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Risk assessment of heavy metals and polycyclic aromatic hydrocarbons in surface water and white croaker fish from bonny river, Southern Nigeria

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Abstract

This study evaluated the proximate profile of fish and levels of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in selected seafood and surface water from Bonny River in Rivers State, Nigeria. The laboratory analyses were done using standard methods. Proximate analysis of sampled fish parts showed fish skin to be richer in moisture and crude protein content. The physicochemical parameters of surface water obtained from Bonny River showed values within USEPA recommended standards. The mean concentration of heavy metals varied across the analyzed samples, although Hg was below detectable limits in all the samples. PAH in surface water samples and fish muscle recorded mean values of 107.82mg/kg and 29.93mg/kg respectively. Surface water sample recorded total carcinogenic PAHs of 12.75mg/kg which constituted 11.83% of the total PAHs in the surface water sample. Comparatively, fish skin showed lower level of total PAHs, recording 2.50mg/kg (8.31% carcinogenic) as compared with fish muscle which had 6.31mg/kg (21.07% carcinogenic). All samples analyzed showed B[a]P levels below detectable limits. Calculated Chronic Daily Intake Dose (CDI ingest) and Hazard Quotient (HQ) in the sampled fish revealed Hazard Index of 1.35 in fish muscle in exposed adult population, with minimum Total Life Cancer Risk (TLCR) of 2.54E-05 recorded for fish skin. Values obtained were above standards stipulated by USEPA. The study revealed significant presence of heavy metals and PAHs in white croaker fish and surface water samples. This could pose serious public health concern as results indicated probabilistic risk for both carcinogenic and non-carcinogenic adverse health effects.

Keywords: Risk Assessment; Heavy Metals; Polycyclic Aromatic Hydrocarbons; Surface Water

1. Introduction

The various activities of man have led to the introduction of various deleterious contaminants into the environment. Contamination of soil and water with petroleum hydrocarbon, heavy metals and other wastes from anthropogenic sources has adverse effect on soil micro flora and water bodies. The quality and product from these surrounding rivers are now of immense interest and concern to man, since there is direct reliance and dependence of man's existence on them [1, 2].

Heavy metal residues and polycyclic aromatic hydrocarbons (PAHs) in fish and water as well as their hazardous effects on the health of people are a matter of great concern to food hygienists. Subsequently, to safeguard the consumers, periodical evaluation of levels of heavy metals in fish, and water, from suspected polluted areas are of major importance [3]. These pollutants of interest, on accumulation in an ecosystem, not only have a bad influence on fish but also affect the health of human beings through the food chain. For example, the Itai-itai disease known as one of the four big pollution disease of Japan of the Toyama Jintsu River area was the documented case of mass cadmium poisoning [3]. Studies on heavy metals and PAHs in rivers, lakes, fish etc. have been a major environmental focus especially during last decade [4]. The commercial and edible species have been widely investigated in order to check for those hazardous to

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human health [3]. Heavy metals such as copper (Cu), iron (Fe), chromium (Cr), nickel (Ni), cadmium (Cd, and lead (Pb) play an important role in biological systems as they are toxic even in trace amounts [5]. For the normal metabolism of the fish the essential metals must be taken from water, food or sediment [6]. Essential metals can also produce toxic effects when the metal intake is excessively elevated [7].

Indices that serve as indicators for assessing level of pollution of potential sources of livelihood and nutritional source such as fishes, need to be accessed and monitored continually in other to maintain compliance to recommended standard values. The aim of this study was to evaluate the fish proximate profile and accumulation of heavy metals and polycyclic aromatic hydrocarbons in different tissues of selected seafood and surface water from Bonny River in Rivers State, Nigeria.

2. Materials and methods

2.1. Study Area

Bonny River is an arm of the Niger River delta in Rivers state, southern Nigeria. At its mouth, 25 miles (40 km) south-southeast of Port Harcourt, is Bonny town, a river pilot station and oil terminal. Industrial activities have, to a large extent, impacted negatively on the river and surrounding communities within Bonny. The studied area is a riverine and intertidal wetland on the north bank of Bonny River, about 35 miles (56 km) upstream from the Bight of Benin in the Eastern Niger Delta of Nigeria. The sampled area is located within 147º SE 4º 49' 19" N, 7º 5' 1" E and 40ft elevation.

