

Oil Spills And Health Risk Consequences Of *Oreochromis Niloticus* And *Tympanotonus Fuscatus*, Bodo Creek, Rivers State, Nigeria.

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Abstract

The study investigates the potential human health risks due to consumption of *Oreochromis niloticus* and *Tympanotonus fuscatus*, Bodo Creek, Rivers State, Nigeria using the US EPA (2001) human health risk assessment protocol. The study showed that heavy metals in sediment (Pb, 0.029 ± 0.002 mg/L; Cd, 0.019 ± 0.001 mg/L, and Ni, 5.311 ± 0.61 mg/L) exceeded DPR (2002) limits. Evidence of intake and retention of COPCs in Tilapia (*Oreochromis niloticus*) and Periwinkle (*Tympanotonus fuscatus*), showing Pb levels of 0.051 ± 0.002 mg/L in Tilapia and 0.027 ± 0.003 mg/L in Periwinkle, surpassing US EPA limits. The result revealed that PAHs in surface water and fish were below detection limits. Sediment showed significant PAH contamination, with a total of 11.39 mg/kg. TPHs in sediment reached 277.47 mg/kg. Tilapia and Periwinkle showed TPH levels of 12.16 mg/kg and 20.28 mg/kg, respectively, exceeding regulatory health limits. The results highlight significant potential ecological risks and human health risks from tilapia and periwinkle consumption. Noncancer risk analysis showed that Cr and Ni exceeded the threshold for children, with target hazard quotients (THQ) of $1.39E-01$ for Cr and $8.65E-02$ for Ni in Periwinkle. There were observed noncancer risk by both children and adults due to intake of hydrocarbons in tilapia (THQ, HI > 0.1) and no noncancer risk for periwinkle intake (THQ, HI < 0.1). Cancer risk analysis revealed nickel as the highest risk factor, with a target cancer risk (TCR) of $1.24E-04$ for children consuming tilapia. From the findings, it was concluded that Bodo population faces significant health risk due to the elevated levels of heavy metals and petroleum hydrocarbons in local fish. Therefore, it is strongly advised that local authorities implement comprehensive monitoring, effective intervention programs and community health education to mitigate the risks and protect the health of local populations, particularly vulnerable children.

Date of Submission: 07-10-2025

Date of Acceptance: 17-10-2025

I. Introduction

Bodo is the most populous community in Gokana Local Government Area of Rivers State with an estimated human population of 70,000 with over 85 percent of her resident primary engaged in peasant farming and fishing as a source of livelihood (SDN, 2016). The Local government is one of the four local governments in Ogoni, an indigenous group of people located in the Niger Delta region and the South-Eastern geopolitical division of Nigeria.

Oil activities began in the area in the late 50s as early as the discovery and exploitation of crude oil in Bomu oilfield by Shell D'Ichthy, and later Shell BP. Bodo shares boundary with K-Dere community through her shores. Oil operation by the Multinationals began in February, 1958 at K-Dere which was referred to as Bomu Oil Well-1 in the now Bomu oilfield. Bodo community has several oil facilities including oil wells, manifold at Patrick Waterside, and flow stations at Bodo West (UNEP, 2011).

Crude oil exploration and exploitation processes are associated with severe environmental impacts and human health threats. The environment in Bodo and other communities in Ogoni have suffered numerous unreported, unrecorded and few reported spills. For example, in 2008 and 2012, Bodo experienced 2 major Oil spills which had devastating impacts on the lives of the entire community, the aquatic and human ecosystems, endangering faunal and floral life, destruction of farmlands rendering them unfit for the cultivation of various agricultural products (SDN, 2016). Measurements of the combined spill volume gives an estimated 500,000

barrels of crude oil with largescale impacts particularly, the spilt oil having a devastating effect on fish in the area, whose numbers, species have been decimated (Leighday, 2024).

In addition to the degrading and devastating effects of these spills caused by equipment failure, human error, illegal refining and bunkering activities on the environment, other impacts have also been reported to contribute to the devastating effects on the Bodo community. These include health issues, loss of sources of livelihood, lack of potable water, general impact on the standard of living and ultimately deaths.

The pollution evidence was provided by a joint mapping, imagery research by Amnesty International-USA, the Geospatial Technologies and Human Rights Project of the American Association for the Advancement of Science (AAAS). A baseline Imagery captured on 4 December 2006 served as a baseline for the extent of environmental deterioration especially most riparian vegetation with no evidence of pollution in the tidal flats, rivers and streams around Bodo. However, the second satellite imagery captured by 26 January 2009, revealed high level of environmental degradation evidenced by Large dead vegetation stripes especially in proximity to waterways, rainbow effect in waterways leading to Bodo and the tidal flats adjacent to the settlement (on which the boats of local residents are visible) have changed from a muddy yellow to an oily grey color (AAAS, 2011).

Although, SPDC has made commitments to clean-up the shorelines of Bodo through the Bodo Mediation Initiative, the project has not yielded efficient result as occasional spills continue to occur in the area with uncomplimentary professional clean-up process. Hence, the people of Bodo and her environs are continually being exposed to the negative impacts of oil pollution.

II. Research Methods

Study Area Description

The geographic coordinates of the study area were 4°36'05.2"N 7°16'01.6"E, 4°36'59.0"N 7°15'17.0"E, 4°36'07.5"N 7°16'04.5"E, 4°36'08.0"N 7°16'04.5"E called Nweemuu community reported as one of the fishing ports and settlements for peasant fishing and farming, located in coastal plain of Bodo. The community is seated in a wetland, native to mangrove forest and diversities of aquatic lives surviving in the saline and brackish ecosystem. Bodo community is situated in Ogoniland, an ethnic group numbering over 2 million and spread over a 1,050-square-kilometre (404-square-mile) landscape.



Figure 1. Map of fish sampling locations from the creek of Bodo (Source: Nona, 2024).

Materials and sampling

All fish samples (Tilapia (*O. niloticus*, n =10 and Periwinkle (*T. fuscatus*, n>300)) were collected from the creek and mudflats by throw-nets and handpicking respectively. Surface water were collected using cleaned laboratory wares while sediment samples were collected using calibrated soil auger at variable depths at different points. All grab samples were taken and stored in an ice chest, and transported to the laboratory immediately after sampling where they were preserved prior to analysis.

Sample analysis

Unstable water monitoring parameters (Temperature, DO, TDS, EC, Turbidity, Salinity) were analyzed in situ using standard grade Hannah Multi Parameter Meter in accordance with relevant APHA and ASTM standards while the stable Parameters were analyzed under standard laboratory practices. Levels of chemicals of potential concern (COPC) to the ecosystem and human health were analyzed in the sediment and fish samples.

The collected samples were analyzed for seven heavy metals including Pb, Cr, Cd, Ni, Pb, Cu, , and Fe, priority polycyclic aromatic hydrocarbons, and total petroleum hydrocarbons using standard methods for the testing of surface water, sediments and aquatic life. Concentrations of the heavy metals in all samples were measured using an Atomic Absorption Spectrometry spectrometry (APHA 3111B). Prior to analysis with the AAS, the composite samples of the fish samples, Periwinkle samples and the sediments were prepared. Each of the composite samples were homogenized, wet ashed with concentrated sulphuric acid and digested with aqua-regia (mixture of hydrochloric acid and nitric acid in the ratio of 3:1). The digests were filtered with known volume of water into clean and well labelled containers for AAS analysis.

