

Heavy metals in crab and tilapia fish from Korle and Kpeshie Lagoon: Implications for human consumption

Umudi Ese Queen¹, Odimgbe Ezekiel Izudike², Olubunmi Abiola Adewusi³, Abdulkarim Shehu Salihu⁴, Erienu Kennedy Obruche⁵

¹ Department of Chemical Science, University of Delta, Agbor, Nigeria

² Department of Industrial chemistry, Ebonyi State University, Abakaliki, Nigeria

³ Department of Chemistry, Lagos State University, Ojo, Lagos, Nigeria

⁴ Department of Industrial Chemistry, Federal University Dutsin-Ma, Kastina State, Nigeria

⁵ Department of chemistry, Delta State College of Education, Mosogar,

Corresponding Author: Erienu Kennedy Obruche

Abstract

Lagoons represent highly productive coastal ecosystems that offer essential natural services; however, pollution within these areas leads to detrimental alterations in the environment. In Ghana, both Korle and Kpeshie Lagoons are subjected to waste discharges from industrial activities and municipal sewage. It is crucial to control and monitor the contaminants present in these ecosystems to safeguard environmental health. This study investigated the levels of heavy metals (arsenic, cadmium, chromium, copper, lead, and zinc) in crabs (*Callinectes amnicola*) and fish (*Sarotherodon melanotheron*) from Kpeshie and Korle Lagoons, comparing the findings to the environmental standards established by international organizations such as the WHO and US EPA. The concentrations of metals in *Sarotherodon melanotheron* were measured in mgkg^{-1} as follows: As, 0.397 ± 0.07 ; Cd, 1.10 ± 1.31 ; Cr, 5.895 ± 9.76 ; Cu, 3.494 ± 4.56 ; Pb, 1.227 ± 5.77 ; Zn, 23.225 ± 10.93 . In *Callinectes amnicola*, the concentrations were: As, $0.288 \pm 0.07 \text{ mgkg}^{-1}$; Cd, $4.60 \pm 2.69 \text{ mgkg}^{-1}$; Cr, $39.521 \pm 55.89 \text{ mgkg}^{-1}$; Cu, $31.085 \pm 16.26 \text{ mgkg}^{-1}$; Pb, $10.902 \pm 12.95 \text{ mgkg}^{-1}$; Zn, $36.042 \pm 17.8 \text{ mgkg}^{-1}$. The levels of cadmium, chromium, and lead in both *Callinectes amnicola* and *Sarotherodon melanotheron* surpassed the permissible limits set by FAO/WHO. The estimated target hazard quotient (THQ) for cadmium, chromium, and lead in the fishery examined at Kpeshie Lagoon was found to be less than 1, suggesting that the regular consumption of *Callinectes amnicola* and *Sarotherodon melanotheron* does not present a significant non-carcinogenic health risk to consumers.

Keywords: Crabs, tilapia fish, heavy metals, korle and kpeshie lagoons

Introduction

Heavy metals, particularly those originating from anthropogenic activities, are an increasingly prevalent environmental concern due to their persistence, toxicity, and bioaccumulation in aquatic ecosystems (Obruche *et al.*, 2019) [11]. These metals, including lead (Pb), mercury (Hg), cadmium (Cd), and arsenic (As), can enter water bodies through various pathways, such as industrial effluents, agricultural runoff, untreated sewage, and atmospheric deposition (Addo *et al.*, 2011) [2]. Aquatic organisms, including fish and crustaceans, are particularly vulnerable to these pollutants because they absorb and accumulate them from contaminated water and sediment. Consequently, seafood, which serves as a staple source of protein for millions of people worldwide, can become a significant vector for heavy metal exposure to humans (Umudi *et al.*, 2011) [18]. In Ghana, the Korle and Kpeshie lagoons, located in the Greater Accra Region, are important bodies of water supporting both commercial and artisanal fisheries (Itodo *et al.*, 2021) [8]. These lagoons are heavily impacted by urbanization, pollution from industrial activities, and agricultural runoff, making them potential hotspots for the accumulation of heavy metals. Fish species such as tilapia (*Oreochromis niloticus*) and crabs (*Scylla serrate* and *Callinectes amnicola*) are commonly harvested from these lagoons and form an integral part of the local diet. These species are well known for their nutritional value, being rich in essential proteins, fatty acids, vitamins, and minerals (Obruche *et al.*, 2018). However, the presence of heavy

