed from the study, the common pathway to a high risk of exposure to PAHs contamination in the River was via oral intake as children showed higher vulnerability with specific PAHs risk values exceeding the permissible limit of 1×10^{-6} and 1×10^{-4} compared to risk values for adults. Such higher risk values for children were visibly seen from Chrysene and Dibenz (a, h) anthracene. Adults showed significantly higher risk values above the permissible limit from Benzo (a) pyrene via oral exposure. The findings clearly showed that children having higher risk values than adults via oral exposure would suffer more cancer related sickness over a period of time. Therefore, it is recommended that the River is remediated by the relevant bodies for the use of the community.

Acknowledgement

The authors appreciate staff of the Centre for Environmental Management and Green Energy (CEMAGE) and the people of Oruma Community for their support towards the successful completion of this research.

Funding Details

This research was funded by the authors.

Data Availability Statement

The data used for this research is available for the public to access upon convincing request to the corresponding author.

Disclosure Statement

The authors declare that there is no competing interest.

References

Adegoke, O., Oyebamiji, A., Edet, J., Osterloff, P., & Ulu, K. (2017). *Geology of the Niger Delta Basin', Cenozoic Foraminifera and Calcareous Nanno fossil Biostratigraphy of the Niger Delta, Amsterdam, Netherlands*. Elsevier, 25-66.

Akanimo, N. E., Bassey, O. C., & Daniel, C. E. (2022). Human Health Risk Assessment of Polycyclic Aromatic Hydrocarbons in Water Samples around Eket Metropolis, Akwa Ibom State, Nigeria. *Asian Journal of Environment & Ecology*. 19, 58-71.

Benson, C., Enembe, O., & Best, O. (2022). Polycyclic Aromatic Hydrocarbons: Evaluation of concentrations in environmental media in Bayelsa State. *Toxicology Research and Application Journal indexing and metrics*. 7-10.

Chinemerem, C. N., Stephen O. A., & Kingsley, C. P. (2024). Polycyclic aromatic hydrocarbon in community drinking water, Nsisioken, Nigeria: Source and health risk assessment. *Environmental Analysis Health and Toxicology*. 39(2).

Ekanem, N. A., Bassey, O. C., & Daniel, C. E. (2022). Human Health Risk Assessment of Polycyclic Aromatic Hydrocarbons in Water Samples around Eket Metropolis, Akwa Ibom State, Nigeria. *Asian Journal of Environment & Ecology*. 19, 58-71.

Ezekwe, E, I. (2018). Ecological and potential health effects of hydrocarbon and heavy metal concentrations in the Kolo creek Wetlands, South-South. *Nigerian.International Journal of Environmental Sciences & Natural Reources*. 100. 19-35.

Ganiyu, S. A., Komolafe, A. E., Basheeru, K. A., Lasisi, R. A., & Adeyemi, A. A. (2024). Levels, distribution, origins, and human health risk evaluation of polycyclic aromatic hydrocarbons in groundwater around a petroleum depot wastewater discharge point. *Environmental Chemistry and Ecotoxicology*, 6 (2024) 303–314.

Grau, C. R., Roudybush, T., Dobbs, J., & Watthen, J. (1997). Altered Yolk Structure and Reduced Hatchability of Eggs from Birds Fed Single Doses of Petroleum Oils. *Science*. 195, 779-781.

Horward, I., Okpara, E., & Techato, K. (2021). Toxicity and Risks Assessment of Polycyclic Aromatic Hydrocarbons in River Bed Sediments of an Artisanal Crude Oil Refining Area in the Niger Delta, Nigeria. *MDPI Journals*. 13(22), 3295.

Ibrahim, M. S., Joseph, C. A., Abdullateef, B., Fatima, S. M., Musa, H., & Adamu, A. A. (2024). Carcinogenic Risk Assessment of Some Polycyclic Aromatic Hydrocarbons in Water Samples from Gubi Dam, Bauchi State, Nigeria. *Nigerian Research Journal of Chemical Sciences*, 12(1).

Ite, A. E., Ufot, U., F., Ite, M., U., Isaac, I., O., & Ibok, U., J. (2016). Petroleum industry in Nigeria: environmental issues, national environmental legislation and implementation of international environmental law. *American Journal of Environmental Protection*, 4 (1), 21-37.

National Population Commission of Nigeria, 2006 National Census.

Ofori, S., Cobbina, S., & Doke, D. (2020). The occurrence and levels of Polycyclic Aromatic Hydrocarbons (PAHs) in African environments – a systematic review. *Environmental Science and Pollution Research*, 27(4).

Olayinka, O. O., Adetomi, A., Olarenwaju, O. O., & Adeyinka, A. A. (2018). Concentration of Polycyclic Aromatic Hydrocarbons and Estimated Human Health Risk of Water Samples Around Atlas Cove, Lagos, Nigeria. *Journal of Health and Pollution*, 8(20), 1812010.

Smith, J., Gaither, K., & Pande, P. (2022). Competitive Metabolism of polycyclic aromatic hydrocarbons (PAHs): Assessment using In Vitro Metabolism and Physiologically based Pharmacokinetic (PBPK) modelling. *Int J Environ Res Public Health*. 19(14).

U.S. Environmental Protection Agency (2005) Supplemental guidance for assessing susceptibility from early-life exposure to carcinogens'. (EPA/630/R-03/003F). Washington, DC. Retrieved 5 May, 2023 from https://www3.epa.gov/airtoxics/childrens_supplement_final.pdf.

U.S. Environmental Protection Agency (2017) Basic Information about the Integrated Risk Information System, IRIS Toxicity Values. Retrieved 5 May, 2023 from

https://www3.epa.gov/airtoxics/childrens_supplement_final.pdf.

U.S. Environmental Protection Agency (USEPA) (1999) Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A) Interim Final', Washington, D.C. 20450. Retrieved 24 May, 2020 from https://epa.gov/report