Total Petroleum Hydrocarbon and Poly Aromatic Hydrocarbon were measured using Gas chromatography flame ionization detector (GC-FID) using ASTM D3921 and ASTM D8100 respectively. 250ml of the sample was extracted with DCM/Hexane mixture; this was then concentrated to 2ml and then cleanup in a sodium sulfate packed column, thereafter injected into the GC-FID.

Quality assurance and quality control

The sample containers (glass bottles) were prewashed to remove external contaminants before they were used. All the sample containers were labelled for proper sample identification and temperature controlled using ice pack stored in a plastic cooler and conveyed to the BGI Laboratories Limited, Port Harcourt on the same sampling date for controlled preservation and analysis. The geographical location coordinate of each sample represented in DMS was dully recorded for easy referencing. Coordinates for both soil and water, date of sample collection were properly documented. A 70 to 130% recovery of surrogates was set as acceptable limit in this study and obtained recoveries were above 80%. High surrogate recoveries like those obtained in this study indicate that the target analytes will be detected, if present. Surrogate recoveries with the target acceptable range are an indication of suitability and accuracy in analytical method.

Health risk assessment

This study used the US.EPA (2001) probabilistic risk assessment module to conduct the probable risk of exposure to chemicals of potential concern (COPC) in fish samples from Bodo community.

Noncancer risk

The approach relies on the estimation of an exposure level for the human population (adults and children), that is likely to be without an appreciable risk of deleterious effects during a lifetime. The Target hazard quotient and target hazard indices are used to characterize the noncancer risk to the exposed population with reference to established toxicity reference value of 0.1 (US EPA, 2024a).

Target Hazard Index,

Cancer risk

The cancer risk approach uses Equation 3 to estimate the possible deleterious effect that may arise from above a threshold risk limit of 1.0E-06.

Target cancer risk (TCR_o) =

Cumulative Lifetime Cancer Risk (ΣILCR)

The cumulative individual cancer risk (ΣILCR) is a measure of the potential cancer risk due to an individual's exposure to more than one carcinogenic heavy metals or hydrocarbons through a single exposure route (i.e., a particular fish species). (Sibe et al., 2019). It evaluates the combined risk tendency of all COPC in a diet and used

Where n = 1, 2, ----, n is the target risk of individual carcinogenic COPC in a fish diet.

Parameter Definitions

COPC = concentration of chemical of potential concern in the diet (mg/kg).

R_f = 0.0371 kg/bw/day(adult) and 0.0186kg/bw/day(child) = fish ingestion rate value varies among different population groups, exposure pathway and exposure scenario location (US EPA, 2005). The United States Department of Agriculture (USDA) has developed a national fish consumption model by children as one-half that of the adult population (MDEP, 1996). Hence, this study adopted one-half the per capita fish ingestion rate (13kg/bw/year) for the Nigerian child (6.5kg/bw/year).

B_w = resident adult body weight (kg) 70 kg and 15kg for child resident. EF exposure frequency (days/yr) 350 days/yr for both adult and child resident. ED = reasonable maximum exposure duration (yr) for adult resident/fisher = 30 yrs and 6 yrs for child resident/fisher child (US EPA, 2001). AT averaging time = (30 yrs

and 6yrs for adult and child noncarcinogens) = (365 days x 70 yrs =25550 days, (carcinogens)), (365 days x 30 yrs = 10950 days, adult noncarcinogens)), and 6yrs x 365 =2190days child, (carcinogens)). RfD_o oral chronic reference dose (mg/kg-day) – chemical-specific. THI target hazard index (unitless) 0.1. THQ target hazard index (unitless) 0.1 (US EPA, 2024a). TCR_o target cancer risk due to oral intake of COPC in fish.

ATSDR (2024) uses minimal risk levels (MRL) as an analogous to US EPA RfD_o to estimate the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure.

These substance specific estimates, which are intended to serve as screening levels, are used by ATSDR health assessors and other responders to identify contaminants and potential health effects that may be of concern at hazardous waste sites. EPA has not established an RfD or RfC for lead. Although, by comparison to most other environmental toxicants, there is a low degree of uncertainty about the health effects of lead, EPA believes that it is inappropriate to develop an RfD for lead. In addition, “it appears that some of these effects, particularly children's neurobehavioral development, may occur at blood lead levels so low as to be essentially without a threshold” (U.S. EPA, 2000a).

In 2022, the Superfund Health Risk Technical Support Center National Center for Environmental Assessment Office of Research and Development published a document that provides the data, methods, and assumptions for deriving Provisional Peer-Reviewed Toxicity Values (PPRTVs) for six carbon-fractions of petroleum hydrocarbons. The six TPH fractions were assigned representative compounds for determination of toxicity values and chemical-specific parameters to calculate RSLs.

Toxicity assessments of low aliphatics (C5-C8) uses n-hexane/n-heptane/cyclo-hexene, medium-range aliphatic hydrocarbons (C9-C18) uses n-nonane, high aliphatics (C19-C32) uses white mineral oil, while low aromatics (C6-C8) uses benzene, mid-aromatics (C9-C10) uses 1,2,3-trimethylbenzene, and high aromatics (C10-C32) uses benzo (a) pyrene as a representative compounds and utilizes the respective default exposure values, risk values for the evaluation of risk screening levels (US EPA, 2009a, 2009b, 2022). It is however more recommended to use the provisional peer-reviewed toxicity values (PPRTV) in risk screenings. The provisional oral reference dose (p-RfD) obtained from PPRTV calculations (US EPA, 2009a,b; 2022) for low-ranged aliphatics (C5-C8) is 6×10^{-2} , midranged alipahtics is (C9-C18) is 1×10^{-2} and high-ranged aliphatics (C19-C32) is 3×10^0 while the sub-chronic provisional reference dose (p-sRfD) for low carbon-ranged aromatics (C6–C8) are 1×10^{-2} , 8×10^{-1} , 5×10^{-2} , 4×10^{-1} (BTEX respectively). RfD and p-RfD for medium carbon-ranged and high carbon-ranged aromatics exist in the literature.