metals in these aquatic organisms raises concerns about the safety of their consumption, particularly in regions where seafood constitutes a major dietary component (Erienu *et al.*, 2022; Obruche *et al.*, 2025) [6, 9]. Given the potential for bioaccumulation of toxic substances in these organisms, it is essential to assess their concentrations in the local seafood and evaluate the associated risks to human health (Aglan & Appiah, 2014) [3]. While the global discourse on heavy metal contamination in marine ecosystems has been widely explored, there is limited research focusing specifically on these particular lagoons, especially concerning the human health implications of consuming contaminated crab and tilapia (Bentum *et al.*, 2011) [4].

Heavy metals, even at low concentrations, can pose serious health risks when consumed over extended periods (Oduro *et al.*, 2001; Umudi *et al.*, 2025) [14, 20]. The human body has limited capacity to eliminate many of these metals, and their accumulation can lead to chronic conditions such as renal failure, neurological disorders, cardiovascular diseases, and even cancers. For populations that rely heavily on fish and shellfish as their primary source of animal protein, the consumption of contaminated seafood could have severe public health implications. Therefore, assessing the concentrations of heavy metals in crab and tilapia from the Korle and Kpeshie lagoons is crucial for understanding the risks associated with their consumption and for formulating appropriate regulatory and safety measures (Obruche *et al.*, 2019) [15].

The findings of this study will provide valuable insight into the extent of pollution in these water bodies and their impact on aquatic life, as well as highlight the potential health risks for consumers (Ekpo *et al.*, 2023) [17]. Furthermore, it will serve as a basis for policy recommendations to safeguard both environmental and public health. By evaluating the concentrations of heavy metals in these two widely consumed species, this research aims to contribute to a broader understanding of pollution in urban lagoons in Ghana and across similar ecological contexts in sub-Saharan Africa (Umudi *et al.*, 2025) [22].

This study seeks to investigate the levels of heavy metals in crab and tilapia fish from the Korle and Kpeshie lagoons in Ghana.

Materials and Method

Study Area

The Korle and Kpeshie lagoons, where the research was conducted, are situated in the Greater Accra Region of Ghana. These lagoons are shallow aquatic bodies located in coastal low-lying regions that were once characterized by picturesque sand dunes, expansive mangroves, marshes, and scrubs, which provided ample and appropriate feeding, roosting, and nesting habitats for numerous species of water birds. Korle lagoon spans an area of approximately 0.127 square kilometers and is positioned in the southwestern section of the Accra Metropolis, with an elevation of around 7 meters above sea level. The Korle Lagoon is linked to the Odaw River, which originates from the Abokobi and Adjankote hills, traversing through Ashongman, Atomic Energy, West Legon, Achimota, Alajo, Avenor, and Agbogbloshie before finally discharging into the lagoon, along with two other significant drainage channels (Biney, 1982). The Korle lagoon, located between the geographical coordinates of 0° 13' 07.72"W; 5° 31' 48.32"N and 0° 13' 20.60"W; 5° 31' 47.46"N, was capable of supporting finfish and shellfish during the mid-twentieth century. This major basin receives discharges of industrial and municipal sewage, as well as floodwaters from a catchment area of 400 square kilometers. The discharged water carries silt and debris into the lagoon, which frequently obstructs the primary outlet to the sea. Consequently, the flow rate diminishes due to this blockage, leading to a depletion of oxygen in the lagoon's water. The quality of the water improves towards the sea, where tidal actions contribute to reducing pollution levels in this section of the lagoon (Olowu *et al.*, 2010) [12].

Field Reconnaissance Study

Before the data collection in the study area, a reconnaissance study lasting three days was conducted from October 20th to 22nd, 2025, to assess the extent of human activities such as waste disposal, e-waste recovery, and various vehicle repair workshops located along the lagoons. The reconnaissance survey provided insights into the necessary tools and methodologies for sampling (Umudi *et al.*, 2025) [25].