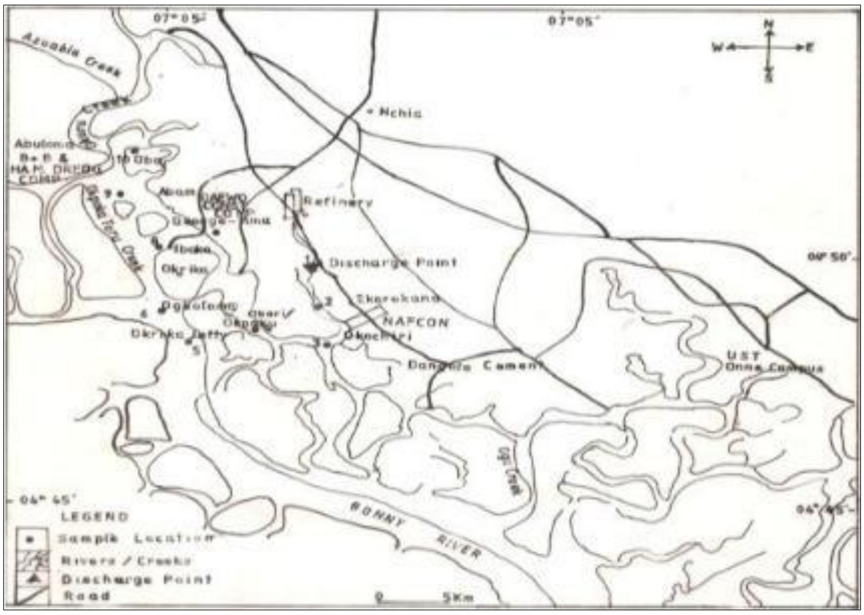

Figure 1 The study area: Bonny River and its suburbs

2.2. Methods

2.2.1. Fish and Surface Water Sample Collection

Samples of white croaker fish (*Genyonemus lineatus*) were collected in July 2024 in plastic containers from Bonny River. This specie was selected considering its consumption rate and availability. Collected fish samples were immediately transferred in sterile isothermal container for onward delivery to the laboratory for analysis. The samples were analyzed for proximate composition, heavy metals and PAH levels.

Surface water sample was collected from the Bonny River in plastic vials at a depth of 25 cm under water at different points and the vials immediately capped. Sampling was done in triplicates at each sampling point and was done in July 2024. The samples were placed in ice-cold chest packs and transported to the laboratory, where they were stored at 4°C temperatures. Additional surface water samples (Control) were collected from a different location located 500 km distance, south of Bonny River and without any known history of pollution.

2.2.2. Determination of Physicochemical and Microbial Parameters in surface water samples

Parameters such as pH, conductivity, turbidity, temperature and TDS were determined in-situ using the water checker electrometric instrument (model: Hanna H19828). Other physicochemical (TSS, COD, DO, BOD, Total Hardness, Chloride, Fluoride, Phosphate, Sulphate, Total Oil & Grease - TOG, Nitrate and Nitrite) in the surface water samples were determined using standard methods applicable to them. Microbial parameters in water samples were analyzed according to APHA standard methods [8].

2.2.3. Proximate Analysis

Proximate analysis was carried out according to the procedure of Association of Official Analytical Chemist (AOAC) [9] for moisture, ash, crude fibre and crude protein content. Carbohydrate component was calculated by the Difference Method [9] by subtracting the sum (g/100g dry matter) of crude protein, crude fat, ash and fibre from 100g. The caloric value was determined based on the Atwater Factor [10].

2.2.4. Heavy metal and PAH determination

Sixteen (16) priority PAHs listed by the USEPA and cited by the International Agency for Research on Cancer (IARC) were analyzed in surface water and fish samples [11, 12]. Sample analysis followed the method described by Odesa and Olannye [13]. The samples were homogenized and 25 ml of dichloromethane was used for the extraction after it has been dehydrated with anhydrous sodium sulfate (**Na_2SO_4)**. The samples were further evaporated and a portion of the solution was examined using Gas Chromatography Flame Ionisation Detector (GC model: Agilent 6890N) and Atomic Absorption Spectrophotometry (AAS model: SP-AA4530). The congeners were detected via flame ionization detection. Heavy metal levels in seafood were determined using an atomic absorption spectrophotometer (ASTM-E594-96).

