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RESEARCH ARTICLE

PETROLEUM HYDROCARBON CARCINOGENS IN ORGANS OF COMMERCIALLY AVAILABLE FISH SPECIES FROM CRUDE OIL POLLUTED ESCRAVOS RIVER IN DELTA STATE, NIGERIA

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ABSTRACT

This study investigates the presence and distribution of petroleum hydrocarbon carcinogens in the organs of commercially available fish species collected from the Escravos River in Delta State, Nigeria. The Escravos River is known to be heavily impacted by crude oil pollution due to oil exploration and production activities in the region. The bioaccumulation of petroleum hydrocarbons, including polycyclic aromatic hydrocarbons (PAHs), in fish tissues poses potential risks to both aquatic organisms and human consumers. Samples of various commercially important fish species were collected from different locations along the Escravos River and analyzed for the presence of petroleum hydrocarbon carcinogens using gas chromatography-mass spectrometry (GC FID 5890 SERIES II) techniques. Preliminary findings indicate elevated levels of petroleum hydrocarbon carcinogens, particularly PAHs, in the organs of fish sampled from the polluted areas of the Escravos River. Liver and adipose tissues exhibited higher concentrations of PAHs compared to muscle tissue, suggesting organ-specific bioaccumulation patterns. The presence of these carcinogens in commercially available fish species highlights potential health risks to consumers, particularly those reliant on fish as a dietary staple. This study underscores the urgent need for comprehensive environmental monitoring and management strategies to mitigate the impact of crude oil pollution on aquatic ecosystems and human health in the Escravos River region. Further research is warranted to assess the long-term effects of petroleum contamination on fish populations and human communities' dependent on aquatic resources in the study area.

KEYWORDS

Aquatic ecosystems, Bioaccumulation, Spectrometry

1. INTRODUCTION

Research into petroleum hydrocarbon carcinogens in fish species inhabiting crude oil-polluted regions primarily aims to comprehend the bioaccumulation and health implications of these pollutants (Olaji et al., 2020; Nwilo et al., 2021; Atlas, 2018; Shen et al., 2019). Fish residing in areas contaminated with crude oil can amass petroleum hydrocarbons in their tissues via various routes, including ingestion of tainted food and water, as well as direct contact with sediment (Benson et al., 2020). This accumulation can result in elevated levels of carcinogenic compounds within the fish. Studies have revealed that different organs of fish species may exhibit varying degrees of petroleum hydrocarbon accumulation (Gobas et al., 2022; Rose et al., 2022; Nkpaa et al., 2018). For instance, the liver and adipose tissues often show higher concentrations compared to muscle tissue. This non-uniform distribution of hydrocarbons suggests distinct uptake and metabolism within the fish's body (Asuquo et al., 2021). Petroleum hydrocarbons encompass numerous compounds known or suspected to be carcinogenic, such as polycyclic aromatic hydrocarbons (PAHs) (Nwilo et al., 2021; Atlas, 2018; Shen et al., 2019). These substances can instigate DNA damage, disrupt cellular function, and foster tumor development in exposed organisms, including fish. Prolonged exposure to low levels of carcinogens in fish tissues from polluted regions may heighten the risk of cancer occurrence in both fish and humans consuming contaminated fish (Gobas et al., 2022; Rose et al., 2022). Various fish species exhibit differing sensitivities to petroleum hydrocarbon exposure and variations in their capacity to metabolize and eliminate these compounds. Some species may accumulate higher levels of carcinogens than others, influenced by factors like feeding habits, metabolic rates, and lipid content (Olaji et al., 2020; Nwilo et al., 2021). Consumption of fish tainted with petroleum hydrocarbons poses health hazards to humans, including an elevated risk of cancer and other adverse health outcomes (Nwilo et al., 2021).

Regulatory bodies often establish thresholds for permissible concentrations of contaminants in fish intended for human consumption, aiming to mitigate health risks. Petroleum pollution can yield significant ecological ramifications, including declines in populations, disruption of ecosystems, and enduring habitat degradation. Research indicates that fish species dwelling in crude oil-polluted environments possess the capacity to accumulate petroleum hydrocarbons, including carcinogenic compounds, in their tissues, with ramifications for both ecosystem vitality and human health. Ongoing monitoring and investigation are imperative to comprehend the enduring effects of petroleum pollution on aquatic ecosystems and human well-being.

The objective of this endeavor is to quantitatively ascertain the total hydrocarbon carcinogens present in the organs of commercially available

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fish sourced from the Escravos River in Delta State, Nigeria. Before embarking on this research, my interest was directed towards the health implications of aquatic organisms consumed within the local communities adjacent to the Escravos River. These communities primarily inhabit aquatic environments due to limited land availability, leading to various health issues and environmental degradation. Waste disposal poses a significant challenge, with many communities resorting to dumping waste into the river due to logistical and financial constraints. Moreover, industrial activities have escalated the generation of waste, exacerbating pollution levels in the water body. Additionally, the observation of fish mortality and floating carcasses suggests heightened pollution levels, often attributable to crude oil extraction activities prevalent in the region. Aquatic organisms, including fish, possess permeable skin, enabling the bioaccumulation of pollutants dissolved in water, ultimately entering the food chain. The outcomes of this research endeavor will shed light on the presence of total hydrocarbon carcinogens in fish organs sourced from the Escravos River, providing valuable insights into environmental and public health concerns. This study represents a pioneering effort within the designated study area.