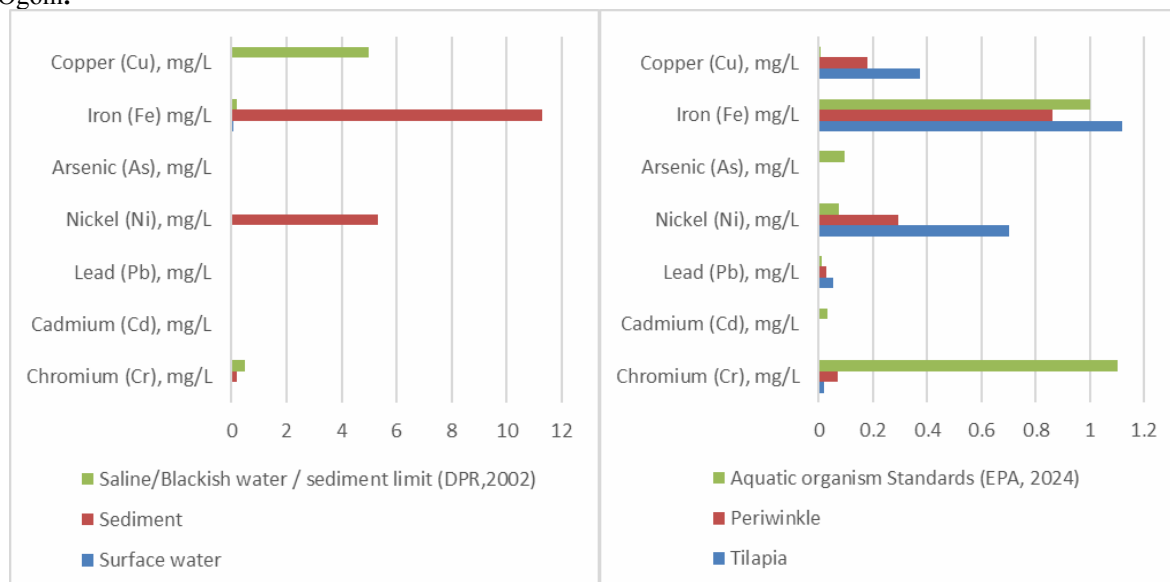
Parameter	Surface water	Sediment	Saline/Blackish water / sediment limit (DPR,2002)	Tilapia	Periwinkle	Aquatic organism Standards (EPA, 2024)
Chromium (Cr), mg/L	BDL	0.201±0.01	0.5	0.021±0.001	0.070±0.001	1.1
Cadmium (Cd), mg/L	0.009±0.0001	0.019±0.001	0.003	BDL	BDL	0.033
Lead (Pb), mg/L	BDL	0.029±0.002	0.015	0.051±0.002	0.027±0.003	0.012
Nickel (Ni), mg/L	0.041±0.0002	5.311±0.61	0.02	0.701±0.052	0.291±0.011	0.074
Arsenic (As), mg/L	BDL	0.007±0.0001	0.001	BDL	BDL	0.096
Iron (Fe) mg/L	0.079±0.0003	11.268±0.90	0.20	1.119±0.21	0.863±0.042	1
Copper (Cu), mg/L	0.011±0.001	0.001±0.0001	5	0.371±0.071	0.181±0.010	0.0048

III. Results And Discussion

Results

Table 1 below presents heavy metal concentrations in surface water, sediment, Tilapia (*Oreochromis niloticus*) and Periwinkle (*Tympanotonus fuscatus*) from Bodo Creek, Ogoni. Sediment revealed higher concentrations of most heavy metals, particularly nickel (Ni) at 5.311±0.61 mg/L and iron (Fe) at 11.268±0.90 mg/L, indicating significant contamination from industrial or oil-related activities. In surface water, cadmium (Cd) and nickel (Ni) are detected, with Cd at 0.009±0.0001 mg/L, which may pose ecological risks.

Tilapia and periwinkle also showed varying levels of bioaccumulation, with tilapia exhibiting notable concentrations of nickel (0.701±0.052 mg/L) and copper (0.371±0.071 mg/L). Periwinkle contains significant levels of chromium (0.070±0.001 mg/L) and iron (0.863±0.042 mg/L), highlighting potential metal uptake from sediment. The presence of heavy metals in these organisms suggests potential risks to aquatic life and human health through the food chain in Bodo Creek.

Table 1. Heavy metals concentrations in the environment and in the tissues of fishes, Bodo fishing creek, Ogoni.**Figure 2.** Visual representation of the concentrations of heavy metals in (a), surface water and sediments (b), and fish tissues sampled at Bodo Creek, Ogoni.**Table 2.** Levels of Eighteen polycyclic aromatic hydrocarbons (PAHs) of priority concern in the tissues of organisms and the environment, Bodo Creek, Ogoni

PARAMETER	SAMPLE MATRIX			
	Surface water	Sediment	Tilapia	Periwinkle
1,2,3- Trimethylbenzene	-	-	-	-
Naphthalene	-	-	-	-
2-Methylnaphthalene	-	-	-	-
Acenaphthylene	-	-	-	-
Acenaphthene	-	-	-	-
Fluorene	-	-	-	-
Anthracene	-	-	-	-
Phenanthrene	-	-	-	-
Fluoranthene	-	-	-	-
Pyrene	-	-	-	-
Benz (a) anthracene	-	-	-	-
Chrysene	-	1.94±0.07	-	-
Benzo (b) fluoranthene	-	-	-	-
Benzo (k) fluoranthene	-	3.15±0.09	-	-
Benzo (a) pyrene	-	2.85±0.08	-	-
Dibenz(a,h)anthracene	-	1.06±0.04	-	-
Indeno(1,2,3-cd)pyrene	-	1.13±0.05	-	-
Benzo (g,h,i) perylene	-	1.26±0.06	-	-
TPAHs	<0.001	11.39±0.39	<0.001	<0.001

*Concentrations below detection limit is represented as a dash (-)

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Table 2 indicates the concentrations of eighteen priority polycyclic aromatic hydrocarbons (PAHs) in surface water, sediment, tilapia, and periwinkle from Bodo Creek, Ogoni. Most PAHs were below detection limits in surface water, Tilapia (*Oreochromis niloticus*), and Periwinkle (*Tympanotonus fuscatus*), suggesting minimal contamination or very low sensitivity of detection in these matrices. However, several PAHs were detected in the sediment, with notable values: chrysene (1.94±0.07 mg/kg), benzo(k)fluoranthene (3.15±0.09 mg/kg), benzo(a)pyrene (2.85±0.08 mg/kg), dibenz(a,h)anthracene (1.06±0.04 mg/kg), indeno(1,2,3-cd)pyrene (1.13±0.05 mg/kg), and benzo(g,h,i)perylene (1.26±0.06 mg/kg). These findings point to sediment as the primary reservoir for PAH contamination, likely from oil pollution. The total PAHs (TPAHs) in sediment (11.39±0.39 mg/kg) pose potential risks to the ecosystem, especially for benthic organisms.

Table 3. Levels of speciated hydrocarbons (C8-C40) of priority concern in the tissues of organisms and the environment, Bodo Creek, Ogoni

PARAMETER	SAMPLE MATRIX			
TPHs	Surface water	Sediment	Tilapia	Periwinkle
C8	-	2.3653	0.0132	-
C9	-	3.6693	0.1015	-
C10	-	5.0647	0.0239	-
C11	-	8.1208	0.1023	-
C12	-	3.1475	0.1902	-
C13	-	8.3086	1.7531	-
C14	-	6.604	0.9739	-
C15	-	21.6311	1.0674	-
C16	-	12.627	0.2017	-
C17	-	2.5266	1.1125	-
C18	-	40.7509	4.6320	-
C19	-	17.6186	1.9842	-
C20	-	16.8005	-	-
C21	-	5.3518	-	-
C22	-	3.2565	-	-
C23	-	7.6668	-	-
C24	-	5.2692	-	-
C25	-	2.3354	-	-
C26	-	3.9811	-	-
C27	-	8.3817	-	1.9643
C28	-	2.4993	-	0.1606
C29	-	6.8711	-	0.8830
C30	-	2.4232	-	0.8532
C31	-	2.1575	-	1.6046
C32	-	4.315	-	5.8912
C33	-	8.5717	-	0.6377
C34	-	8.4101	-	1.2770
C35	-	4.3779	-	3.1107
C36	-	5.8034	-	0.0916
C37	-	2.0379	-	0.9273
C38	-	4.1074	-	0.4904
C39	-	6.147	-	1.5928
C40	-	9.3652	-	0.7979
Pr	-	5.6377	-	-
Ph	-	19.2677	-	-
TPHCs	<0.001	277.4695	12.1559	20.2823