Samples Collection and Sampling

Crabs (*Callinectes amnicola*) were procured from fishermen operating in the Korle and Kpeshie lagoons, as illustrated in Figure 1. Their lengths were measured in the field using a measuring tape, while weights were recorded in the laboratory using a weighing scale. The samples were placed in sealable polyethylene bags, clearly labeled, and preserved on ice in an ice chest for transport to the laboratory, where total heavy metal analysis was conducted using Atomic Absorption Spectrophotometry (AAS).

Tilapias (*Sarotherodon melanotheron*) were also acquired from fishermen at the Korle and Kpeshie lagoons (see Figure 2). The lengths of these samples were measured with a tape measure, labeled, and stored in polyethylene bags on ice. They were then transported to the Ecological Laboratory at the University of Ghana for analysis (Oram, 2014) [10].

Sample Preparations and Analysis

Big fisted Swim Crab (*Callinectes amnicola*) Samples

The preparation of crab samples was conducted following the protocols outlined by (USEPA, 1987; Obruché *et al.*, 2019; and Umudi *et al.*, 2025) [11, 19, 25]. The big fisted swim crab samples were dried in an oven at 55°C for 24 hours and then ground in a stainless steel mill to a fine powder that passed through a 1 mm screen. One gram (1g) of each powdered sample was weighed and digested in a 5 ml ternary mixture of 1:1 concentrated nitric acid and perchloric acid for one hour to yield a clear solution. After cooling, the samples were filtered and diluted with distilled water into a 100 ml volumetric flask. AAS was calibrated with standard solutions of the respective metals and de-ionized water prior to measuring the heavy metal concentrations in the digested samples. A total of twenty-four (24) crab samples were analyzed.



Fig 1: Crustacean samples collected from field

Tilapia (*Sarotherodon melanotheron*) Samples

The procedures for preparing tilapia fish were akin to those outlined by USEPA (2004) [24] and Ekpo *et al.* (2025) [5], albeit with some minor modifications. The fish samples underwent washing with distilled water and were subsequently dried in an oven at 55°C for a duration of 24 hours. The desiccated tilapia tissue was then pulverized into a fine powder. A quantity of one gram (1g) from these samples was subjected to digestion using 5 ml of a ternary mixture consisting of 1:1 concentrated nitric acid and perchloric acid within digestion tubes located in a fume hood. Following this, the sample mixtures were filtered into a 100 ml volumetric flask. Distilled water was added to reach the 100 ml mark. The resulting filtrates were analyzed for heavy metals utilizing Atomic Absorption Spectroscopy (AAS). Prior to conducting the measurements, the AAS was calibrated with standard solutions and de-ionized water. In total, 24 samples were analyzed.



Fig 2: *Sarotherodon melanotheron* caught in Kpeshie lagoon

Target Hazard Quotient (THQ)

THQ evaluates the non-carcinogenic health effect of heavy metals. THQ is defined in equation 5 by (US EPA, 2011) as:

$$THQ = \frac{EFr \times Ed \times FIR \times C}{Rfd \times BWa \times ATn}$$

Where;

EFr is the exposure frequency (days per year) (365)

Ed is the exposure duration equivalent to average lifetime (64 years for a Ghanaian adult)

FIR is the daily average intake rate of fish and crustacean (fish: 36g/person/day; crustacean: 5.42g/person/day)

C is the mean heavy metal concentration in fish and crab in the study (in mgkg⁻¹)

Trfi of a particular metal was derived by Håkanson (1980) from (a) "abundance principle"

(b) the "sink-effect" and (c) the "dimension-problem".

Rfd is the oral reference dose of the trace element (Cd: 0.001mgkg⁻¹/day; Pb: 0.004mgkg⁻¹/da; Cr: 0.003mgkg⁻¹/day)

BWa is the average body weight (considered to be 70 Kg for adult)

ATn is the averaged exposure time to the heavy metal (365 days per year x Ed)

Quality Control

Prior to the analysis of the samples, standards and blanks were utilized to verify the calibration of the instrument. Laboratory blanks and standards were mainly employed to assess contaminations and precisions, respectively, of the analytes. The quality assurance protocols also encompassed rigorous cleaning of laboratory glassware.