2. Study Area

The Escravos River, situated in southern Nigeria, derives its name from the Portuguese word "Escravos," meaning "slaves," reflecting its historical significance as a major route for the transatlantic slave trade between Nigeria and the United States during the 18th century. Originating from the Niger River, the Escravos River spans a length of 57 kilometers, ultimately connecting to the Atlantic Ocean and the Gulf of Guinea. Its geographical coordinates are Latitude: 5° 34' 59.99" N and Longitude: 5° 09' 60.00" E (Ibitola, 2009)

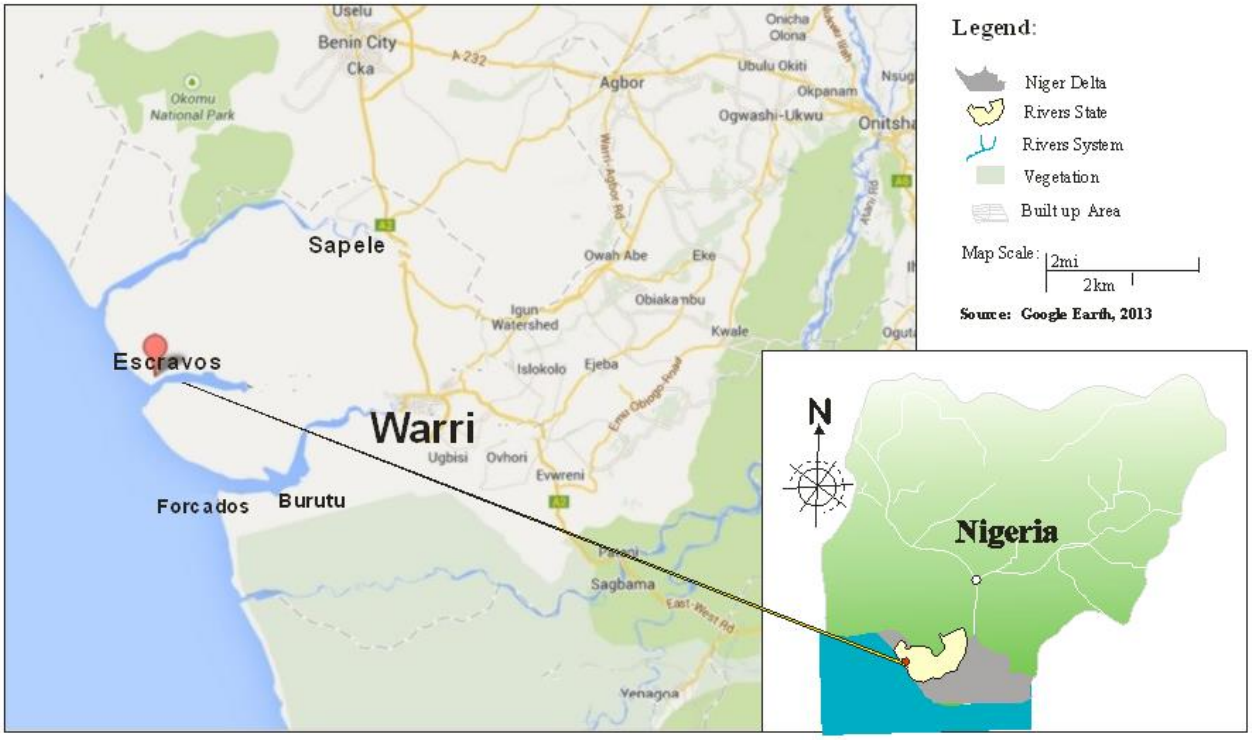

Figure 1: Map of Nigeria showing study area. Source: Google Map 2014.

2.1 Fish Sampling Method

Tilapia fish specimens were procured directly from local fishermen at the Escravos River location. They were promptly wrapped in sterile aluminum foil to maintain their integrity, then transported and securely stored at -20°C until subjected to subsequent analysis.

2.2 Fish Sample Processing

The fish samples were taken out from the refrigerator where they had been stored, allowing them to thaw. Subsequently, they were cleaned under tap water to eliminate any impurities. Following thawing, the fishes were dissected using sterile instruments and dishes to obtain samples from the liver, gills, muscles, and kidneys. These samples were then carefully placed in labeled sample bottles, prepared for further analysis.

2.3 Total Petroleum Hydrocarbons Extraction

The fish samples were pulverized using a mortar and pestle. Subsequently, a 10g portion of finely crushed sample (from the gill, liver, kidney, and muscle) was carefully weighed into a clean 250ml beaker. In a separate container, a solvent mixture comprising 50ml each of acetone and dichloromethane was prepared. Then, 50ml of this solvent mixture was added to each beaker containing the 10g sample. To ensure consistency and accuracy, 1ml of a surrogate mixture was added to each sample. The samples were then subjected to agitation in a sonicator at 70˚C for 15 minutes. Following agitation, 10g of anhydrous sodium sulfate was introduced to achieve high purity and facilitate clear extraction. The extracts were separated from the mixture and collected into a round bottom flask. This process was repeated using an additional 50ml of the solvent mixture, followed by sonication and settling of the beakers, with the extracts again decanted into the same round bottom flask. Finally, the extracts were concentrated to a volume of 3ml using a rotary evaporator, as described by (Schwab et al, 1999).

2.4 Column Preparation

The columns were filled with 10g of silica gel (100-200 mesh) and glass fiber wool, both pre-conditioned by baking at 105˚C overnight. To create a slurry, 10ml of n-hexane was added to the column, following the method outlined by (Schwab et al., 1999).

2.5 Fractionation and re-concentration of extracts

The concentrated extracts were divided into aliphatic and aromatic fractions using a column packed with glass fiber wool and silica gel. Polyaromatic hydrocarbons (PAHs) were fractionated by passing dichloromethane (DCM) through the column, as DCM has an affinity for PAHs. Total petroleum hydrocarbons (TPH) were fractionated using n-hexane due to its affinity for TPH. Each fractionated sample was collected in a round-bottom flask and concentrated to 2ml. These concentrates were then stored in chromatographic vials, ready for TPH/PAH analysis using GC FID 5890 SERIES II. The samples in the vials were stored at 4˚C before GC analysis.

2.6 Gas Chromatography Analysis

The concentrated extracts were divided into aliphatic and aromatic fractions using a column packed with glass fiber wool and silica gel. Polyaromatic hydrocarbons (PAHs) were fractionated by passing dichloromethane (DCM) through the column, as DCM has an affinity for PAHs. Total petroleum hydrocarbons (TPH) were fractionated using n-hexane due to its affinity for TPH. Each fractionated sample was collected

in a round-bottom flask and concentrated to 2ml. These concentrates were then stored in chromatographic vials, ready for TPH/PAH analysis using GC FID 5890 SERIES II. The samples in the vials were stored at 4°C before GC analysis.

2.7 Statistical Analysis

All data were subjected to one-way Analysis of Variance (ANOVA) using SPSS version 16 to test for the significant level of the parameters across the groups. The level of significance was chosen at P<0.05 and the results were presented as mean ± standard error.