2.3. Health Risk Assessment for PAHs and Heavy metals

Health risk evaluation was performed for children and adult population using Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Quotient and Hazard Index and Carcinogenic Risk (CR) assessment.

2.3.1. Estimated Daily Intake (EDI)

Approximate daily consumption of the seafood was determined using the formula below, taking into account the levels of PAHs and heavy metals in the chosen sea food samples.

$$EDI = \frac{Cm \ x \ IR}{BW x 10-3} \quad \ldots\ldots\ldots.(1)$$

Where BW is the average adult and child body weight who consume the seafood, IR is the ingestion rate of heavy metals and PAHs in kg/day, and Cm is the saturation of metals and PAHs in each chosen seafood in mg/kg.

2.3.2. Hazard Quotient (HQ)

The Target Hazard Quotient (HQ), which is the ratio of the computed chronic intake (CDI) to the ingestion reference dose (RfD) of the chosen heavy metals, is typically used to highlight the degree of non-carcinogenic concerns [14]. USEPA [15] provides the formula, which is displayed in equation 2. If HQ > 1, it suggests that the exposed population is more likely to experience bad health impacts. Conversely, if HQ < 1 then there is no possibility of negative health effects with the ingestion reference dose for heavy metals to be that set by the WHO 2017, with PAHs having the ingested reference dose to be Acy 6.0 x 10^{-2}, Acp 6.0- x 10^{-2}, Flr 4.0 x 10^{-2}, Ant 3.0 x 10^{-1}, Phe3.0 x 10^{-2}, Flt 4.0 x 10^{-2} and Pyr 3.0 x 10^{-1} [15].

$$HQ = \frac{CDI}{RfD} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

The ratio of estimated daily intake (EDI) to RfD was used to compute the health risks associated with consuming seafood. Equation 4 was used to determine the EDI [16].

$$THQ = \frac{EDI \ X \ EF \ X \ ED}{AT \ X \ RFD} x10\text{-}3 \quad \ldots\ldots\ldots\ldots(3)$$

$$RFD_{derm} = RFD_{oral} \ x \ ABSgi \quad \ldots\ldots\ldots\ldots\ldots(4)$$

The ABSgi value is the gastrointestinal absorption factor. It has no unit of its own, Cr (0.25), Pb, (0.1), Cd (0.08), Cu (0.3) and Zinc (0.61) with Ni not assigned and is 0.89 for PAHs [17].

2.3.3. Hazard Quotient and Hazard Index

Hazard quotient (HQ) and hazard index (HI) methodology were used to quantify the risks related to exposure to non-carcinogens in the pollutants. The likelihood that an individual would experience a negative outcome is represented by the quotient, which is a number without a unit and is calculated by dividing the average daily dosage (ADD) of a particular heavy metal or PAH by the corresponding reference dose (RfD) (mg/kg/day) for both ingestion and dermal contact.

Hazard quotient for oral and skin contact of water and sediment samples as well as ingestion of seafood were calculated using the formula below [18].

$$HQ = \frac{ADD}{RfD}$$

According to [21], the total of the HQs for every congener in each sample was used to construct the Hazard Index (HIs) for the two pollutants, heavy metals and PAHs [21]. Contaminant HQ and HI values less than 1 are regarded as safe and suggest unlikely adverse health impacts, but values greater than 1 indicate a potential detrimental health effect [18].

$$HI = \mathbf{\Sigma} HQ$$

Hazard index (HI) = ΣTHQ ($THQ_{Cd}+ THQ_{Ni}+ THQ_{Cu}+ THQ_{Ar}+ THQ_{Cr}+ THQ_{Pb}+ THQ_{Fe}+ THQ_{V}$) or HI = $THQ_{ingest}+ THQ_{dermal}$