Data Analysis

The data were presented in tables as mean ± SD. The concentrations of heavy metals in sediments, water, crab, and fish obtained in this study were analyzed using ANOVA statistical tools within SPSS. A 95% confidence level was applied in all instances to compare the means. All descriptive statistics and graphs were generated using Microsoft Excel version 10.

Results and Discussion

This section presents and discusses the findings from the data analysis conducted for the study. The results of the analyzed samples are depicted in Tables 1 and 2.

Heavy Metal Concentration in Crab (*Callinectes Amnicola*) *Callinectes amnicola* were collected exclusively from Site 1 and Site 4 of Kpeshie Lagoon, as Sites 2 and 3 were unable to sustain any life. The mean concentrations of arsenic, cadmium, chromium, copper, lead, and zinc in *Callinectes amnicola* from Site 1 were 0.303 ± 0.05 mgkg⁻¹; 5.483 ± 2.88 mgkg⁻¹; 71.908 ± 64.80 mgkg⁻¹; 26.812 ± 19.72 mgkg⁻¹; 13.667 ± 17.40 mgkg⁻¹; and 45.183 ± 20.70 mgkg⁻¹, respectively. For Site 4, the mean concentrations were as follows: arsenic, 0.273 ± 0.08 mgkg⁻¹; cadmium, 3.713 ± 2.26 mgkg⁻¹; chromium, 7.133 ± 6.64 mgkg⁻¹; copper, 35.358 ± 11.11 mgkg⁻¹; lead, 8.138 ± 5.61 mgkg⁻¹; and zinc, 26.900 ± 7.40 mgkg⁻¹, as shown in Table 1. One-way ANOVA analysis indicated no significant differences (p > 0.05) in the mean concentrations across the sites, except for chromium and zinc (Table 1). These results are consistent with the findings of Ugochukwu *et al.* (2025) [23] and Abeokuta *et al.* (2025) [1].

Table 1: Mean heavy metals concentrations in *Callinectes amnicola*

Sampling Sites (crustacean) at Kpeshie Lagoon				
Elements	S1 (mg/kg)	S4 (mg/kg)	US EPA 2010	p-value
As	0.303 ± 0.05	0.273 ± 0.08	0.50	0.29
Cd	5.483 ± 2.88	3.713 ± 2.26	0.50	0.11
Cr	71.908 ± 64.80	7.133 ± 6.64	0.50	0.002
Cu	26.812 ± 19.72	35.358 ± 11.11	70.00	0.20
Pb	13.667 ± 17.40	8.137 ± 5.61	0.50	0.31
Zn	45.183 ± 20.70	26.900 ± 7.40	80.00	0.008

Heavy Metal Concentration in Fish (*Sarotherodon Melanotheron*)

Fish samples were exclusively found at Kpeshie Lagoon, specifically at sites 1 and 4, as sites 2 and 3 yielded no samples. The average concentrations of metals analyzed in *Sarotherodon melanotheron* samples from sites 1 and 4 exhibited a similar trend in arsenic and cadmium values. The average arsenic concentrations recorded in fish were 0.3714 ± 0.07 mgkg⁻¹ for site 1 and 0.423 ± 0.07 mgkg⁻¹ for site 4. The mean cadmium levels were 1.517 ± 1.65 mgkg⁻¹ at site 1 and 0.683 ± 0.70 mgkg⁻¹ at site 4. The mean concentrations of chromium, copper, and zinc in fish

were as follows: (site 1) 2.454 ± 4.58 mgkg⁻¹; (site 4) 9.321 ± 12.34 mgkg⁻¹, (site 1) 2.929 ± 2.2 mgkg⁻¹; (site 4) 4.058 ± 6.15 mgkg⁻¹, and (site 1) 28.642 ± 11.33 mgkg⁻¹; (site 4) 17.81 ± 7.58 mgkg⁻¹, respectively, as presented in table 4.5. The lead concentrations in *Sarotherodon melanotheron* were measured below the detection limit (BDL), except for site 4,

which recorded a level of 28.3 mgkg⁻¹. No significant differences ($p > 0.05$) were observed in the mean concentrations, with the exception of zinc (Table 2). These results align with the studies conducted by Festus-Amadi *et al.* (2021)^[7] and Umanah *et al.* (2025)^[21] on the same species.

