

IMPACT OF ARTHROPOGENIC ACTIVITIES AND HEAVY-METALS ON THE DISTRIBUTION OF BENTHIC-FAUNA COMMUNITY IN OKERENKOKO

¹Gbuvboro Anthonia Ejiroghene; Ulakpa Eyankware Oghenerukevwe Ruth; Ukuli Marckson Arerepade; Obele-Chuka Chiamaka Gabriella ²Oyamakin Oluwafemi Samuel

¹Department of Environmental Management and Pollution, Faculty of Environmental Management, Nigeria Maritime University, Okerenkoko, 332105, Delta State, Nigeria.

²Biostatistics Unit, Department of Statistics, University of Ibadan, Nigeria

DOI: <https://doi.org/10.56293/IJASR.2025.6703>

IJASR 2025
VOLUME 8

ISSUE 5 SEPTEMBER - OCTOBER

ISSN: 2581-7876

Abstract: Nigerian aquatic systems have been contaminated at various levels since the discovery of oil and gas. Heavy metals, physiochemical and benthic invertebrate community were investigated on the Okerenkoko estuary. Surface water samples and sediments were collected across five stations in the month of September and October between 08: 00 and 12: 00hrs. Water samples were analyzed following established methods while sediments collected with grab were sieved, sorted and benthic organisms were preserved in 5% formalin. Heavy metals, (Cr, Cu, Hg, Zn, Cd, and Pb) were analyzed using a Varian 220 (rapid sequential) Atomic Absorption Spectrometer (AAS). The ANOVA Output: indicates significant changes in heavy metals in sediment, with a p-value of (0.033). with a significant difference between TDS, pH, and EC with high p-values. Analysis of variance showed, no significant difference ($p > 0.05$) as observed in the mean values of the physiochemical parameters across all stations, due to differences in physiochemical parameters and heavy metals in sediments. Linear regression analysis suggests a strong negative connection that as physiochemical factors grows, benthic-fauna is likely to decline. A total of 30 individuals comprising 6species, 5genera, 5families, 4orders, 3classes, and 2phyla. Members of the Phylum Mollusca constituted (88.2%) and (84.6%) in September and October, with *Tympanotonus fuscatus var fuscatus* being the dominant species, Phylum Arthropoda constituted (11.8%) and (15.4%) in September and October. The studies' low species diversity patterns reflect, human activities (artisanal distilleries). The most Adaptive species, *Tympanotonus fuscatus var fuscatus*, was established. As to sensitive, *Callinectes similis* and *Penaus monodon*. This might indicate that Okerenkoko waterbody is progressively exposed to indiscriminate anthropogenic stress. The routine study and regular monitoring of the state of the waterbody be conducted and analysis of the dynamic interplay among components is necessary for sustainable water quality management.

Keywords: Benthic-organisms, Anthropogenic stress, Okerenkoko waterbody, Heavy-metals, physiochemical.

1. Introduction

Nigeria's aquatic systems have been contaminated at various levels since the discovery and exploitation of crude oil and its byproducts began in the Niger Delta zones. Aquatic ecosystems are mostly utilized for the disposal of garbage, human sewage, and waste waters from residential areas, slaughterhouses, and enterprises. Storm water runoff and sewage discharge, into different water systems are two common examples. Degradation, deterioration, and underdevelopment of the environment are major public issues at both the national and international levels. Adeyemo et al, (2018). Rapid industrialization has both direct and indirect negative consequences on our ecosystems. The changes in the aquatic ecosystem by human and natural activities is one of the leading causes of disease breakout and death worldwide. Ewutanure and Olaife (2021). Pollutant concentrations are rising due to anthropogenic stresses such as habitat disturbance (dredging, increased sedimentation, damming, and mangrove destruction), effluent discharges. Ibanga et al, (2018); Nkwoji et al, (2016) and climate change. As a result, the aquatic flora and fauna species that live in water courses bear the brunt of the stress. Ajayi, (2018). Pollutants are stored in sediments for long periods of time due to the chemical persistence, thereby altering the physiochemical and biochemical properties of the substrata. Anthropogenic discharges in aquatic environments diminishes light penetration and transparency, which has a negative impact on primary productivity and, as a result, affects the benthos community. Unsustainable oil exploration activities in Nigeria have ranked the Niger Delta region as one of