3. Results

Table 1: Mean ± SE of Total aliphatic hydrocarbon component from organs of tilapia fish (mg/kg)

Components	Muscle	Gill	Liver	Kidney	Min.	Max.	P-Value
Octane (C8)	144.33±0.46	*BDL*	56.25±0.31	78.17±0.03	55.52	149.45	P<0.05
Nonane (C9)	1946.70±0.03	2155.49±0.44	697.29±0.21	869.02±0.41	658.25	2210.08	P<0.05
Decane(C10)	*BDL*	*BDL*	*BDL*	*BDL*	-	-	P<0.05
Undecane(C11)	310.37±0.05	303.22±0.32	215.32±0.14	198.58±0.18	185.08	310.37	P<0.05
Dodecane(C12)	80.05±0.32	71.95±0.01	86.33±0.02	88.03±0.12	70.18	90.12	P<0.05
Tridecane(C13)	86.92±0.33	157.98±0.21	64.08±0.16	65.02±0.28	64.08	159.36	P<0.05
Tetradecane(C14)	*BDL*	*BDL*	*BDL*	*BDL*	-	-	P<0.05
Pentadecane(C15)	119.13±0.22	63.05±0.30	60.87±0.04	57.54±0.11	55.97	120.54	P<0.05
Hexadecane(C16)	300.92±0.30	413.82±0.21	287.96±0.18	301.54±0.33	287.02	418.69	P<0.05
Heptadecane(C17)	53.53±0.20	37.68±0.04	58.21±0.03	47.01±0.01	36.85	58.87	P<0.05
Pristane	398.69±0.15	327.69±0.35	348.77±0.14	289.67±0.13	288.03	399.87	P<0.05
Octadecane(C18)	41.82±0.17	22.24±0.01	36.55±0.05	29.36±0.11	21.34	38.40	P<0.05
Phytane	51.69±0.24	77.98±0.02	59.02±0.20	68.66±0.15	51.08	79.58	P<0.05
Nonadecane(C19)	654.82±0.03	477.07±0.23	587.98±0.40	478.09±0.55	472.05	659.36	P<0.05
Eicosane(C20)	104.54±0.08	77.25±0.01	98.14±0.01	66.57±0.28	64.88	109.48	P<0.05
UncosaneC21	74.37±0.05	79.33±0.34	81.02±0.01	46.21±0.42	44.01	81.90	P<0.05
Docosane(C22)	334.72±0.31	408.41±0.33	298.46±0.03	329.07±0.36	299.47	411.77	P<0.05
Tricosane(C23)	403.07±0.20	592.23±0.52	421.02±0.12	408.55±0.70	400.98	599.60	P<0.05
Tetracosane(C24)	96.23±0.15	99.49±0.15	87.02±0.19	75.12±0.07	79.58	101.24	P<0.05
Pentacosane(C25)	357.05±0.13	274.36±0.08	125.22±0.14	149.28±0.09	125.22	358.09	P<0.05
Hexacosane(C26)	596.29±0.12	693.02±0.03	478.98±0.19	357.48±0.17	354.55	693.02	P<0.05
Heptacosane(C27)	209.99±0.25	83.12±0.20	124.09±0.22	147.98±0.05	85.22	212.08	P<0.05
Octacosane(C28)	187.99±0.41	88.58±0.40	96.03±0.08	95.55±0.02	84.06	189.34	P<0.05
Nonacosane(C29)	146.66±0.33	327.17±0.23	108.08±0.02	147.02±0.12	108.66	330.58	P<0.05
Triacontane(C30)	215.80±0.08	102.40±0.16	145.09±0.14	125.22±0.33	101.51	216.01	P<0.05
Untriacontane(C31)	103.99±0.01	107.37±0.20	111.87±0.16	86.69±0.03	86.01	114.09	P<0.05
Dotriacontane(C32)	236.72±0.07	95.06±0.50	158.15±0.07	251.11±0.11	94.07	254.10	P<0.05
Tritriacontane(C33)	83.70±0.22	309.67±0.06	65.74±0.31	125.67±0.17	65.74	310.71	P<0.05
Tetratriacontane(C34)	797.46±0.12	1230.76±0.44	258.39±0.08	143.54±0.33	143.07	1230.76	P<0.05
Pentatriacontane(C35)	52.13±0.02	125.05±0.02	88.88±0.23	77.32±0.140	52.01	92.44	P<0.05
Hexatriacontane(C36)	317.87±0.03	367.54±0.47	489.18±0.31	229.36±0.24	224.58	490.10	P<0.05
Heptatriacontane(C37)	470.19±0.30	222.55±0.36	189.57±0.71	217.64±0.05	189.07	474.05	P<0.05
Octatriacontane(C38)	49.87±0.45	59.16±0.18	44.02±0.41	33.21±0.04	32.51	61.23	P<0.05
Nonatriacontane(C39)	109.06±0.03	147.67±0.04	106.15±0.05	108.24±0.33	105.33	149.04	P<0.05
Tetracontane(C40)	165.63±0.24	789.82±0.05	136.81±0.02	188.93±0.18	134.84	790.17	P<0.05
TOTAL ALIPHATIC (mg/kg)	9302.33±1.08	10388.16±0.98	6270.64±0.85	5980.56±1.20	5978	10390	P<0.05