2.3.4. Carcinogenic Risk Assessment

The malignant growth slant factor (SF) was duplicated by the CDI or EDI to gauge the HQs for cancer-causing risk from ingestion/dermal openness to surface water, as indicated in equation (5). The Incremental Lifetime Cancer Risk (ILCR) is calculated using potential cancer risk when the ratios are larger than 1.

$$CR = EDI \text{ x } CSF \text{ for seafood \& water}^{\text{sample}} \quad (5)$$

According to the toxicological assessments and risk system created by the USEPA, WHO, and International Agency for Research on Cancer (IARC), the following heavy metals have carcinogenic slopes coefficients of 0.38, 0.84, and 0.5 that indicate they are recognized human carcinogens: Cd, Ni, Cr, and Pb. and 8.5 × 10−3 (mg L-1 day-1) [29] while verified cancer slope factor for PAHs is 11.5 mg/kg/day [19].

2.4. Statistical analysis

Statistical analysis of data All values were expressed as mean ± SD and then subjected to analysis of variance (ANOVA) using the Statistical Package for Social Sciences (SPSS) version 17.0 (SPSS Inc., Chicago Illinois). Statistical significance was considered at P=0.05.

3. Results and discussion

3.1. Proximate composition of sampled white croaker fish (*Genyonemus lineatus*)

The proximate composition of sampled fish parts is as shown in Fig 1. The result shows that ash content was 2.3% in fish skin and 2.83% in fish muscle; 68.17% moisture content in fish skin and 61.76% in fish muscle; 18.45% crude protein in fish skin and 13.13% in fish muscle; 0.97% crude lipid in fish skin and 0.81% in fish muscle; 1.06% crude fibre in fish skin and 1.83% in fish muscle; 9.04% carbohydrate in fish skin and 19.63% in fish muscle. Fish skin recorded higher moisture and crude protein content than fish muscle.

Carbohydrate (CHO) content of the croaker fish sample corroborated earlier research work by Dallinger [20] who reported 13% - 20.41% carbohydrate levels in tilapia fish. Carbohydrates are powerful energy sources and are needed for life maintenance in both plants and animals [21]. Crude fibre composition recorded in this study (1.06% and 1.83% in fish skin and muscle respectively) was below the 21.20% reported by Ejei-Okeke et al. [22] and 55.60% recorded by Nwauzoma and Dawari [23]. Fibre content in food represents the indigestible carbohydrate and lignin level 24]. Belewu et al. [25] stated that fibre is helpful in precluding diet related diseases such as diverticular and xhemorrhoids. Fibre cleanses the digestive tract by eliminating potential carcinogens and preventing excess cholesterol absorption [26]. Fibre as well adds bulk to the diet and prevent excess intake of starchy food [27] and may thus guard against metabolic conditions suchlike diabetes mellitus and hypercholesterolemia [28]. The crude protein values (18.45% in fish skin and 13.13% in fish muscle) compares favorably with the 20% protein content reported by Nwauzoma and Dawari [23]. This also corroborate findings of Chen *et al.* [29], Torruco-Uco *et al.* [30] and USDAARS [31] that the protein content of Catfish is around 21 – 26 %. Dietary fats play a role in increasing the tastiness of food by absorbing and retaining flavours [32].

3.2. Physicochemical and microbial parameters (surface water samples)

Results for physicochemical parameters of sampled surface water are shown in Table 1. The analyzed parameters were observed to be higher than values reported for control samples. However, total coliform count (CFU/ml) was below detectable limit.

COD was significantly high in the surface water samples (574.33±0.15mg/l) compared to the control sample which recorded 306.77±3.95mg/l. These values exceed the USEPA bench mark of 100mg/l which is suggestive that the surface water sample under study is polluted. COD results are always higher than BOD. However, the higher the equivalent oxygen content of a given waste, the higher is its COD and the higher is its polluting potential [33]. The COD values obtained in this study suggests that the surface water sample is an indication of pollution.