the world's five most severely impacted; with petroleum-damaging their ecosystems. Sam and Zabbey, (2018); Adafa, (2012). Other Niger Delta ecosystem studies have shown poor water quality, decreased biodiversity, and human health hazards as a result of high industrial and crude oil exploration Wokoma, and Njoku, (2017); Mahamood et al, (2021). Oil spills from crude oil exploration, theft, and illegal bunkering causes ecosystem degradation, loss of aquatic life, water contamination, public health impairment (skin lesions, respiratory ailments, food poisoning, cancer, loss of arable land, and other livelihood structures of coastal communities) and extinction of wildlife and biodiversity. Onyena and Kabari, (2020). Oil spills are a major source of worry due to the massive economic loss and long-term, considerable impact on marine ecosystems, local economies, and coastal society and people. Baiyu et al, (2019). The negative consequences of maritime oil spills have been recorded in numerous ways over the years of oil and gas exploitation. Baiyu et al, (2019). Anthropogenic activities such as the deposition of mixed garbage in bodies of water, onshore and offshore hydrocarbon spillage, and open defecation; adds potentially toxic elements (PTEs) to water resources. Naeem et al, (2013). Given the significance of water quality, several countries have established systems and agencies to conduct water quality monitoring programs. These systems assist decision-makers in better understanding, interpretation, and utilizing existing data to protect water resources. Ite et al, (2018). In Nigeria, for example, the government has launched a variety of programs to safeguard water supplies. The Nigerian government announced a state of emergency in the water, sanitation, and hygiene (WASH) sector in November 2018, as part of efforts to preserve increasingly degraded water supplies and an increase in water-borne infections. Sah et al, (2019). However, due to inadequate funding, poor service delivery, the lack of stakeholder participation, and execution, this effort has failed to produce the intended results. Wang et al, (2020). Since the late 1950s, when Nigeria discovered significant quantities of oil and began exporting it, the Niger Delta region has seen a number of oil spills. The 2008/09 Bodo oil disaster, for example, devastated surface and subsurface water sources, farmlands, and nearly 69,000 households. Pegg and Zabbey (2013). Gbaramatu Kingdom is a hotspot for oil and gas exploratory activities in the Niger Delta region, with attendant soot, hydrocarbon contamination, and locals in unplanned settlements along the Escravos coastline. Gbaramatu Kingdom hosts many oil and gas infrastructures such as oil and gas pipelines, gas flaring chimneys, oil wells, oil fields, oil drilling platforms, and sub-stations. Following its artisanal oil activities, the area is widely known for its low surface water quality and mangrove deterioration. Kabari et al, (2023). Warri Coastal settlements in Delta State include Oporoza, Okerenkoko, Kurutie, Isaba, Egwa, Diebiri, Ekpemu and Ekpogbene. All of these communities are water inlets that flow into the Escravos river (coastlines) and deposit into the Atlantic Ocean. Farmers and fishermen make up the majority of the population, who live in scattered riverine communities along the Escravos River. Peasant youths from various areas participate in artisanal crude oil refining as a source of income Sam, et al (2022); Sam and Zabbey, (2019); Naeem et al, (2013). These illegal artisanal refining spills into different inlets, poses an ecological risk, resulting in aquatic contamination of our waterways, which finally ends up in the sea. During the wet season, the pits excavated to hold the residual items (artisanal waste materials) are often overflowing, resulting in environmental contamination. Gbuvboro and Ulakpa, (2023). Despite the fact that these villages are home to considerable oil infrastructure, the standard of living in these communities is shockingly low. This investigation highlights the interplay between anthropogenic activities, heavy metals accumulation and the influences they have on the physiochemical parameters in water; leading to variation patterns in benthic organism distribution.