BDL = Below Detectable Lim

Table 2: Mean ± SE of Polynuclear Aromatic Hydrocarbon component from organs of tilapia fish (mg/kg)							
Components	Muscle	Gill	Liver	Kidney	Min	Max	P-Value
Naphthalene	4.32±0.12	3.06±0.11	3.54±0.01	7.36±0.05	2.85	8.33	P<0.05
Acenaphthylene	11.08±0.33	3.86±0.25	4.54±0.02	4.26±0.14	3.20	12.09	P<0.05
Acenaphthene	7.70±0.14	26.32±0.03	15.34±0.12	8.26±0.11	7.52	26.77	P<0.05
Fluorene	7.37±0.18	2.96±0.15	3.69±0.30	4.65±0.25	2.47	8.30	P<0.05
Phenanthrene	3.98±0.02	9.99±0.13	8.14±0.12	7.77±0.24	3.42	10.23	P<0.05
Anthracene	135.57±0.33	85.12±0.01	122.36±0.33	129.39±0.18	85.02	136.88	P<0.05
Fluoroanthene	35.68±0.21	7.58±0.11	26.36±0.31	13.26±0.22	6.55	36.09	P<0.05
Pyrene	16.51±0.33	8.25±0.02	8.87±0.05	12.22±0.04	8.25	17.87	P<0.05
Chrysene	3.32±0.25	6.15±0.14	3.95±0.12	8.69±0.13	3.08	8.94	P<0.05
Benz(a)anthracene	6.78±0.17	2.69±0.54	5.37±0.19	4.23±0.08	2.33	7.45	P<0.05
Benzo(b)fluoranthene	3.76±0.24	4.90±0.20.16	4.09±0.27	5.64±0.17	3.24	6.80	P<0.05
Benzo(k)fluoranthrene	3.95±0.18	3.76±0.18	14.02±0.24	12.08±0.31	3.47	12.66	P<0.05
Benzo(a)pyrene	20.95±0.32	3.12±0.11	7.14±0.08	16.65±0.11	2.85	21.12	P<0.05
Indeno(1,2,3-cd)pyrene	36.33±0.44	14.17±0.30	24.56±0.15	18.21±0.36	13.18	38.02	P<0.05
Dibenz(a,h)anthracene	8.94±0.14	6.08±0.22	6.23±0.11	7.09±0.09	5.54	9.30	P<0.05
Benzo(g,h,i)perylene	7.10±0.17	4.90±0.05	7.89±0.01	6.88±0.05	4.80	7.95	P<0.05
Total PAH (mg/kg)	313.43±0.67	192.96±0.45	266.17±0.81	266.72±0.36	192.96	318.02	P<0.05

Table 3: Mean ± SE of Total Petroleum Hydrocarbon(TPH)				
Components	Muscle	Gill	Liver	Kidney
ΣAliphatics	9302.33±1.85	10388.16±1.52	6270.64±1.87	5980.56±1.08
ΣPAHs	313.43±1.64	192.96±1.09	266.17±1.35	266.72±1.07
ΣTPH (mg/kg)	9615.76±1.06	10581.13±1.09	6536.81±1.54	6247.29±1.87

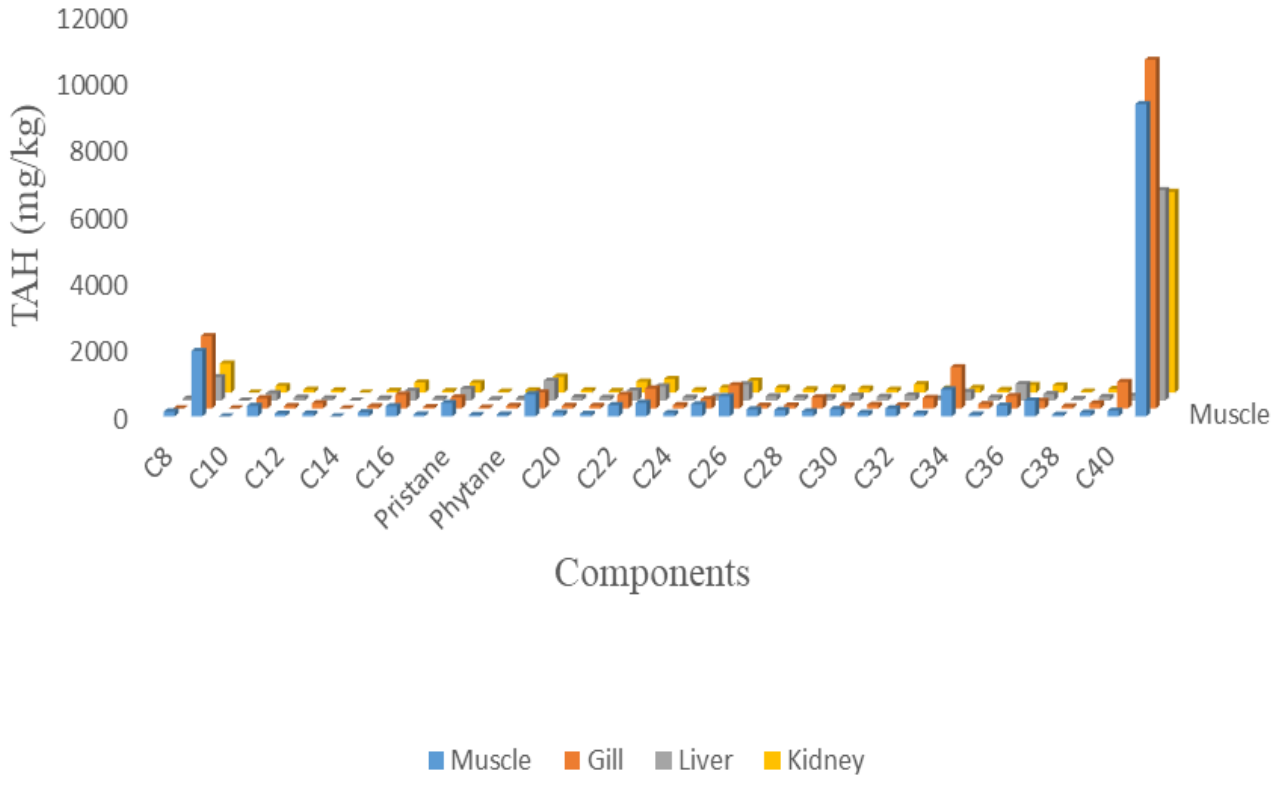

Figure 7: Total aliphatic hydrocarbon content (mg/kg)