Table 2: Mean heavy metal concentrations in *Sarotherodon melanotheron*

Sampling Sites (Fish) at Kpeshie Lagoon						
Elements	S1 (mg/kg)		S4 (mg/kg)		FAO/WHO 2011	p-value
As	0.371 ± 0.07		0.423 ± 0.07		0.26	0.85
Cd	1.517 ±	1.65	0.683 ±	0.70	0.20	0.12
Cr	2.454 ±	4.58	9.321 ±	12.34	0.50	0.08
Cu	2.929 ±	2.20	4.058 ±	6.15	20	0.56
Pb	0.05 ±	0.00	2.404 ±	8.16	1.00	0.32
Zn	28.642 ±	11.33	17.81 ±	7.58	40.00	0.02

Correlation studies of the korle and kpeshie lagoons

The inter-metal correlation between pairs of heavy metals in crab and fish of the Korle and Kpeshie Lagoons were determined using Pearson Correlation Coefficient and presented in Tables 3.

Table 3: Heavy Metals Relationship in Organisms from Kpeshie Lagoon Crustacean Tilapia

	As	Cd	Cr	Cu	Pb	Zn		As	Cd	Cr	Cu	Pb	Zn
As	1						As	1					
Cd	0.316	1					Cd	-0.562	1				
Cr	0.051	0.074	1				Cr	0.125	-0.026	1			
Cu	-0.023	0.131	-0.762	1			Cu	0.333	-0.112	-0.189	1		
Pb	0.044	0.260	0.754	-0.598	1		Pb	0.353	-0.016	-0.067	0.454	1	
Zn	-0.092	0.207	0.528	-0.348	0.420	1	Zn	-0.347	0.450	-0.369	-0.184	-0.151	1

The large-fisted swim crab exhibited significant positive correlations in metal concentrations between Pb-Cr ($r = 0.754$; $p < 0.05$) and Zn-Cr ($r = 0.528$; $p < 0.05$). Additionally, notable trends were observed in Cu-Cr ($r = -0.762$; $p < 0.05$) and Pb-Cu ($r = -0.598$; $p < 0.05$). In tilapia, the correlation analysis indicated a significant negative downward trend between Cd-As ($r = -0.562$; $p < 0.05$), while significant positive correlations were found between Pb-Cu ($r = 0.454$; $p < 0.05$) and Zn-Cd ($r = 0.450$; $p < 0.05$).

Target Hazard Quotient (THQ)

Three elements, namely Cd, Cr, and Pb, were chosen to assess the THQ for *Callinectes amnicola* and *Sarotherodon melanotheron*. The evaluations for cadmium and lead were derived from the potential ecological risk index values, whereas chromium assessments were based on its concentrations within the studied organisms (*Callinectes amnicola* and *Sarotherodon melanotheron*). The THQ values for these elements were recorded as being less than one in both species. A THQ value of less than one (<1) suggests that the heavy metals are unlikely to result in any non-carcinogenic health effects for consumers. Nevertheless, the THQ values for chromium were alarmingly close to one for both *Callinectes amnicola* and *Sarotherodon melanotheron*. While chromium may not currently pose any non-carcinogenic health risks to regular consumers of crab and tilapia, caution should be exercised regarding the frequency of consumption.