1.1 Macro-Benthic fauna

Macro-Benthic invertebrates are back-boneless organisms that dwell on or in the sediment of a body of water or are stuck to rocks or debris near the bottom. They are as follows: Crustaceans: (shrimp and crayfish) Clams and mussels are examples of mollusks. Oligochaetes (aquatic worms) and annelids (leeches) Gastropods (snails) and aquatic insect larvae Greenberg, (1992). They play a vital role in the aquatic ecology because they are part of the aquatic food chain. They are also used to measure water quality and as pollution indicators. 1992 (APHA, AWWA, and WEF). Bio-indicators offer a more accurate picture of changing aquatic conditions than chemical and microbiological data, which only show short-term changes. Ravera, (2000); Idowu and Ugwumba, (2005). Most benthic invertebrates graze on detritus that settles on the water's surface and serves as food for a variety of fishes. Ikomi, et al (2005). They also hasten the decomposition of decaying organic stuff into simpler inorganic forms like phosphates and nitrates. Oil pollution lands on aquatic medium, killing species that reside there; it also settles on the ocean floor, killing benthic (bottom-dwelling) organisms like shrimp and crabs. The oil spill reduces the quantity of chlorophyll in sediment, which affects benthic macrofauna. Li et al (2013), as well as ecological functioning, by slowing or even eliminating microalgal production, increasing bacterial respiration, and inducing a transition from an autotrophic to a heterotrophic system. In his research, Li et al (2013), concluded that the impacts of an oil spill on macrofauna were more severe than on benthic microalgae, and that immobile infauna were more affected than

motile epifauna. The use of benthic communities and macroinvertebrates as bioindicators of aquatic ecosystem health serves an important ecological function as a link between energy inputs and transmission to other trophic levels via the food web. Nkwoji et al, (2020). Other than physiochemical measures that represent short-term changes, macroinvertebrates provide thorough information and comprehension of environmental changes. Ikomi, et al (2005). Some macroinvertebrates are relatively resistant to pollution and can represent the cumulative impacts of xenobiotics in the environment, Nejadhashem, and Herman, (2015). Because of their ubiquity and stationary character, macroinvertebrates can integrate environmental circumstances. Nkwoji and Awodeyi, (2018); Nkwoji et al, (2016). Their assemblages are a good representation of any ecosystem's local environmental conditions, Onyena. (2019). which is why they are used as pollution indicators in most studies.

1.2 Heavy Metals in Sediments

Unlike physiochemical approaches that represent transient changes, macroinvertebrates offer comprehensive knowledge and comprehension of environmental changes. Ikomi, et al (2005). Some macroinvertebrates are relatively pollution tolerant and can represent the cumulative effects of xenobiotics in the ecosystem. Nejadhashem, and Herman, (2015). Because they are sedentary and widely distributed, macroinvertebrates are able to adapt to changing environmental conditions, Nkwoji and Awodeyi, (2018); Nkwoji et al, (2016). According to, Onyena. (2019). their assemblages serve as a good representative of the local environmental conditions of any ecosystem, which is why most research use them as pollution indicators. Marine organisms in contaminated marine ecosystems are forced to absorb certain heavy metals (HMs) from their local environment due to high concentration exposure to metals. Xie et al, (2020); Ibrahim et al, (2020). Human health is negatively impacted by heavy metals, which have been produced by anthropogenic and industrial activities as well as modern industrialization. Seafood contamination with heavy metals is another issue that affects human and animal health globally. Mousavi, et al, (2013); Ghorani et al (2016); Luo et al, (2020). As stated by Jawed et al, (2020); Nejadhashem, and Herman, (2015); O'Connell et al, (2008). Higher concentrations of metallic ions are poisonous due to their damaging nature, making their presence in the environment a major problem. Several human organs are impacted by the acute and long-term harmful effects of heavy metals. Complications from the harmful effects of heavy metals include birth defects, cancer, vascular damage, nervous system abnormalities, skin lesions, immune system dysfunction, and malfunctions of the digestive and kidney systems. Simultaneous exposure to two or more metals may have cumulative effects, Fernandes et al, (2012); Cobbina et al, (2016); Costa, (2019); Gazwi et al (2020). A few of the most frequent heavy metals that poison the environment are mercury, cadmium, chromium, zinc, copper, and lead.