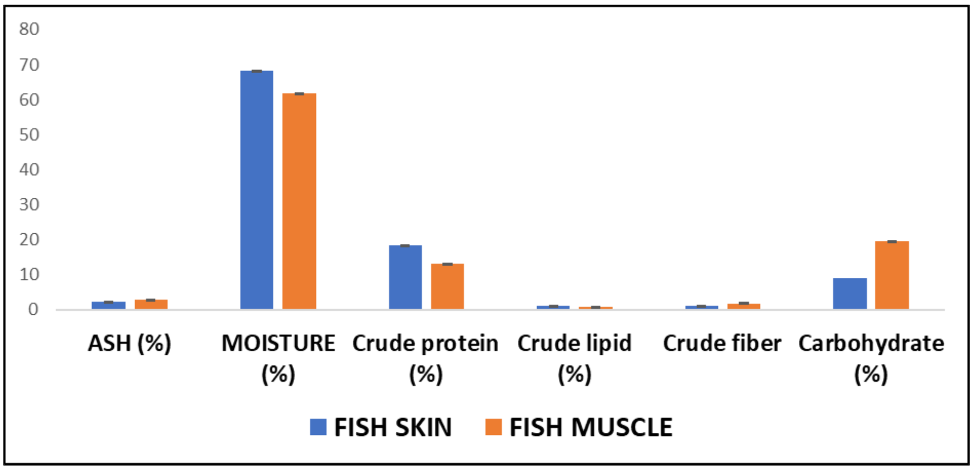

Figure 2 Proximate composition of fish sample

Table 1 Physicochemical and Microbial Parameters in Groundwater Sample

PARAMETERS	**WATER SAMPLES**	
	CONTROL	BR-SW
pH	6.80 ± 0.01	8.51 ± 0.01
E.C (Us/cm)	521.11 ± 0.90	743.33 ± 0.01
TSS (mg/l)	1.79 ± 0.03	4.61 ± 0.01
TDS (mg/l)	312.67 ± 0.54	445.96 ± 0.05
DO (mg/l)	8.35 ± 0.03	11.30 ± 0.06
COD (mg/l)	306.77 ± 3.95	574.33 ± 0.15
BOD5 (mg/l)	5.75 ± 0.03	8.35 ± 0.01
T. Hardness (mg/l)	819.43 ± 0.82	1519.87 ± 0.48
Chloride (mg/l)	191.28 ± 0.97	316.73 ± 0.3.46
Nitrate (mg/l)	6.77 ± 0.12	8.63 ± 3.46
Nitrite (mg/l)	2.76 ± 0.07	5.22 ± 0.05

Phosphate(mg/l)	0.74 ± 0.07	1.51 ± 0.02
Sulphate(mg/l)	173.18 ± 1.22	255.17 ± 0.01
Fluoride (mg/l)	0.18 ± 0.00	1.03 ± 0.00
TOG (mg/l)	11.85 ± 3.33	10.55 ± 0.00
T. Coliform (CFU/ml)	10.40 ± 0.00	BDL

Values are Mean ± SEM. Data with the same alphabets (a, b) as superscript indicate non-significant differences ($p \geq 0.05$), while that with different alphabets as superscript indicate significant differences ($p \leq 0.05$); BR-SW - Bonny River Surface Water

Table 2 PAH content of selected seafood sample

Non-carcinogenic PAHs (mg/kg)	**FISH SKIN**	**FISH MUSCLE**	**BR-SW**
Naphthalene	1.80	8.85	13.29
Acenaphthylene	9.36	-	-
Acenaphthene		1.25	9.50
Fluorene	1.57		18.88
Phenanthrene	9.48	11.93	15.28
Anthracene	-	-	-
Fluoranthene	-	1.58	26.95
Pyrene	5.38	-	11.14
Carcinogenic PAHs (mg/kg)	-	-	-
Benzo (g, h, i) perylene	-	-	-
Benz(a)anthracene	-	-	-
Chrysene	2.50	6.30	12.75
Benzo(b)fluoranthene	-	-	-
Benzo(k)fluoranthene	-	-	-
Benzo(a)pyrene	-	-	-
Indeno (1,2,3-cd) pyrene	-	-	-
Dibenz (a, h) anthracene	-	-	-
TOTAL	30.12	29.93	107.81
∑ Carcinogenic PAHS	2.50	6.30	12.75
‰ Carcinogenic	8.31	21.06	11.82