*Concentrations below detection limit is represented as a dash (-)

Table 3 presents the concentrations of speciated hydrocarbons (C8-C40) in surface water, sediment, tilapia, and periwinkle from Bodo Creek, Ogoni. Most hydrocarbons are below detection limits in surface water, indicating minimal contamination. However, sediment shows significant levels of hydrocarbons across various carbon chains, with a total petroleum hydrocarbon concentration (TPHCs) of 277.4695 mg/kg. This suggests sediment acts as a major sink for hydrocarbons, likely due to oil spills and industrial activities in the area.

In tilapia, C13-C19 hydrocarbons were detected, with C18 showing the highest concentration (4.6320 mg/kg), indicating some level of bioaccumulation. Periwinkle shows detectable levels of C8-C40 hydrocarbons, with C32 (5.8912 mg/kg) being the most prominent. The presence of hydrocarbons in these organisms poses ecological risks, indicating potential contamination of the food chain. Overall, sediment and biota contamination highlight ongoing environmental issues in Bodo Creek due to petroleum pollution.

Discussion

Noncancer Risk Evaluation of Heavy Metals Consumed through Tilapia and Periwinkle

Table 4. Non-cancer Risk of Heavy Metals due to Fish Consumption, Bodo Community, Rivers state, Nigeria.

Metals (ppm)	THQ				Standard	
	Tilapia			Periwinkle		Threshold (US EPA, 2024)
	Adult	Child		Adult	Child	
Cr	3.56E-03	4.16E-02		1.19E-02	1.39E-01	1.00E-01
Cd	0.00E+00	0.00E+00		0.00E+00	0.00E+00	
Pb	0.00E+00	0.00E+00		0.00E+00	0.00E+00	
Ni	1.78E-02	2.08E-01		7.39E-03	8.65E-02	
As	0.00E+00	0.00E+00		0.00E+00	0.00E+00	

Fe	8.12E-04	9.50E-03		6.27E-04	7.33E-03
Cu	4.71E-03	5.51E-02		2.30E-03	2.69E-02
THI	2.69E-02	3.15E-01		2.22E-02	2.59E-01

THQ =Target Hazard quotient, THI = Target Hazard Index

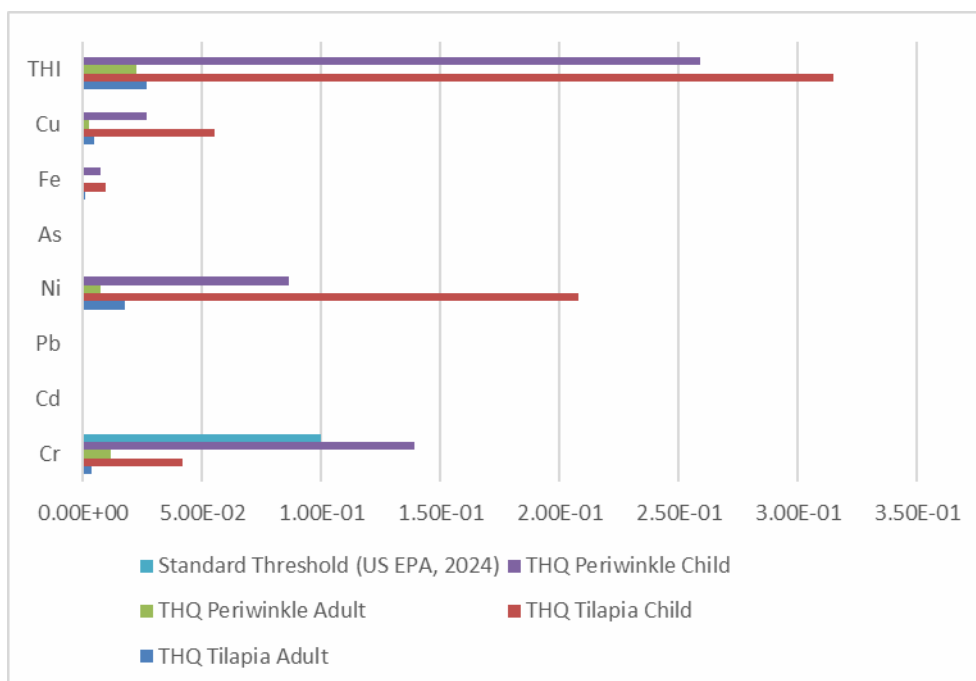


Figure 3: Visual representation of non-cancer risk of heavy metals due to fish consumption, Bodo Community, Rivers state, Nigeria.

Among all 7 heavy metals studied (Table 4), Cr ($3.56\text{E-}03$, adults; $4.16\text{E-}02$, Child and $1.19\text{E-}02$, adult; $1.39\text{E-}01$, child), and Ni ($1.78\text{E-}02$, adults; $2.08\text{E-}01$, child and $7.39\text{E-}03$, adults; $8.65\text{E-}02$, child) have greater potential to cause harm due to chronic consumption of tilapia and periwinkle respectively. Fe is highly unlikely to pose a non-cancer effect via fish consumption.

The findings from this research revealed that consumption of Cr, Cd, Pb, Ni, As, Fe and Cu lacks the tendency to pose non-cancer effect to the adult population who consume Tilapia (*Oreochromis niloticus*) and Periwinkle from Bodo creek. The target hazard quotients for all heavy metals due to consumption of both tilapia and periwinkle were observed below the non-cancer risk threshold of 0.1 and 1.0 recommended by the US EPA (2024). However, intake of Ni and Cr by the children population via tilapia and periwinkle respectively exceed the non-cancer threshold and may pose significant intoxication. The target hazard index (HI) which measures effect due to cumulative consumption of all heavy metals through one dietary route for children indicates high potential of heavy metals intoxication in children through chronic exposure to the two fishes studied in Bodo.