2. MATERIALS AND METHODS

2.1 DESCRIPTION OF STUDY AREA

The Okerenkoko settlement is situated in Delta State, Nigeria's Warri South-West Local Government Area, within the Gbaramatu Kingdom. Some of the largest proven oil and gas reserves in Delta State and the Niger Delta region are found in this LGA. Coastal communities including Oporoza, Okerenkoko, Kurutie, Isaba, and Diebiri are located in Gbaramatu Kingdom in Nigeria's Niger Delta region. These communities produce oil, and the kingdom is home to 1,293,282 people from its eight local government districts. The resources of Gbaramatu Kingdom are abundant in gas and crude oil. This is demonstrated by the existence of multiple integrated and surrounding crude oil fields that are jointly operated by national and international corporations, with a daily production capacity of several hundred thousand barrels. The multibillion-dollar Escravos Gas to Liquid (EGTL) project is situated in Warri South-West. Chevron and the Nigeria National Petroleum Corporation are the owners and financiers of the EGTL project (NNPC). Okerenkoko is situated along the Escravos River, which is largely recognized for its inland waterborne transportation, shipping, and gas and oil industries in Nigeria. Its coordinates are 5°37'07.4" N and 5°24'25.3" E. The renowned Escravos Tank Farm and Terminal, run by the NNPC/Chevron Joint Venture, and the Atlantic Ocean, which is roughly thirty-five nautical miles from Warri, the closest urban center, are both conveniently close to the Okerenkoko village. In fact, the trip from Warri to the University site will take less than ten minutes by helicopter and approximately 45 minutes by speed boat. The fact that the Okerenkoko town in the Gbaramatu kingdom has a unique location that allows it to open into the Atlantic Ocean through the Escravos River may be of interest to you. This is because the oil and gas industry, which has long been the backbone of the Nigerian economy, uses this route for oceangoing vessels. It is also upsetting to witness other activity that takes on in this extremely significant water body. The Okerenkoko estuary is subject to human influences and environmental stressors, including pollution from open laundry, bathing, defecating, home sewage, garbage, dumping of refuse into

the water, and artisanal petroleum product refining. These factors also result in influxes from nearby creeks and creek-inlets. Concerns regarding water quality monitoring have been generated by the uncontrolled disposal of urban pollutants, runoff, evaporation into the atmosphere, and municipal and industrial pollutants into sea, stream, and river water bodies.