Table 4: THQ Estimation of Fishery

Element	Cd	Pb	Cr	TTHQ
<i>Callinectes amnicola</i>	0.33	0.19	0.93	1.45
<i>Sarotherodon melanotheron</i>	0.52	0.34	0.92	1.78

Conclusion

The analysis results of fish from Kpeshie lagoon indicated elevated concentrations of metals such as cadmium, chromium, and lead within the tissues of both tilapia and crustaceans. Furthermore, this study revealed that the metal concentrations (Cd, Cr, Cu, Pb, Zn) in *Callinectes amnicola* exceeded those found in *Sarotherodon melanotheron*, with the exception of arsenic. According to the heavy metal concentration values in *Callinectes amnicola* and *Sarotherodon melanotheron*, along with the ranking of the ecological potential risk index (RI), the Target Hazard Quotient (THQ) calculated based on the metal levels in fishery resources was below one (1). This indicates that individuals who consume tilapia and crab daily from Kpeshie lagoon are not at risk of experiencing any non-carcinogenic health effects. Nevertheless, it is recommended to regulate the consumption rate, as the levels of cadmium, chromium, and lead, which lack nutritional benefits, have the potential to bioaccumulate.

References

1. Abeokuta OJ, Uriri SA, Obruchek EK, Okurame O. Hydrochemical Assessment of Borehole Water Quality in Eku, Delta State, Nigeria. *Journal of Science, Technology and Environmental Studies*, 2025;1(2):17-25.
2. Addo MA, Okley GM, Affum HA, Acquah SA, Gbadago JK, Senu JK, *et al.* Water quality and level of some heavy metals in water and sediments of Kpeshie lagoon, La-Accra, Ghana. *Res J Environ Earth Sci.*, 2011;3(5):487-497.
3. Aglanu ML, Appiah OD. The Korle Lagoon in Distress: The stress of Urban Solid Waste on Water Bodies in