Noncancer Risk Evaluation of Petroleum Hydrocarbons through Tilapia and Periwinkle

Table 5. Daily Intake of Petroleum Hydrocarbons Through the Consumption of Fishes, Bodo Community, Rivers State, Nigeria

INDEX	THQ				STANDARD
Sample	Tilapia		Periwinkle		Threshold (US EPA, 2024)
Petroleum hydrocarbons	Adult fisher/resident	child resident	Adult fisher/resident	child resident	1.00E-01
C8	6.71E-04	7.85E-03	-	-	
C9	5.16E-03	6.03E-02	-	-	
C10	0.00E+00	0.00E+00	-	-	
C11	5.20E-03	6.08E-02	-	-	
C12	9.67E-03	1.13E-01	-	-	
C13	8.91E-02	1.04E+00	-	-	
C14	4.95E-02	5.79E-01	-	-	
C15	5.42E-02	6.35E-01	-	-	

C16	1.03E-02	1.20E-01	-	-
C17	5.65E-02	6.61E-01	-	-
C18	2.35E-01	2.75E+00	-	-
C19	1.01E-01	1.18E+00	-	-
C20	-	-	-	-
C21	-	-	-	-
C22	-	-	-	-
C23	-	-	-	-
C24	-	-	-	-
C25	-	-	-	-
C26	-	-	-	-
C27	-	-	3.33E-04	3.89E-03
C28	-	-	2.72E-05	3.18E-04
C29	-	-	0.00E+00	0.00E+00
C30	-	-	1.45E-04	1.69E-03
C31	-	-	2.72E-04	3.18E-03
C32	-	-	9.98E-04	1.17E-02
C33	-	-	1.08E-04	1.26E-03
C34	-	-	2.16E-04	2.53E-03
C35	-	-	5.27E-04	6.16E-03
C36	-	-	1.55E-05	1.82E-04
C37	-	-	1.57E-04	1.84E-03
C38	-	-	8.31E-05	9.72E-04
C39	-	-	2.70E-04	3.16E-03
C40	-	-	1.35E-04	1.58E-03
THI	6.17E-01	7.21E+00	3.29E-03	3.84E-02

THQ =Target Hazard quotient, THI = Target Hazard Index

Toxicity assessments of medium carbon-ranged aliphatic hydrocarbons (C9-C18) and high carbon-ranged aliphatics (C19-C32) in tilapia and periwinkle is presented in Table 5. Using the US EPA (2024) updated target hazard thresholds of THQ and THI of 0.1, it was found that intake of middle-carbon-ranged aliphatics is predominant in tilapia while high-carbon-ranged aliphatics was predominant in periwinkle. The exposure and risk evaluation revealed a normal trend of child greater susceptibility than adults.

Adults consumption of C9-C18 were below the noncancer risk threshold of 0.1 except C18 and C19 while C12-C19 exceeded the 0.1 threshold due to tilapia consumption. Adults and children consumption of all high-carbon petroleum hydrocarbons in periwinkle were found below the threshold noncancer limit in the study area. The cumulative individual lifetime noncancer risk that may arise due to the consumption of TPHs through tilapia fish were all found above the minimum risk limit threshold level of 0.1. the target hazard index, THI for adults were 6.17E-01 while children were 7.21E+00 (Table 5) via tilapia. However, THI for both adults and children were well-below the acceptable risk limit indicating high uncertainty of ingestion risk from petroleum hydrocarbons in periwinkle from Nweemuu, Bodo.

Evaluation of Cancer Risk of Heavy Metals through Tilapia and Periwinkle Exposure

Table 6. Cancer risk due to fish consumption, Bodo Community, Rivers state, Nigeria.

Fish sample	Age group	Heavy Metals (ppm)						TCR
		Cr	Cd	Pb	Ni	As	ΣILCR _i	
Tilapia	Adult	2.29E-06	-	9.44E-08	1.16E-04	-	1.20E-04	1.0E-06
	Child	1.25E-05	-	5.15E-07	1.240E-04	-	1.30E-04	1.0E-06
Periwinkle	Adult	7.623E-06	-	4.99E-08	5.77E-05	-	6.54E-05	1.0E-06
	Child	4.16E-05	-	2.73E-07	3.15E-04	-	3.57E-04	1.0E-06

ΣILCR_i = Cumulation of individual lifetime cancer risk, TCR = Target cancer risk

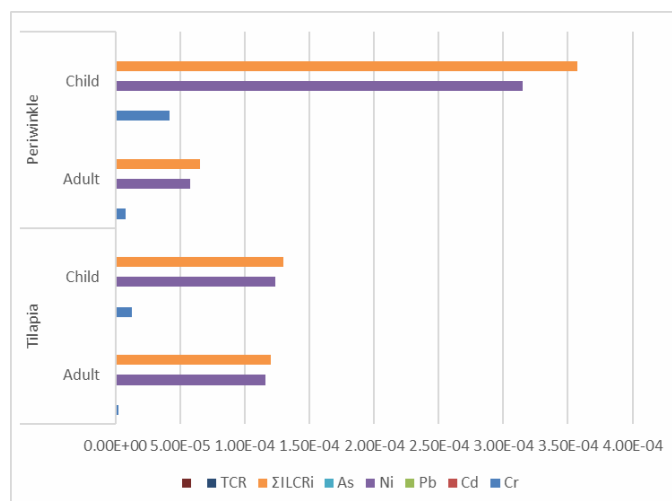


Figure 4: Visual representation of cancer risk due to fish consumption, Bodo Community, Rivers state, Nigeria.

The potential carcinogenic effects due to consumption of fishes (tilapia and periwinkle) from Nweemuu, Bodo community by the children and adult population is shown in Table 6. The carcinogenic heavy metals (Cr, Cd, Pb, Ni and As) were investigated and results show that intake of Pb via both exposure pathways has the least potential for cancer risk (adults: $9.44\text{E-}08$ and children: $5.15\text{E-}07$) and (adults: $4.99\text{E-}08$ and children: $2.73\text{E-}07$) for tilapia and periwinkle intake respectively while the greatest cancer risk is due to Ni intake by both population group and through both exposure pathways (Tilapia and periwinkle). Children ($1.24\text{E-}04$ and $3.15\text{E-}04$) and adults ($1.16\text{E-}04$ and $5.77\text{E-}05$) in tilapia and periwinkle respectively. Generally, both Cr and Ni cancer risk exceeded the target threshold cancer risk level of $1.0\text{E-}06$ indicating greater tendency to chronic effect by an individual over a lifetime in Nweemuu, Bodo. The results show greater susceptibility of children (greater than the safe limit of $1.0\text{E-}04$ – $1.0\text{E-}06$) to developing cancer due to oral intake of contaminants of potential concern (COPC) due oil spill pollution in the Bodo creeks. In addition, the combined potential (ΣILCRi) long-term (lifetime) cancer effects that may be posed to an individual consuming all metals though each fish exceeded the safe limits with children being at greatest risk ($3.57\text{E-}04$) due to intake of metals in periwinkle.

IV. Conclusion

This study provides a comprehensive assessment of the environmental and health risks associated with heavy metals, polycyclic aromatic hydrocarbons (PAHs), and total petroleum hydrocarbons (TPHs) in Bodo Creek, Ogoni. The physicochemical analysis revealed that while surface water quality parameters such as pH (7.44 ± 0.06), turbidity (8.8 ± 0.07 NTU), and biological oxygen demand (BOD) (5.34 ± 0.03 mg/L) generally met WHO standards, certain factors like elevated temperature ($30.88\pm2.10^\circ\text{C}$), electrical conductivity (EC) ($23,300\pm40.1$ $\mu\text{S/cm}$), and low dissolved oxygen (DO) (3.83 ± 0.01 mg/L) suggest potential stress on aquatic life. The high levels of total dissolved solids (TDS) ($14,730\pm20.3$ mg/L) and elevated EC further indicate substantial ionic pollution, chiefly due to oil-related activities.