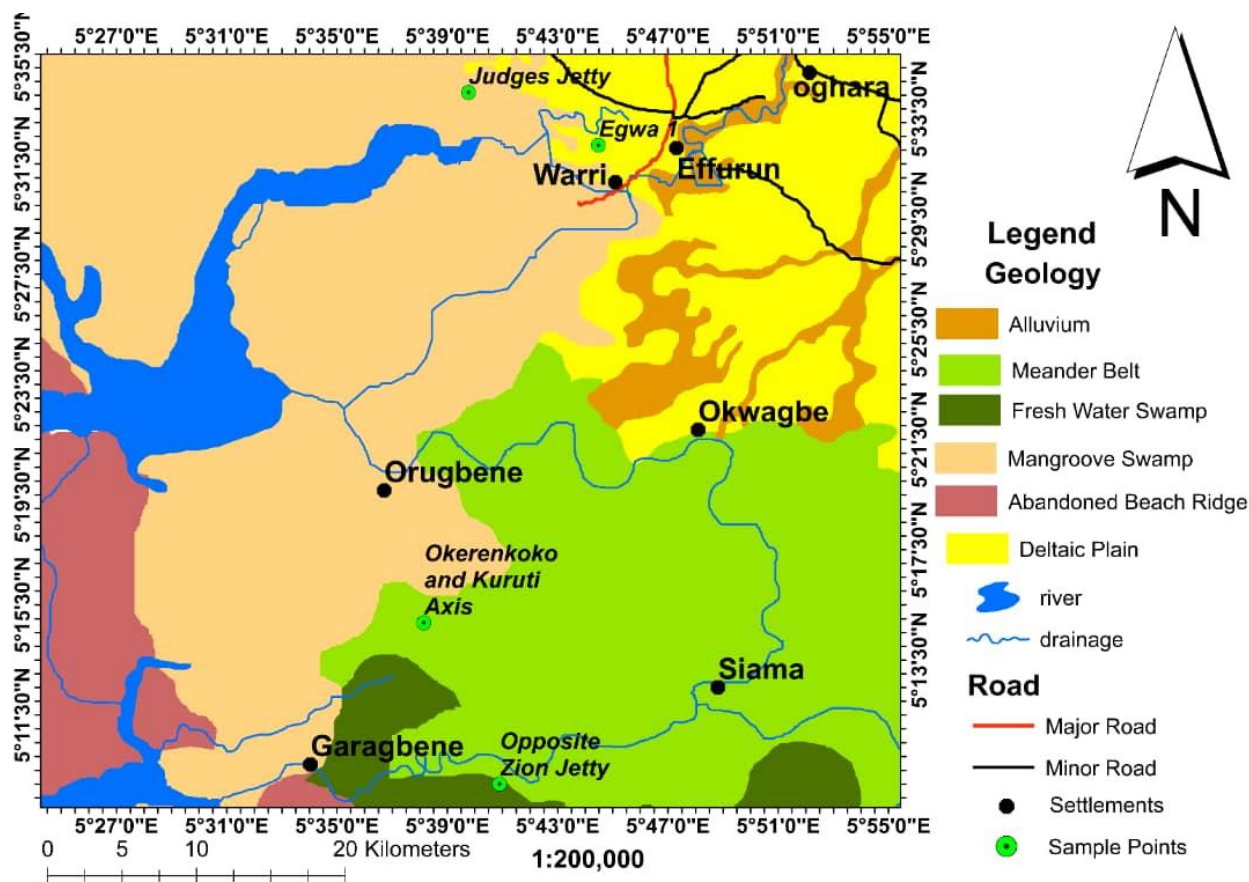


Figure 1: Map of study Area showing the Sampling Stations.

Table 1: Sampling stations and their Coordinates.

SAMPLING STATIONS	LATITUDE	LONGITUDE
Edge of Okerenkoko and Kuruti Axis	05°.60'14.51	5°.38'08.78
Opposite Zion Jetty	05°.62'08.60	5°.40'53.50
Zion Jetty	05°.62'43.41	5°.39'40.81
Judges Jetty	05°.63'34.06	5°.39'64.17
Egwa 1	05°.63'32.11	5°.44'28.60

The exact locations of the sampling stations were obtained with the aid of the Global Positioning System (GPS).

2.3 Water sample collection:

At each study station, between 0800 and 1200 hours, 1-liter plastic containers with pre-labelled labels were used to collect surface water samples for chemical parameter analysis. Using the Temp-PH-EC-TDS probe (Model number P-3), an Ipc-pen multifunction water quality tester sampling equipment, the temperature (Celsius, °C), PH (salinity), EC, and TDS of the surface water were measured in-situ. Water samples were subjected to a titrimetric laboratory test to measure the dissolved oxygen (DO). The measurement of BOD1–BOD5 and COD, as outlined in APHA

1992, was done in the lab using water samples that were collected in 250 ml amber sampling vials and incubated in the dark for five days.

2.4 Analysis of heavy metals in sediments:

After sediment samples are packed in a zip-lock bag, the sediments for the heavy metal analysis were brought to the lab for additional examination. An analysis was conducted on heavy metals such as Cr, Cu, Hg, Zn, Cd, and Pb utilizing the triple acid wet oxidation digestion method. After the sediment sample was allowed to dry at room temperature, it was sieved using a 2 mm mesh sieve. Three acids were then used to digest the 2.0 g of soil that was placed into a beaker. Under a fume hood, 1 ml of HClO₄, 3 ml of concentrated HNO₃, and 1 ml of HF were added and heated. Heating was resumed and halted when dense white vapors emerged. After letting it cool, 40–50 milliliters of distilled water were added. Whatman No. 42 filter paper was used to completely filter the mixture. After that, distilled water was added to bring the solution up to par. The Varian 220 (rapid sequential) Atomic Absorption Spectrometer was equipped with an air-acetylene flame into which the soil extracts and standard solutions were aspirated.

2.5 Collection and analysis of benthic samples:

Using a motorized boat with an outboard engine, the modified Van-Veen grab was utilized to gather benthic samples at each of the five study locations throughout the months of September and October. Every station's collected sediment was in-situ sieved using a 0.5 mm screen. After being sieved, the samples were transferred to a lab for examination and kept in 10% formalin. The samples were sorted in the labs, and the clean benthos were fixed with 70% ethanol. Benthic samples were recognized to at least genus / species level and their distribution was evaluated through analysis of the sorted benthicfauna, which was then classed and identified using the pertinent identification guidelines.