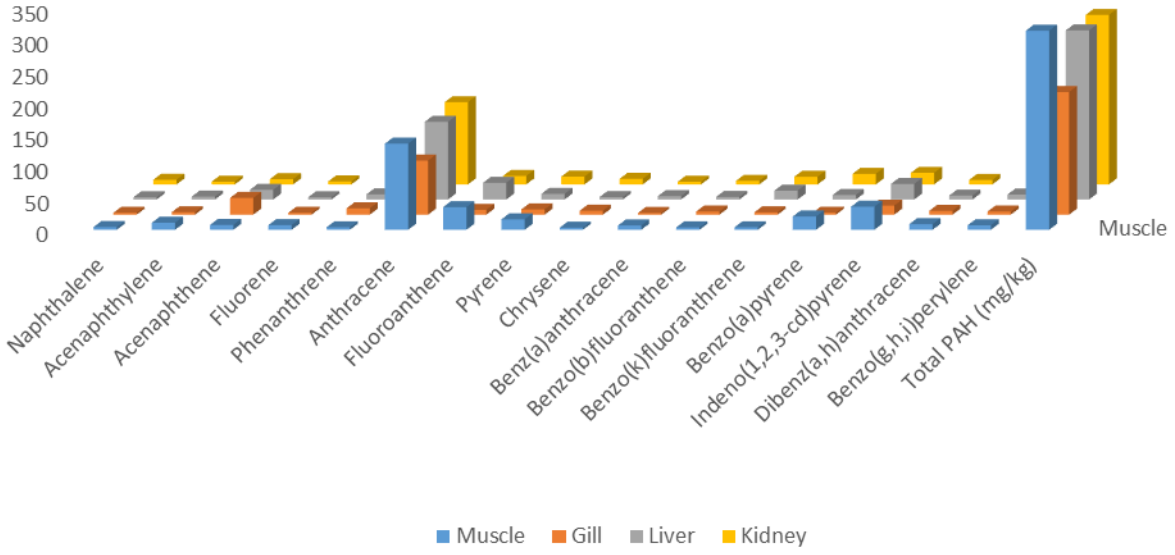

Figure 8: Polynuclear Aromatic Hydrocarbon Content (mg/kg)

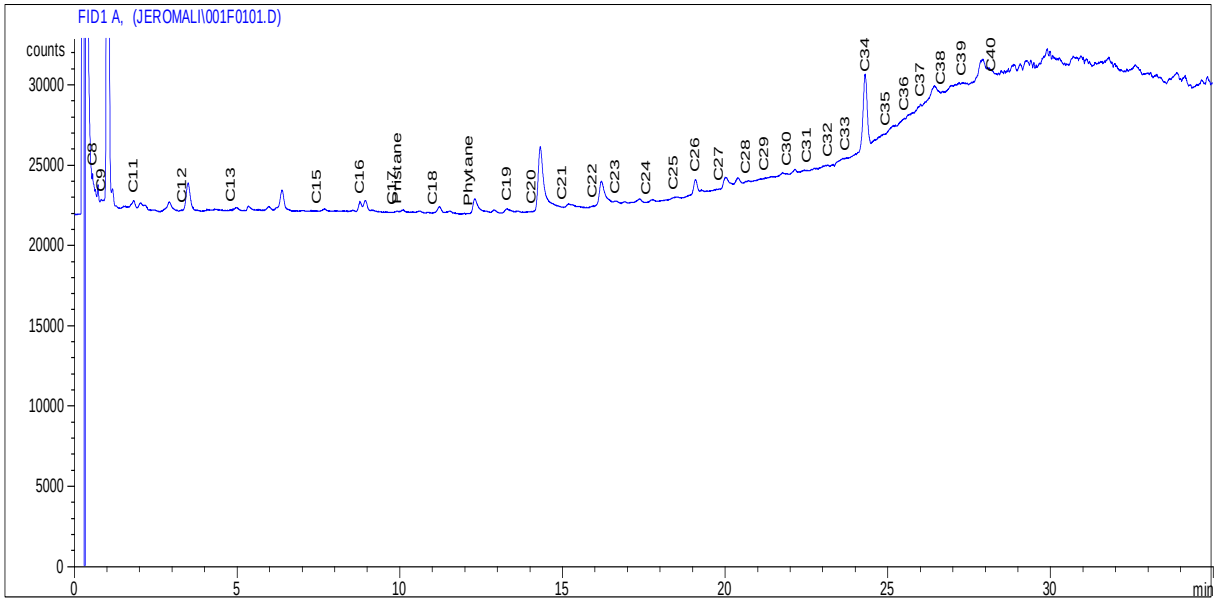

Figure 9: Chromatogram for the Aliphatic Hydrocarbons from the muscles of the tilapia species

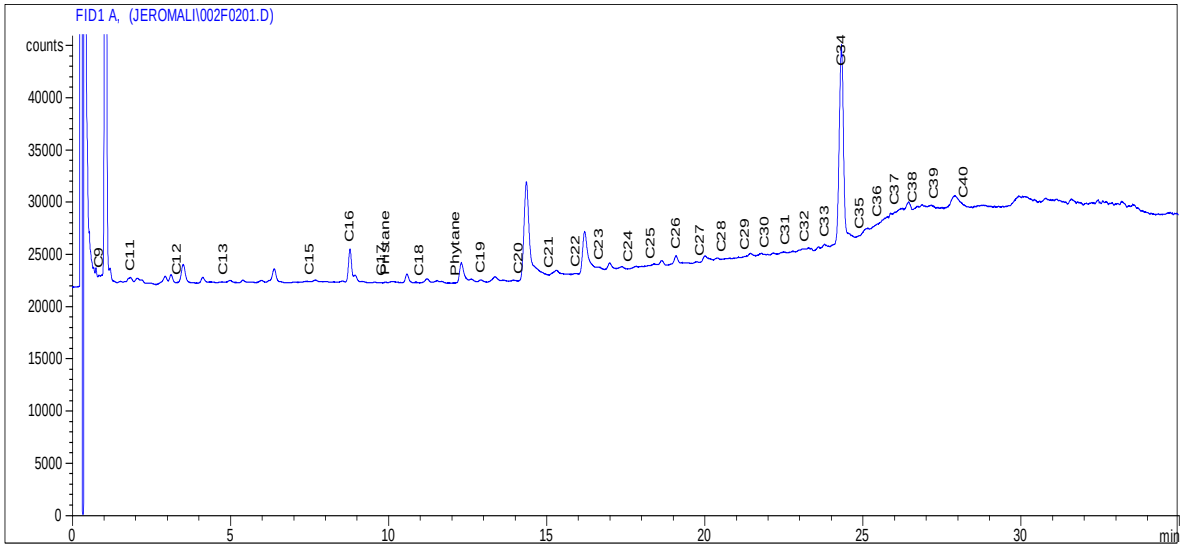

Figure 10: Chromatogram for the Aliphatic Hydrocarbons from the Gills of the tilapia species