The heavy metal analysis showed significant contamination in sediments, with elevated concentrations of lead (Pb) (0.029 ± 0.002 mg/L), cadmium (Cd) (0.019 ± 0.001 mg/L), and nickel (Ni) (5.311 ± 0.61 mg/L), exceeding DPR regulatory limits. These contaminants also revealed varying degrees of bioaccumulation in aquatic species such as Tilapia (*Oreochromis niloticus*) and Periwinkle (*Tympanotonus fuscatus*). Specifically, Pb (0.051 ± 0.002 mg/L) and Ni (0.701 ± 0.052 mg/L) concentrations in fish tissues were above EPA regulatory limits which may trigger cancer risks for consumers. Although Cd was not detected in the tissues, its elevated environmental levels point to potential future risks.

The observed concentrations of PAHs and TPHs in sediments and in the tissue tilapia and periwinkle point to potential health risk that may arise following frequent consumption and bioaccumulation in consumers.

This study revealed that Cr and Ni present the highest non-cancer risks with highest susceptibility for children consuming these fish, as their Target Hazard Quotients (THQ) exceed the recommended threshold of 0.1. However, the non-cancer risks for adults consuming heavy metals were generally within acceptable limits.

Petroleum hydrocarbons (TPHs) show varying levels of risk based on their carbon range (Middle-carbon-ranged aliphatics, C9-C18 and high-carbon-ranged aliphatics, C19-C32).

Cancer risk assessments reveal the potentials for Ni and Cr to induce toxic effects in the target populations with higher chances for children than adults. The risk of cancer due to PAHs were considered negligible as their concentrations were observed below detection limits in the fish tissue studied.

Consequently, this study reveals that the Bodo population and her environs are at significant health risk due to the elevated levels of heavy metals and petroleum hydrocarbons in local fish. Strong local, institutional and governmental intervention measures are required to expedite comprehensive monitoring, effective intervention programs and community health education to mitigate these risk and protect the health of local populations, particularly vulnerable children.

References

- [1]. AAAS, American Association For The Advancement Of Science (2011). Geospatial Technologies And Human Rights Project. Documentation Of Petroleum Release: Bodo, Nigeria. 1200 New York Avenue, NW Washington, DC 20005 USA.
- [2]. Aghoghovwia, O.A. & Ohimain, E.I. (2014). Physicochemical Characteristics Of Lower Kolo Creek, Otuogidi, Bayelsa State. Nigerian Journal Of Agriculture, Food And Environment, 10(1), 23-26.
- [3]. Aghoghovwian, O.A., Oyelese, O.A. & Ohimain, E.I. (2015). Heavy Metal Levels In Water And Sediment Of Warri River, Niger Delta, Nigerian. International Journal Of Geology, Agriculture And Environmental Sciences, 3(1), 20-24.
- [4]. Aghoghovwian, O.A., Umoru, O.D. & Izah, S.C. (2018). Physicochemical Characteristics Of Nun River At Gbarantoru And Tombia Axis In Bayelsa State, Nigeria. Bioscience Methods, 9(1), 1-11. <https://doi.org/10.5376/Bm.2018.09.0001>
- [5]. Akachukwu, D., Nnaji J.C., Ojmelukwe P., Onaja, S. & Odu, S. (2020). Sediment Quality Of Orashi River At Four Oil Producing Communities Of Nigeria. Journal Of Applied. Science & Environmental Management, 2(7), 1145-115.
- [6]. Akan J.C. Abdurahman F.J, Sodipo D.A, Ochanya A.E & Askira Y.K (2010). Heavy Metals In Sediments From River Ngada, Maiduguru Metropolis, Borno State, Nigeria. Journal Of Environmental Chemistry And Ecotoxicology, 12(29), 131-140.
- [7]. Akanimo, E., Edidiong, I., & Ifio, E. (2019). Assessment Of Polycyclic Aromatic Hydrocarbons Levels In Soil Around Automobile Repair Workshops Within Eket Metropolis, Akwa Ibom State, Nigeria. International Journal Of Research And Scientific Innovation, 6(1), 102-107.
- [8]. APHA (2005). Standard Methods For The Examination Of Water And Wastewater (21st Ed.). American Public Health Association.
- [9]. ATSDR (2024). Minimal Risk Levels (Mrls) For Hazardous Substances: Minimal Risk Levels (Mrls) – For Professionals. Available At Minimal Risk Levels (Mrls) – For Professionals|Toxic Substances Portal|ATSDR (Cdc.Gov).
- [10]. Atuma, I.M., Efe, S.I., Ndakara, O.E. (2023). Temperature Trend In Niger Delta Region, Nigeria. Journal Of Management And Social Science Research, 4(1), 29–39. DOI: <http://doi.org/10.47524/Jmssr.V4i1.30>
- [11]. Ayoola, S. O., Olorunsanmi, G. T. & Oke, A. O. (2017) Comparative Assessment Of Total Hydrocarbon Content And Bioaccumulation Of Heavy Metals In Sarotherodon Melanothronat Atlas Cove Area And Okobaba Of Lagos Lagoon. IJEE, 8(2), 152-159.
- [12]. Daka, E.R., Amakiri-Whyte, B. & Inyang, I.R. (2014). Surface And Groundwater Quality In Some Oil Field Communities In Niger Delta: Implications For Domestic Use And Building Construction. Research Journal Of Environmental And Sciences Earth 6(2), 78-84.
- [13]. DPR, Department Of Petroleum Resources. (2002). Environmental Guidelines And Standards For The Petroleum Industry In Nigeria (EGASPIN). Revised Edition. Lagos Nigeria.
- [14]. Edori, O.S. & Nna P.J. (2018). Determination Of Physicochemical Parameters Of Effluents At Discharge Point Into The New Calabar River Along Rumuolumeni Axis, Port Harcourt, Rivers State. Niger Delta, Nigeria. Journal Of Environmental And Analytical Toxicology, 8, 555. <https://doi.org/10.4172/2161-0525.1000585>
- [15]. Edori, O.S., Edori, E.S. & Ntembaba, S.A. (2020). Assessment Of Heavy Metals Concentrations In Sediments At Drainage Points Into The New Calabar River, Rivers State, Nigeria. International Journal Of Research And Innovation In Applied Science, V(X), 9-13.
- [16]. Edori, O.S., Kieri, B.S.I. & Festus, C. (2019). Physicochemical Characteristics Of Surface Water And Sediments Of Silver River, Southern Ijaw, Bayelsa State, Niger Delta, Nigeria. American Journal Of Environmental And Engineering, 3(2), 39-46. <https://doi.org/10.11648/J.Ajese.20190302.12>
- [17]. Ekpote, O.A., Edori, O.S. & Iyama, W. (2019). Concentration Of Polycyclic Aromatic Hydrocarbons From Selected Dumpsites Within Port Harcourt Metropolis, Rivers State, Niger Delta, Nigeria. International Journal Of Environmental Sciences And Natural Resources, 21(14), 1-6.
- [18]. Emmanuel C.N. & Woke G.N. (2019). Physicochemical Parameters Of Woji Creek, River State, Nigeria. Global Journal Of Agricultural Research, 7(4), 12-21.
- [19]. Gijo, A.H., Hart, A.I., Seiyaboh, E.I (2016). The Impact Of Makeshift Oil Refineries On The Macro-Invertebrates Of The Nun River Estuary, Niger Delta, Nigeria. Greener Journal Of Biological Science 6(6), 112-119
- [20]. Ishaq, S.E., Rufus S. & Paul A.A. (2012). An Assessment Of Heavy Metals Loading In River Benue In The Makurdi Metropolitan Area In Central Nigeria. Environmental Monitoring & Assessment, 184(1), 201-207. <https://doi.org/10.1007/S10661-011-1959-0>
- [21]. Kpee, F. & Ekpote, O.A. (2015). Intermittent Variation Of Trace Metals In Tissues Of Periwinkles (Tympanotonus Fuscatus) And Sediments From Kalabari Creeks. Research Journal On Contemporary Issues And Development, 4(3), 95-105
- [22]. Kpee, F. (2012). Pollution Levels Of Heavy Metals In Sediments, Biotas And Water Of Kalabari Creeks, Rivers State, Nigeria. Phd Thesis, University Of Nigeria, Nsukka, Nigeria.
- [23]. Leighday (September, 2024). Shell – Bodo: Oil Spills On The Niger Delta. Background To The Bodo Claims. Retrieved From <https://www.leighday.co.uk/news/cases-and-testimonials/cases/shell-bodo/>
- [24]. Linden, O. & Jonas, P. J. (2013). Oil Contamination In Ogoniland, Niger Delta: A Report. AMBIO DOI 10.1007/S13280-013-0412-8. Royal Swedish Academy Of Sciences. www.kva.se/en
- [25]. MDEP, Massachusetts Department Of Environmental Protection (1996). Ttechnical Update: Default Fish Ingestion Rates And Exposure Assumptions For Human Health Risk Assessments. Update To: Appendix B. Part I Food Consumption, 1. Freshwater Fish Of Guidance For Disposal Site Risk Characterization - In Support Of The Massachusetts Contingency Plan.
- [26]. Moslen, M. M. & Miebaka, C. A (2017). Heavy Metal Contamination In Fish (Callinectes amnicola) From An Estuarine Creek In The Niger Delta, Nigeria And Health Risk Evaluation. Bulletin Of Environmental Contamination And Toxicology. DOI 10.1007/S00128-017-2169-4
- [27]. Nadzifah, Y., Shu Qi, C., & Wan, M.R. (2019). Concentration Of Copper (Cu) In Tinfoil Barb Fish (Barbonymus Schwanenfeldii) Of Kuantan River And Pinang River, Pahang, Malaysia. E3S Web Of Conferences 158, 05003 (2020). <https://doi.org/10.1051/E3sconf/202015805003>.
- [28]. Nduka, J. O. & Aigberua, A. O. (2018) Heavy Metals And Physicochemical Characteristics Of Soils From The Banks Of Effluent Wastewater Retention Pits In The Niger Delta, Nigeria. Biotechnological Research, 4(1), 48-53.