2.6 Statistical analysis:

While the Linear Regression Analysis model was used to determine the effect of Physiochemical parameter and Heavy metals on Benthic fauna distribution across all 5 stations, Post-HOC Analysis was also utilized to determine the pairwise relationship of the Physio-chemical parameters for both months. ANOVA Output was used to determine the variation in means of the Physio-chemical parameters as well as the variation in means of the Heavy Metals in Sediments.

Results:

Table 2: Post-HOC Analysis to determine the pairwise relationship of the Physio-chemical parameters in September

(I) PHYSIO-CHEMICAL		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Temperature	PH	21.5900	24.68036	0.390	-29.3478	72.5278
	TDS	-1613.3600*	24.68036	0.000	-1664.2978	-1562.4222
	EC	-789.5600*	24.68036	0.000	-840.4978	-738.6222
	DO	20.9200	24.68036	0.405	-30.0178	71.8578
	BOD	25.7800	24.68036	0.307	-25.1578	76.7178
	COD	22.7500	24.68036	0.366	-28.1878	73.6878
PH	TDS	-1634.9500*	24.68036	0.000	-1685.8878	-1584.0122
	EC	-811.1500*	24.68036	0.000	-862.0878	-760.2122
	DO	-0.6700	24.68036	0.979	-51.6078	50.2678
	BOD	4.1900	24.68036	0.867	-46.7478	55.1278
	COD	1.1600	24.68036	0.963	-49.7778	52.0978
TDS	EC	823.8000*	24.68036	0.000	772.8622	874.7378
	DO	1634.2800*	24.68036	0.000	1583.3422	1685.2178
	BOD	1639.1400*	24.68036	0.000	1588.2022	1690.0778

	COD	1636.1100*	24.68036	0.000	1585.1722	1687.0478
EC	DO	810.4800*	24.68036	0.000	759.5422	861.4178
	BOD	815.3400*	24.68036	0.000	764.4022	866.2778
	COD	812.3100*	24.68036	0.000	761.3722	863.2478
DO	BOD	4.8600	24.68036	0.846	-46.0778	55.7978
	COD	1.8300	24.68036	0.942	-49.1078	52.7678
BOD	COD	-3.0300	24.68036	0.903	-53.9678	47.9078

Table 2 indicates that there was a noteworthy distinction found in the levels of pH, EC, and total dissolved solids (TDS). In this experiment, TDS was lower than pH and EC, as indicated by the highly significant p-value of less than 0.0001 for these parameters. In particular, TDS seems to be somewhat greater than EC and much lower than pH. This implies that TDS concentrations and pH and EC values are different. Additionally, Electrical Conductivity (EC) reveals considerable variances compared to Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). With a very low p-value, the significant positive mean differences between EC, DO, BOD, and COD show that EC is significantly greater than the other metrics in this study.

Table 3: ANOVA Output for determining the variation in means of the physio-chemical parameters in October.

(I) PHYSIO-CHEMICAL		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Temperature	PH	21.6920	25.59218	0.405	-31.1277	74.5117
	TDS	-1616.2200*	25.59218	0.000	-1669.0397	-1563.4003
	EC	-795.0200*	25.59218	0.000	-847.8397	-742.2003
	DO	21.0600	25.59218	0.419	-31.7597	73.8797
	BOD	25.8600	25.59218	0.322	-26.9597	78.6797
	COD	22.8700	25.59218	0.380	-29.9497	75.6897
PH	TDS	-1637.9120*	25.59218	0.000	-1690.7317	-1585.0923
	EC	-816.7120*	25.59218	0.000	-869.5317	-763.8923
	DO	-0.6320	25.59218	0.981	-53.4517	52.1877
	BOD	4.1680	25.59218	0.872	-48.6517	56.9877
	COD	1.1780	25.59218	0.964	-51.6417	53.9977
TDS	EC	821.2000*	25.59218	0.000	768.3803	874.0197
	DO	1637.2800*	25.59218	0.000	1584.4603	1690.0997
	BOD	1642.0800*	25.59218	0.000	1589.2603	1694.8997
	COD	1639.0900*	25.59218	0.000	1586.2703	1691.9097
EC	DO	816.0800*	25.59218	0.000	763.2603	868.8997
	BOD	820.8800*	25.59218	0.000	768.0603	873.6997
	COD	817.8900*	25.59218	0.000	765.0703	870.7097
DO	BOD	4.8000	25.59218	0.853	-48.0197	57.6197
	COD	1.8100	25.59218	0.944	-51.0097	54.6297
BOD	COD	-2.9900	25.59218	0.908	-55.8097	49.8297