BR-SW - Bonny River Surface Water

Table 3 Heavy metal content of fish sample

PARAMETERS	Pb (mg/l)	Cd (mg/l)	Cu (mg/l)	Ni (mg/l)	Fe (mg/l)	Zn (mg/l)	Mn (mg/l)	Hg
CONTROL	0.236±0.13[a]	0.01±0.00[a]	0.433±0.11[a]	0.58±0.04[a]	3.07±0.04[a]	1.67±0.13[a]	4.03±0.04[a]	BDL
FISH SKIN	0.32±0.01[a]	0.00±0.00[a]	2.35±0.02[a]	0.003±0.00[a]	3.41±0.00[a]	1.92±0.01[a]	4.81±0.00[a]	BDL
FISH MUSCLE	0.76±0.00[a]	0.002±0.00[a]	2.79±0.02[a]	0.01±0.00[a]	1.01±0.00[a]	0.10±0.00[a]	1.73±0.01[a]	BDL
WHO 1993; EU 1998	0.01	0.003 – 0.005	2.961 ± 0.031	2.035 ± 0.017	-	-	-	-
USEPA 2011 MPL	4	0.2	1.023 ± 0.010	0.364 ± 0.014	-	-	-	-
RfD	0.004	0.001	0.825 ± 0.010	0.189 ± 0.011	-	-	-	-
US FDA [34]	-	-	-	70 - 80	-	-	-	-
WHO/FAO [35]	2	1	73	-	-	-	-	-

Table 4 Estimated Dietary Intake for Heavy Metals in fish sample

	Pb (mg/l)		Cd (mg/l)		Zn (mg/l)		Cu (mg/l)		Ni (mg/l)		Mn (mg/l)		Fe (mg/l)	
	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD
CONTROL	0.0008	0.018	3.24E-05	0.0001	0.025	0.013	0.014	0.0329	0.0019	0.004	0.0131	0.0306	0.01	0.0233
FISH SKIN	0.001	0.002	0	0	0.029	0.015	0.0076	0.0179	9.73E-06	2.28E-05	0.0156	0.0366	0.0111	0.0259
FISH MUSCLE	0.002	0.006	6.49E-06	1.52E-05	0.002	0.001	0.009	0.0212	3.24E-05	0.0001	0.00561	0.0131	0.0033	0.0077

Table 5 Hazard Quotient for Heavy Metals in fish sample

	Pb (mg/l)		Cd (mg/l)		Zn (mg/l)		Cu (mg/l)		Ni (mg/l)		Mn (mg/l)		Fe (mg/l)	
	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD
CONTROL	0.21	0.510	3.24E-02	7.60E-02	8.42E-02	4.23E-02	3.51E-01	8.23E-01	9.40E-02	2.20E-01	9.33E-01	0.219	1.24E-02	2.92E-02
FISH SKIN	2.96E-01	6.95E-01	0.00E+00	0.00E+00	9.69E-02	4.86E-02	1.91E-01	4.47E-01	4.86E-04	1.14E-03	1.11E+00	2.61E+00	1.38E-02	3.24E-02
FISH MUSCLE	7.04E-01	1.65E+00	6.49E-03	1.52E-02	5.04E-03	2.53E-03	2.26E-01	5.30E-01	1.62E-03	3.80E-03	4.01E-01	9.39E-01	4.09E-03	9.60E-03

Table 6 Life Cancer Risks for Heavy Metals in fish sample

	Pb (mg/l)		**Cd (mg/l)**		**Zn (mg/l)**		**Cu (mg/l)**		**Ni (mg/l)**		**Mn (mg/l)**		**Fe (mg/l)**	
	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD
CONTROL	6.51E-07	1.52E-06	1.23E-06	2.89E-06	-	-	-	-	3.20E-07	7.49E-07	-	-	-	-
FISH SKIN	8.82E-06	2.07E-05	0.00E+00	0.00E+00	-	-	-	-	1.65E-05	3.88E-05	-	-	-	-
FISH MUSCLE	2.09E-05	4.91E-05	2.46E-06	5.78E-06	-	-	-	-	5.51E-05	1.29E-04	-	-	-	-