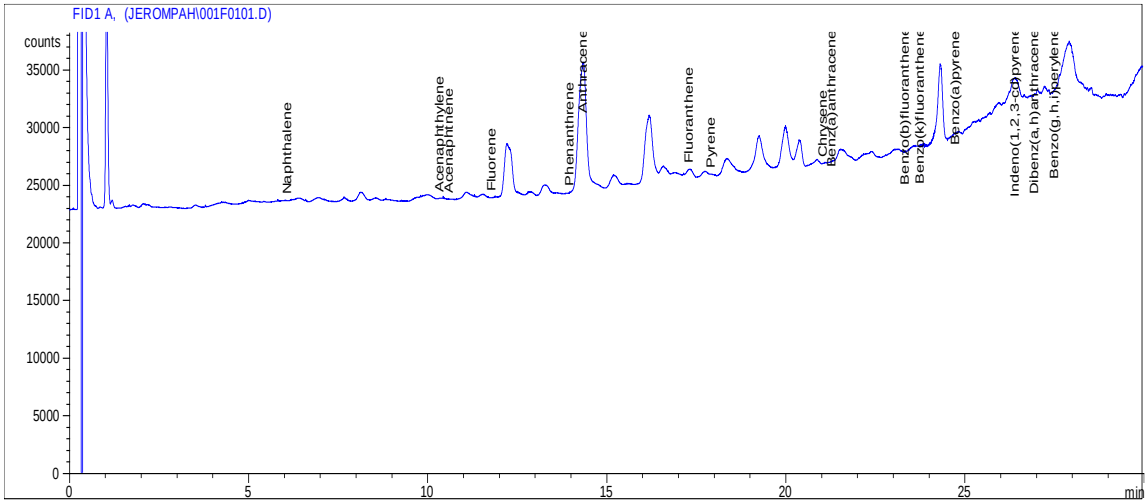

Figure 11: Chromatogram for the Polyaromatic Hydrocarbons from the muscles of the tilapia species

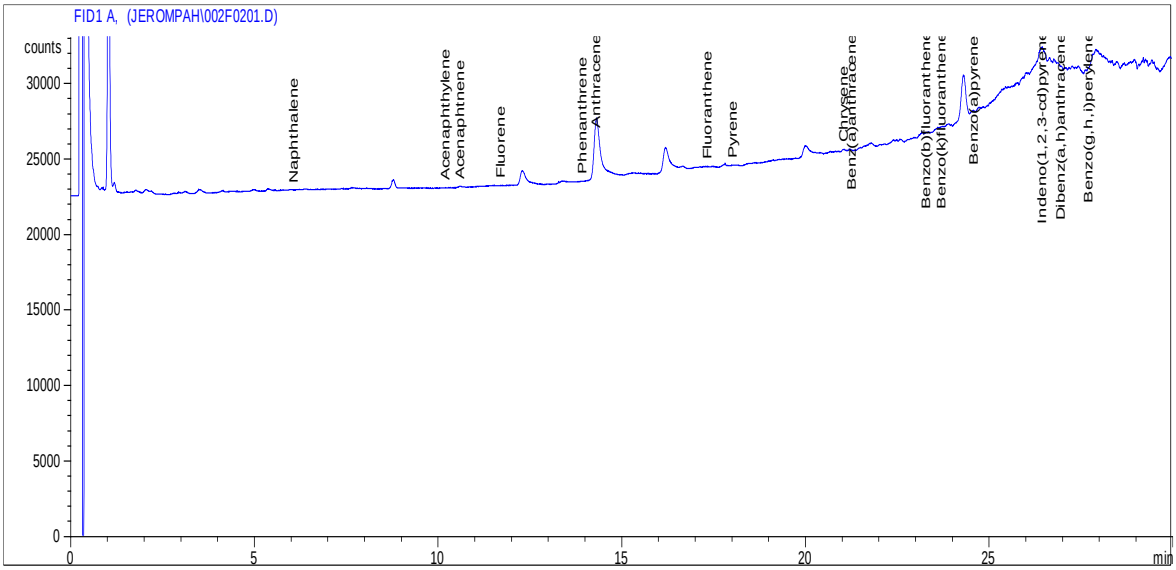

Figure 12: Chromatogram for the Polyaromatic Hydrocarbons from the Gills of the tilapia specie

4. Discussion Of Results

The concentration of various aliphatic hydrocarbons in different components (muscle, gill, liver, and kidney) of an organism, possibly fish, along with minimum and maximum values and statistical significance (p-values) are listed in Table 1. The concentrations are given in mg/kg. The hydrocarbons are categorized based on their carbon chain length, ranging from octane (C8) to tetracontane (C40), and there's also a total aliphatic hydrocarbon concentration provided at the end of the table. For each hydrocarbon, you have the mean concentration ± standard deviation for each component. "BDL" stands for "Below Detection Limit," indicating that the concentration of certain hydrocarbons was not detectable in some components. The "Min." and "Max." values represent the minimum and maximum concentration range observed for each hydrocarbon across the components. The "P-Value" indicates the statistical significance of the differences observed between the components for each hydrocarbon.

In various environmental settings such as air, water, and sediments, polyaromatic hydrocarbons (PAHs) are not found in isolation; rather, they exist as complex mixtures of numerous polynuclear aromatic hydrocarbons. Research indicates that these weakly or non-carcinogenic PAH mixtures have the potential to alter the carcinogenic effects of specific PAHs like benzo(a)pyrene (Anyakora et al., 2018). Human exposure to total petroleum hydrocarbons occurs through multiple routes including air, water, food, and soil. However, dietary intake has been identified as a primary route of exposure to petroleum hydrocarbons, particularly PAHs (Dhananjayan and Muralidharan, 2022). This underscores the importance of understanding the complexities of hydrocarbon mixtures and their potential impacts on both environmental and human health.