- Accra, Ghana. Int J. Innov. of Appl. Studies,2014:7(2):717-728.
4. Bentum JK, Anang M, Boadu KO, Koranteng-Addo EJ, Antwi EO. Assessment of heavy metals pollution of sediments from Fosu lagoon in Ghana. Bulletin of the Chemical Society of Ethiopia,2011:25(2):191-196.
 5. Ekpo Ekokodu Rose, Erienu Obruche Kennedy, Abiye Clement Marcus. Spatial and Temporal Variations in the Concentrations of Polycyclic Aromatic Hydrocarbon, in Ambient Air From Three Different Locations in River State, Nigeria. International Journal of New Chemistry,2025:12(4):567-580.
 6. Erienu Obruche Kennedy, Itodo Adams, Wuana Raymond, Sesugh Ande. Polycyclic Aromatic Hydrocarbons in Harvested Rainwater in Warri and Agbarho, Nigeria. Bulletin of chemical society of Ethiopia,2022:36(4):27-35.
 7. Festus-Amadi IR, Erhabor OD, Ogwuche Christiana E, Obruche EK. Characterization of Contaminated Sediments Containing Polycyclic Hydrocarbons from Three Rivers in the Niger Delta Region of Nigeria. Chemistry Research Journal,2021:6(3):1-12.
 8. Itodo AU, Wuana RA, Erhabor OD, Obruche EK, Agbendeh ZM. Evaluating the Effects of Roofing Materials on Physicochemical Properties of Harvested Rainwater in Warri, Delta State, Nigeria. Chemical Society of Nigeria Journal, Kano,2021:12(1):234-245.
 9. Obruche EK, Emakunu SO, Ugochukwau GC. Rainwater Harvesting: Microbial and Chemical Water Quality Assessment in Warri District. Mosogar Journal of Science Education,2025:10(1):36-45.
 10. Oram B. Drinking Water Testing and Conductivity of Water. Professional Geologist (PG) Environmental Engineering and Earth Science Department Wilkes University, 2014.
 11. Obruche EK, Erhabor OD, Itodo AU, Itopa ST. Spectrophotometric determination of iron in some commercial iron containing tablets/capsule. International journal of advanced trends in computer applications,2019:1(1):231-235.
 12. Olowu RA, Ayejuyo OO, Adejoro A, Adewuyi GO, Osundiya MO, Onwordi CT, *et al.* Determination of Heavy Metals in Crab and Prawn in Ojo Rivers Lagos, Nigeria. E-Journal of Chemistry,2010:7(2):526-530.
 13. Obruche EK, Ogwuche CE, Erhabor OD, Mkurzurum C. Evaluation of the inhibitive effect of African Marigold (*Tagetes erecta L.*) Flower Extracts on the Corrosion of Aluminium in Hydrochloric Acid. International Journal of Advances in Scientific Research and Engineering,2018:4(12):167-177.
 14. Oduro W, Ellis WO, Oduro I, Tetteh D. Nutritional quality of selected Ghanaian crabs species. Journal of the Ghana Science Association,2001:3(3):37-40.
 15. Obruche EK, Ogwuche CE, Erhabor OD, Mkurzurum C. Investigating Corrosion Inhibition Effects of *Tagetes Erecta L.* Leaf Extract on Aluminium in Acidic Medium. Global Scientific Journals,2019:7(1):1-17.
 16. Ogwuche CE, Obruche EK. Physio-chemical analysis of palm oils (*elaeis guineensis*) obtained from major markets in agbarho, unenurhie, opete, ughelli and evwreni town, Delta state, Nigeria. International journal of trend in scientific research and development,2020:4(2):56-60.
 17. Ekpo RE, Marcus AC, Obruche EK. Spatial and Temporal Variations in the Concentration of Particulate Matter in Ambient Air from three Different Locations in River State, Nigeria. International Journal of Scientific Research in Chemical Science,2023:10(4):32-38.
 18. Umudi EQ, Obruche EK, Sani MI, Onwugbuta GC, Aghemwenhio IS, Ikechukwu SC, *et al.* Evaluation of Polycyclic Aromatic Hydrocarbons (PAHs) Contents of Fishes, Waters and Sediments of Rivers Niger: Human Health Risk Assessment. Journal of Basics and Applied Sciences Research,2025:3(5):187-199. <https://dx.doi.org/10.4314/jobasr.v3i5.20>
 19. U.S. Environmental Protection Agency (U.S. EPA). Quality Assurance/Quality Control (QA/QC) for 301h Monitoring Programs: Guidance on field and laboratory Methods, EPA-430/9-86-004, 1987.
 20. Umudi EQ, Ese Ekanem, Sani MI, Onwugbuta GC, Suleiman A, Magashi L, *et al.* Degradation Efficiencies of the Total Petroleum Hydrocarbons (TPHs) in the Soil Amended with Palm Bunch Ash and Tween 80 in Ibenomo L.G.A, Akwa Ibom State. International Journal of Chemistry and Chemical Processes,2025:11(5):1-20 [10.56201/ijccp.vol.11.no5.2025.pg1.21](https://doi.org/10.56201/ijccp.vol.11.no5.2025.pg1.21)
 21. Umanah FI, Oyibo RU, Rita CN, Bashir MA, Ibebuikwe UO, Obruche EK. Self-Concept, Self-Efficacy and Parental Involvement as Predictors of Academic Achievement of Junior Secondary School Students in Delta South Senatorial District. Journal of Education Research and Library Practice,2025:9(8):51-65.
 22. Umudi EQ, Odontimi N, Sani MI, Chidi H, Onwugbuta GC, Odejebi B, *et al.* Assessment of the Seasonal Variations in Heavy Metals Concentration in the Ughelli Central Market River, Delta State, Nigeria. International Journal of Applied Science and Mathematical Theory,2025:11(6):78-88 <https://doi.org/10.56201/ijasmt.vol.11.no6.2025.pg78.88>
 23. Ugochukwu GC, Ataine TI, Erienu KO. Determination of the Physicochemical Properties of Soil Amended with Cassava Mill Effluent in Mosogar Area of Delta State. Mosogar Journal of Science Education,2025:10(1):81-89.
 24. U.S. Environmental Protection Agency (U.S. EPA). Quality criteria for water. US Environmental Protection Agency, Washington, D. C., USA, 2004.
 25. Umudi EQ, Ese Ekanem, Ekpenyong IO, Sani MI, Onwugbuta GC, Suleiman A, *et al.* Seasonal Assessment of Heavy Metals Concentrations in Sediment of the Sapele River, Nigeria Journal of Science Innovation Technology Research,2025:9(9):124 - 139.