Table 7 Hazard Index and TLCR for Heavy Metals in fish sample

PARAMETER	HAZARD INDEX		TLCR	
	ADULT	CHILD	ADULT	CHILD
CONTROL	0.69E+00	0850E+00	3.27E-06	7.67E-06
FISH SKIN	1.71E+00	3.83E+00	2.54E-05	5.94E-05
FISH MUSCLE	1.35E+00	3.15E+00	7.85E-05	1.84E-04
REF	1	1	1.00E-06 – 1.00E-04	1.00E-06 – 1.00E-04

Table 8 Incremental Life Cancer Risks (ILCR) for Heavy Metals in fish sample

LOCATION	ILCR INGESTION		ILCR DERMAL		ILCR INHALATION		ΣILCR	
	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD
FISH SKIN	2.03E-09	7.11E-10	-	-	-	-	2.03E-09	7.11E-10
FISH MUSCLE	5.12E-09	1.8E-09	-	-	-	-	5.12E-09	1.8E-09
WATER	1.01E-07	3.64E-09	8.27E-06	7.97E-06	-	-	8.371E-06	7.974E-06

3.3. Heavy Metals in Fish Tissues

The mean concentration of heavy metals in the samples are as shown in Table 2. Pb ranged from 0.32 ± 0.01mg/kg in fish skin to 0.76±0.00mg/kg in fish muscle; Cu ranged from 2.35±0.02 in fish skin to 2.79±0.02mg/kg in fish muscle; Fe ranged from 1.01±0.00mg/kg in fish muscle to 3.42 mg/kg in fish skin. Hg was detectable limit in all the samples analyzed.

The level of these metals in the Control surface water sample was in the order Cu<Mn < Fe < Pb < Zn < Ni < Cd < Hg, while in fish skin, it was in the order: Mn < Fe <Cu < Zn < Pb < Ni < Cd < Hg and in Fish muscle Cu < Mn < Fe < Pb < Zn < Ni < Cd < Hg. Obtained values were shown to exceed US FDA [34] and WHO/FAO [35] recommended standards as shown in Table 3. The variation in the levels of heavy metals in fish parts could be due to variance in the absorption capacity showcased within the fish alimentary system and via dermal contact with pollutants in the surrounding water [36]. Pb, Cd, and Ni recorded significant ($p<0.05$) presence in the various fish parts.

3.4. Polycyclic Aromatic Hydrocarbon Concentration in Fish Tissues and Water Sample

Table 3 presents mean PAH compounds in fish and surface water samples. PAH in surface water samples and fish muscle recorded mean values of 107.82mg/kg and 29.93mg/kg respectively. Surface water sample recorded total carcinogenic PAHs of 12.75mg/kg which constituted 11.83% of the total PAHs in the water Sample. Comparatively, fish skin showed lower level of total PAHs recording 2.50mg/kg (8.31% carcinogenic) as compared with fish muscle which had 6.31mg/kg (21.07% carcinogenic).

3.5. Health Risk Assessment

Calculated Chronic Daily Intake Dose (CDI ingest) and Hazard Quotient (HQ) in the sampled fish revealed Hazard Index of 1.35 in fish muscle in exposed adult population, with minimum Total Life Cancer Risk (TLCR) of 2.54E-05 recorded for fish skin. Values obtained were above standards stipulated by USEPA [37].

All samples analyzed showed B[a]P levels below detectable limits. Calculated Chronic Daily Intake Dose (CDI ingest) and Hazard Quotient (HQ) in the sampled fish revealed Hazard Index of 1.35 in fish muscle in exposed adult population, with minimum Total Life Cancer Risk (TLCR) of 2.54E-05 recorded for fish skin. Values obtained were above recommended standards stipulated by USEPA [37].

4. Conclusion

Findings reveal that physicochemical and microbiological water quality indicators for surface water from Bakana River are not in full compliance with permissible regulatory values, suggesting surface water contamination. The study also revealed significant presence of heavy metals and PAHs in white croaker fish and surface water samples. This could pose serious public health concern as results indicated probabilistic risk for both carcinogenic and non-carcinogenic adverse health effects. Therefore, consumers of the studied fish specie from Bonny River may be exposed to the risk of consuming carcinogenic environmental pollutants.

Compliance with ethical standards

Disclosure of conflict of interest

Authors have declared that no competing interests exist.

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