The study examined the levels of Total Aliphatic Hydrocarbons (TAH) in tilapia fish samples, revealing varying concentrations across different tissues. Conducted in the Escravos River spanning Kurutie/Okerenkoko in Delta State, Nigeria, this research analyzed TAH and Polycyclic Aromatic Hydrocarbons (PAH) in the muscles, gills, livers, and kidneys of tilapia fish species. A comprehensive analysis encompassed thirty-five components of n-alkanes, constituting the TAH profile. The findings unveiled significant variations in TAH concentrations among the examined tissues. Notably, the gills exhibited the highest mean concentration (10388.16±0.98 mg/kg) of TAH, contrasting with the kidneys, which displayed the lowest mean concentration (5980.56±1.20 mg/kg) of TAH. Previous studies corroborate these findings, highlighting gills as the primary site for TAH accumulation, while muscles tend to harbor the lowest concentrations by (Enueku et al., 2019). The relatively lower TAH concentration in the kidneys implies diminished bioaccumulation compared to the gills, which exhibit pronounced bioaccumulation tendencies. The elevated TAH levels observed in the gills can be attributed to their continuous exposure to pollution sources. Being highly vascularized and involved in respiration, gills serve as a critical interface for pollutant uptake from water, resulting in their heightened accumulation of TAH.

Table 1 and Figure 7 present the mean ± standard error of the total aliphatic hydrocarbon component in various organs of tilapia fish (mg/kg). Analysis of octane (C8) bioaccumulation across the tilapia fish organs revealed concentrations ranging from 55.52 to 149.45 mg/kg, with the gills exhibiting concentrations below the detectable limit. Notably, the muscle and liver of the tilapia species displayed the highest and lowest concentrations of octane at 144.33±0.46 and 56.25±0.31 mg/kg, respectively. Contrary to findings, no record of C8 aliphatic hydrocarbon

was found in the organs of commercially available fishes from Oliha market by (Enueku et al., 2019).

Regarding nonane (C9) aliphatic hydrocarbon bioaccumulation, the organs of the analyzed tilapia fish demonstrated the highest concentrations compared to other aliphatic hydrocarbons, ranging from 658.25 to 2210.08 mg/kg. In contrast, similar research on fish organ samples reported lower concentrations of C9 aliphatic hydrocarbon, ranging from 3.72 to 22.32 mg/kg (Enueku et al., 2019).

The analysis of C10 (decane) aliphatic hydrocarbon concentrations revealed levels beyond the detectable limit across all four studied fish organs. For C11 (undecane) aliphatic hydrocarbon, concentrations ranged from 185.08 to 310.37 mg/kg, with the muscle exhibiting the highest (310.37±0.05 mg/kg) and the kidney the lowest (198.58±0.18 mg/kg) bioaccumulation. C12 (dodecane) aliphatic hydrocarbon concentrations ranged from 70.18 to 90.12 mg/kg, with the kidney registering the highest (88.03±0.12 mg/kg) and the gills the lowest (71.95±0.01 mg/kg) concentrations. Notably, C14 (tetradecane) was undetected in the organs, indicating concentrations and bioaccumulation levels below the detectable limit of the GC-FID.

Across various aliphatic hydrocarbons (C15-C40), minimum concentrations in the organs ranged from 21.34 to 472.05 mg/kg, while maximum concentrations ranged from 38.40 to 790.17 mg/kg. The notable presence of high concentrations of Total Aliphatic Hydrocarbons (TAH) in the tilapia fish organs suggests significant exposure of the Escravos River to contaminants and pollutants. These findings align with previous studies, emphasizing the potential health risks posed by pollutants in riverine areas along the Escravos River (Olaji et al., 2020; Benson et al., 2020; Dhananjayan and Muralidharan, 2022; Rose et al., 2022). The observed concentrations underscore the pressing need for effective measures to mitigate pollution and safeguard both environmental and human health in these regions.

Figure 9 and 10 depict the Chromatograms illustrating Aliphatic Hydrocarbons present in the muscles and gills of tilapia species, respectively, while Figure 11 and 12 show the Chromatograms for Polyaromatic Hydrocarbons from the muscles and gills of the same species. Table 2 and Figure 8 present the Mean ± Standard error of Polynuclear Aromatic Hydrocarbon components in the organs of tilapia fish (mg/kg). Sixteen aromatic components comprising PAHs were analyzed in this study. PAHs, being widespread anthropogenic pollutants, can accumulate to high concentrations in food webs due to their lipophilicity, persistence, and toxicity. These residues are known to accumulate in the tissues of non-target organisms, posing potential health risks. PAHs exhibit toxicity, carcinogenicity, and mutagenicity across all organisms, including humans, as highlighted by previous studies (Nacci et al., 2021; Armstrong et al., 2014; Anyakora et al., 2018). Their metabolites have the potential to bind to proteins and DNA, leading to biochemical disruption, cellular damage, and cancer in humans. Among PAHs, compounds such as naphthalene, acenaphthylene, acenaphthene, fluorene, anthracene, fluoranthene, and pyrene are considered less carcinogenic, whereas benzo(a)anthracene, chrysene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(b)fluoranthene, indeno(1,2,3)perylene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene are highly carcinogenic (USEPA, 1993). For PAHs analyzed in this research, naphthalene exhibited maximum and minimum concentrations of 8.33 and 2.85 mg/kg, respectively. The highest average bioaccumulation was observed in the kidney of tilapia fish (7.36±0.05 mg/kg), while the gills exhibited the lowest value (3.06±0.11 mg/kg). Acenaphthylene and acenaphthene displayed minimum bioaccumulation across organs at 3.20 and 7.52 mg/kg, respectively, with maximum concentrations of 12.09 and 26.77 mg/kg, respectively. The high mean concentrations recorded in the gills and muscles are consistent with their direct interaction with the contaminated medium, leading to higher ingestion rates. These findings contrast with values reported from an investigation in Degele Community, Nigeria by (Olaji et al., 2020).