- [29]. NIS, Nigerian Industrial Standards (2007). Nigerian Standard For Drinking Water Quality. ICS 13.060.20
- [30]. Nkpaa, K. W., Wegwu, M. O. & Essien, E. B. (2013). Heavy Metals Concentrations In Four Selected Seafood From Crude Oil Polluted Waters Of Ogoniland, Rivers State, Nigeria. Arch. Appl. Sci. Res., 5(4), 97-104.
- [31]. Nkpaa, K. W., Onyeso, G. I., & Achugasim, O. (2017) Heavy Metals Levels In Shellfish From Bodo City And B-Dere, Ogoniland, Rivers State, Nigeria, And Evaluation Of Possible Health Risks To Consumers. Sustainable Water Resources Managanagement, 3, 83–91. DOI 10.1007/S40899-017-0096-5.
- [32]. Nona (26 September, 2024) Bodo (Gokana, Nigeria). Available From Bodo (Nigeria) Map -N <https://Nona.Net/Features/Map/Placedetail.2239375/Bodo/Ona.Net>
- [33]. Nwineewii, J.D. & Unochukwu P.G. (2018). An Evaluation Of The Level Of Some Physicochemical Parameters In The New Calabar River, Rivers State, Nigeria. The Pharmaceutical And Chemical Journal, 5(3), 135-142
- [34]. Obini, U., Okafor, C.O., & Afiukwa, J.N. (2013). Determination Of Levels Of Polycyclic Aromatic Hydrocarbons In Soil Contaminated With Spent Motor Engine Oil In Abakaliki Auto-Mechanic Village. Journal Of Applied Science And Environmental Management, 17(2), 169-175.
- [35]. Ogeleka, D.F., Edjere, O., Nwudu, A., And Okieime, F. E (2016) Ecological Effects Of Oil Spill On Pelagic And Bottom Dwelling Organisms In The Riverine Areas Of Odidi
- [36]. Ogolo, S.G., Ugbomeh A.F. & Isitor, G.N. (2017). Physico-Chemical Parameters Of Iwofe And Bakana Rivers, Tributaries Of The New Calabar River, Niger Delta, Nigeria. Research Journal Of Pure Science And Technology, 1(2), 18-24
- [37]. Onojake, M.C., Sikoki, F.D, Omokheyke, O & Akpiri R.U (2017). Surface Water Characteristics And Trace Metals Level Of The Bonny/New Calabar River Estuary, Niger Delta, Nigeria. Applied Water Science, 7(2), 951-959
- [38]. Osa-Igwehede, I., Anegebe, B., Okunzuwa I.G., Ighodaro, A. & Aigbogun, J. (2016). Levels Of Heavy Metal Concentration In Water, Sediment And Fish Of Ikpoba River, Benin City, Edo State, Nigeria. International Journal Of Chemical Studies, 4(1), 48-53
- [39]. Osakwe, S.A. & Peretiemo-Clark, B.O. (2008). Evaluation Of Heavy Metals In Sediments Of River Ethiopie, Delta State, Nigeria. 31st CSN Conference Paper, 611-613
- [40]. Polish Environment Ministry (2002). Quality Standards For Soils Due To A Particular Pahs Content.
- [41]. Rahmanian, M., Ali, S.H.B., Homayoonfard, M., Ali, N.J., Rehan, M., Sadeh, Y. & Nizami, A.S. (2015). Analysis Of Physiochemical Parameters To Evaluate The Drinking Water Quality In The State Of Perak, Malaysia. Journal Of Chemistry, Article I.D:716125, 10 Pages. [Http://Dx.Doi.Org/10.1155/2015/16125](http://Dx.Doi.Org/10.1155/2015/16125)
- [42]. SDN, Stakeholder Democratic Network (2016). Bodo Mediation Initiative: Final Project Report. Summary Brief Of The Journey And The Lessons. Available At [Https://Stakeholderdemocracy.Org/Wp-Content/Uploads/2016/06/Merged-Bodo-Mediation-End-Reportd.Pdf](https://Stakeholderdemocracy.Org/Wp-Content/Uploads/2016/06/Merged-Bodo-Mediation-End-Reportd.Pdf)
- [43]. Seiyaboh, E.I., Tariwari, A.C.N., & Okologbue, B.C. (2016). Physicochemical Quality Assessment Of River Orashi In Eastern Niger Delta Of Nigeria. Journal Of Environmental Treatment, 4(4), 143-148
- [44]. Sharif, R., Chong, R. & Meng, C. K (2 016). Human Health Risk Assessment Of Heavy Metals In Shellfish From Kudat Sabah. Malasia Journal Of Nutrition, 22(2), 301 – 305.
- [45]. Sibe, L., Osuji, L. C. & Hart, A. I. (2019). Probabilistic Risk Assessment Of Heavy Metals In Shellfish From An Artisanal Refining Site, K-Dere, South-South Nigeria. IOSR Journal Of Environmental Science, Toxicology And Food Technology (IOSR-JESTFT). 13 (12). Ver. II. 53-62
- [46]. Tancee, F. B. G. & Yabrade, F. N. (2016). Assessing The Impact Of Artisanal Petroleum Refining On Vegetation And Soil Quality: A Case Study Of Warri South West Salt Wetland Of Delta State, Nigeria. Research Journal Of Environmental Toxicology 10, 205.212.
- [47]. Taylor, A.A., Tsuji, J.S., Mcardle, M.E., Adams, W.J., & Goodfellow, W.L. (2022). Recommended Reference Values For Risk Assessment Of Oral Exposure To Copper. Risk Analysis, 43, 211 - 218.
- [48]. Tchobanoglous, G., Burton, F.L. & Stensel, H.D. (2003). Metcalf & Eddy Wastewater Engineering: Treatment And Reuse (4th Ed). Tata Mcgraw-Hill.
- [49]. U.S. EPA (2000). Integrated Risk Information System (IRIS) Database. National Center For Environmental Assessment, Office Of Research And Development, Washington, DC.
- [50]. U.S. EPA (2000a). Integrated Risk Information System (IRIS) Chemical Assessment Summary: Tetraethyl Lead; CASRN 78-00-2. National Center For Environmental Assessment. Available At Tetraethyl Lead (CASRN 78-00-2) | IRIS | US EPA
- [51]. U.S. EPA (2009b). Provisional Peer Reviewed Toxicity Values For White Mineral Oil (Casrns 8012-95-1 And 8020-83-5). U.S. Environmental Protection Agency, Superfund Technical Support Center, National Center For Environmental Assessment, Cincinnati, OH
- [52]. U.S. EPA. (2011). Exposure Factors Handbook 2011 Edition (Final). National Center For Environmental Assessment, Office Of Research And Development. Washington D.C. (1436 Pp, 21.3 MB).
- [53]. US EPA (1999). Data Collection For The Hazardous Waste Identification Rule: Section 15.0 Human Health Benchmarks. Office Of Solid Waste Washington, DC 20460.
- [54]. US EPA (1999b). Integrated Risk Information System (IRIS) On Nickel, Soluble Salts. National Center For Environmental Assessment, Office Of Research And Development, Washington, DC. 1999.
- [55]. US EPA (2004). Issue Paper On The Human Health Effects Of Metals: Risk Assessment Forum, Contract #68-C-02-060
- [56]. US EPA (2005). Human Health Risk Assessment Protocol For Hazardous Waste Combustion Facilities. Final Report. Office Of Solid Waste And Emergency Response (5305W). EPA530-R-05-006. [Https://Www.Epa.Gov/Osw](https://Www.Epa.Gov/Osw)
- [57]. US EPA (2009a).Provisional Peer-Reviewed Toxicity Values For Midrange Aliphatic Hydrocarbon Streams. Superfund Health Risk Technical Support Center National Center For Environmental Assessment Office Of Research And Development U.S. Environmental Protection Agency Cincinnati, OH 45268
- [58]. US EPA (2019). National Primary Drinking Water Regulations: Inorganic Chemicals: Chemical Contaminant Rules Summary [Https://Www.Epa.Gov/Ground-Water-Anddrinking-Water/National-Primary-Drinking-Water-Regulations#Inorganic](https://Www.Epa.Gov/Ground-Water-Anddrinking-Water/National-Primary-Drinking-Water-Regulations#Inorganic)
- [59]. US EPA (2022). Provisional Peer-Reviewed Toxicity Values (Pprrts) Assessments. Superfund Health Risk Technical Support Center National Center For Environmental Assessment Office Of Research And Development. Available At Provisional Peer-Reviewed Toxicity Values (Pprrts) Assessments | US EPA
- [60]. US EPA (2024a).Regional Screening Levels (Rsls) - Generic Tables-Tables As Of: May 2024. Available At [Https://Www.Epa.Gov/Risk/Regional-Screening-Levels-Rsls-Generic-Tables](https://Www.Epa.Gov/Risk/Regional-Screening-Levels-Rsls-Generic-Tables) | US EPA
- [61]. US EPA (May 1, 2024). Water Quality Criteria: National Recommended Water Quality Criteria - Aquatic Life Criteria Table. Available At [Https://Www.Epa.Gov/Wqc/National-Recommended-Water-Quality-Criteria-Aquatic-Life-Criteria-Table#Table](https://Www.Epa.Gov/Wqc/National-Recommended-Water-Quality-Criteria-Aquatic-Life-Criteria-Table#Table)
- [62]. US EPA. (1986). Guidelines For Estimating Exposures (51 Fed. Reg. 34042-34054, September 24). Washington, D.C.: Office Of Health And Environmental Assessment, Office Of Research And Development, U.S. EPA.