The minimum concentrations of Fluorene, Phenanthrene, Anthracene, Fluoroanthene, Pyrene, and Chrysene are 2.47, 3.42, 85.02, 6.55, 8.25, and 3.08 mg/kg, respectively, while their maximum concentrations are 8.30, 10.23, 136.88, 36.09, 17.87, and 8.94 mg/kg, respectively. Notably, Anthracene exhibited notably high mean concentrations across the organs, with muscle concentrations as high as 135.57±0.33 mg/kg and gill concentrations at 85.12±0.01 mg/kg. Anthracene is known to target human skin, blood, intestines, and the lymph system. Exposure to high doses can cause skin damage, itching, burning, and edema. Additionally, it may lead to symptoms such as headache, loss of appetite, nausea, and inflammation of the stomach and intestines. Laboratory studies have shown that exposure to Anthracene can induce tumors in animals through various routes including ingestion, inhalation, and skin contact (Faust, 1991). The minimum concentrations of benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthrene, and benzo(a)pyrene are 2.33, 3.24, 3.47, and 2.85 mg/kg, respectively, while their maximum concentrations are 7.45, 6.80, 12.66, and 21.12 mg/kg, respectively. Studies by Faust (1991) reported that pregnant mice fed high doses of PAH (benzo(a)pyrene) experienced reproductive issues, with offspring exhibiting birth defects and decreased body weight. Exposure to high levels of benzo(a)pyrene in food caused liver and blood problems in mice. The minimum concentrations of indeno(1,2,3-cd)pyrene, Dibenz(a,h)anthracene, and benzo(g,h,i)perylene are 13.18, 5.54, and 4.80 mg/kg, respectively, while their maximum concentrations are 38.02, 9.30, and 7.95 mg/kg, respectively. Biological monitoring of PAH exposure is crucial due to their widespread presence and toxicological significance. However, the health effects of individual PAHs vary, with some classified as known or probable carcinogens by the International Agency for Research on Cancer (Mohanraj et al., 2012; EPRI, 2000). Inhalation exposure to certain PAHs, including benzo(a)pyrene, is associated with an increased risk of lung cancer, highlighting the serious health threats posed by these compounds (EPRI, 2000).

In this study, the total concentration of n-alkanes is denoted as ΣAliphatics, the total concentration of Polycyclic Aromatic Hydrocarbons as ΣPAH, and ΣTPH represents the total petroleum hydrocarbon. These values exhibited distinct trends. For ΣAliphatics, the gills displayed the highest average concentration, while the kidney exhibited the lowest. Conversely, for ΣPAH, the muscle showed the highest average concentration, with the gills displaying the lowest. Regarding ΣTPH, the gills exhibited the highest average concentration, while the kidney displayed the lowest. Interestingly, other studies have shown a similar trend for ΣAliphatics and ΣPAH, with the gills consistently recording the highest average concentration and the muscles showing the lowest. The reported mean concentrations of Total Aliphatic Hydrocarbons (TAH) and Polycyclic Aromatic Hydrocarbons (PAH) in the organs of tilapia fish exceeded the European Union recommended limit of 2 µg/kg; wet weight for fish. This observation underscores the significant human impact on the Escravos river ecosystem.

5. Conclusion

In conclusion, our study highlights the significant presence of petroleum hydrocarbon carcinogens, particularly polycyclic aromatic hydrocarbons (PAHs), in the organs of commercially available fish species from the crude oil-polluted Escravos River in Delta State, Nigeria. The findings reveal organ-specific bioaccumulation patterns, with liver and adipose tissues showing higher concentrations of PAHs compared to muscle tissue. These results underscore the potential health risks posed to both aquatic organisms and human consumers relying on fish from the polluted river for sustenance. The elevated levels of petroleum hydrocarbon carcinogens in fish organs emphasize the urgent need for effective environmental management strategies to mitigate the impact of crude oil pollution on aquatic ecosystems and human health in the Escravos River region. Regulatory measures aimed at controlling industrial activities and reducing pollutant discharges into the river are imperative to safeguard environmental quality and public health. Furthermore, our findings underscore the importance of ongoing monitoring and research efforts to assess the long-term effects of petroleum contamination on fish populations and human communities dependent on aquatic resources in the study area. Collaborative initiatives involving government agencies, industry stakeholders, and local communities are essential to address the complex challenges associated with crude oil pollution and ensure the sustainable management of freshwater resources in the Escravos River basin. Ultimately, proactive measures aimed at reducing pollution, restoring ecosystem health, and promoting sustainable fishing practices are crucial for safeguarding the ecological integrity of the Escravos River and protecting the well-being of both aquatic life and human populations in Delta State, Nigeria.

Recommendations

Based on the findings of our study on petroleum hydrocarbon carcinogens in organs of commercially available fish species from the crude oil-polluted Escravos River in Delta State, Nigeria, the following recommendations are proposed:

- Environmental Remediation: Implement immediate and comprehensive remediation efforts to reduce the levels of crude oil pollution in the Escravos River. This may include cleanup operations, restoration of contaminated habitats, and implementation of technologies for treating oil-contaminated water and sediments.

- Pollution Control Measures: Strengthen regulations and enforcement mechanisms to control industrial activities and prevent further discharge of pollutants into the Escravos River and its tributaries. Implement best practices in waste management, spill prevention, and environmental monitoring to minimize the risk of future contamination incidents.
- Fisheries Management: Develop and enforce sustainable fisheries management practices to prevent overfishing and ensure the long-term viability of fish populations in the Escravos River. This may include the establishment of fishing quotas, seasonal closures, and habitat restoration initiatives to support fish reproduction and migration.
- Public Health Awareness: Increase public awareness and education initiatives to inform local communities about the potential health risks associated with consuming fish from the polluted areas of the Escravos River. Provide guidance on safe fishing practices, proper cooking methods, and alternatives for obtaining safe sources of protein.
- Monitoring and Surveillance: Establish a robust monitoring and surveillance program to regularly assess the levels of petroleum hydrocarbon carcinogens in fish organs and water samples from the Escravos River. This will facilitate early detection of contamination trends, inform risk assessments, and guide decision-making processes for environmental management and public health protection.
- Community Engagement: Foster collaboration and engagement with local communities, indigenous groups, and stakeholders to develop participatory approaches for addressing environmental challenges and promoting sustainable development in the Escravos River basin. Empower communities to actively participate in decision-making processes and contribute to the implementation of solutions that prioritize environmental conservation and social well-being.
- Research and Innovation: Encourage further research and innovation in the fields of environmental science, toxicology, and ecological risk assessment to advance our understanding of the impacts of crude oil pollution on aquatic ecosystems and human health. Support interdisciplinary studies and knowledge exchange initiatives to develop evidence-based solutions for mitigating pollution and promoting resilience in the Escravos River region.

By implementing these recommendations in a coordinated and collaborative manner, stakeholders can work together to address the complex challenges posed by crude oil pollution in the Escravos River and safeguard the health and well-being of both ecosystems and communities in Delta State, Nigeria.

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CONFLICT OF INTEREST

Both authors declare that there is no competing interest with regard to this work. We hereby declare that the originality of this work for publication is to the best knowledge of the authors.

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