- [63]. US EPA. (1989). Risk Assessment Guidance For Superfund, Volume I, Human Health Evaluation Manual (Part A). Interim Final. Office Of Emergency And Remedial Response. EPA/540/1-89/002.
- [64]. US EPA. (2011). Exposure Factors Handbook 2011 Edition (Final). (EPA/600/R-09/052F). Washington, DC.
- [65]. US.EPA. (1991). Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors. Office Of Solid Waste And Emergency Response. OSWER Directive 9285.6-03. Washington, D.C.
- [66]. US.EPA. (2001). Risk Assessment Guidance For Superfund: Volume III - Part A, Process For Conducting Probabilistic Risk Assessment. Office Of Emergency And Remedial Response, Washington, DC. 2046EPA 540-R-02-002 OSWER 9285.7-45 PB2002 963302 [Www.Epa.Gov/Superfund/RAGS3A/Index.Htm](http://www.epa.gov/superfund/RAGS3A/Index.Htm)
- [67]. Vincent-Akpu, I.F & Yanadi, L.O (2014). Levels Of Lead, Iron And Cadmium Contamination In Fish, Water And Sediment From Iwofe Site On New Calabar River, Rivers State. International Journal Of Extensive Research. 3, 10-15.
- [68]. WHO, World Health Organization (Eds). (2011). Guidelines For Drinking-Water Quality, 4th Ed. ISBN 978 92 4 154815 1. Switzerland.
- [69]. Worldfish (2018). Nigeria Strategy: 2018-2022. Penang, Malaysia: Worldfish. Strategy: 2018- 09. Available At 2018-09.Pdf (Worldfishcenter.Org).
- [70]. Zabbey,N. & Hart. A.I (2011). Preliminary Checklist Of Macrozoobenthos Of Bodo Creek In The Niger Delta, Nigeria, Nigerian Journal Of Fisheries, 8(2). 1-5