Table 3 indicates that there is no discernible difference in the mean differences between Temperature and PH and between DO, BOD, and BOD, COD. The corresponding p-values (0.405, 0.853, and 0.908, respectively) are rather high, suggesting that the variation of these parameters is not significantly different from one another. In a similar vein, TDS is substantially greater than EC but significantly lower than PH. In other words, EC is far greater than DO, BOD, and COD. These findings imply notable differences between these characteristics and offer important new information on how they interact.

Table 4: Post-HOC Analysis for determining the pairwise relationship of the Stations of heavy metals in sediments.

(I) Stations		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Station 1	Station 2	1.5807	1.65580	0.351	-1.8733	5.0346
	Station 3	1.6427	1.65580	0.333	-1.8113	5.0966
	Station 4	-0.8168	1.65580	0.627	-4.2708	2.6371
	Station 5	-3.4905*	1.65580	0.048	-6.9444	-0.0366
Station 2	Station 3	0.0620	1.65580	0.971	-3.3919	3.5159
	Station 4	-2.3975	1.65580	0.163	-5.8514	1.0564
	Station 5	-5.0712*	1.65580	0.006	-8.5251	-1.6172
Station 3	Station 4	-2.4595	1.65580	0.153	-5.9134	0.9944
	Station 5	-5.1332*	1.65580	0.006	-8.5871	-1.6792
Station 4	Station 5	-2.6737	1.65580	0.122	-6.1276	0.7803

The differences between the different types of heavy metals discovered in sediment are displayed in Table 4 "Heavy Metals" source of variation. This observation suggests a highly significant difference amongst the various heavy metals, with a Type III Sum of Squares of 535.279, 5 degrees of freedom, and an F-statistic of 13.016. The low p-value of 0.000 indicates a great degree of variance in the sediment, which is noteworthy for this study. Table 4 further indicates that there is a considerable difference in the quantities of heavy metals in the sediment between the stations that were analyzed, for example, when comparing Station one to Station five. The mean difference of -3.4905 with a p-value of 0.048 suggests that heavy metals levels in sediment at Station one is considerably lower than those of Station five. The 95% confidence interval, which excludes zero and highlights the significance of this difference, supports this finding.

Likewise, there is a highly significant variation in the quantities of heavy metals in the sediment at Stations two and five. The sediment at Station two has significantly lower amounts of heavy metals than the sediment at Station five, as indicated by the mean difference of -5.0712 and a p-value of 0.006. This observation is further supported by the confidence interval.

Table 5: Post-HOC Analysis for determining the pairwise relationship of the heavy metals' sediments.

(I) heavy metals		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Copper	Cadmium	1.2736	1.81384	0.491	-2.5100	5.0572
	Zinc	-10.3198*	1.81384	0.000	-14.1034	-6.5362
	Lead	0.0012	1.81384	0.999	-3.7824	3.7848
	Mercury	2.2468	1.81384	0.230	-1.5368	6.0304
	Chromium	-3.2978	1.81384	0.084	-7.0814	0.4858
Cadmium	Zinc	-11.5934*	1.81384	0.000	-15.3770	-7.8098
	Lead	-1.2724	1.81384	0.491	-5.0560	2.5112
	Mercury	0.9732	1.81384	0.598	-2.8104	4.7568
	Chromium	-4.5714*	1.81384	0.020	-8.3550	-0.7878
Zinc	Lead	10.3210*	1.81384	0.000	6.5374	14.1046
	Mercury	12.5666*	1.81384	0.000	8.7830	16.3502
	Chromium	7.0220*	1.81384	0.001	3.2384	10.8056
Lead	Mercury	2.2456	1.81384	0.230	-1.5380	6.0292
	Chromium	-3.2990	1.81384	0.084	-7.0826	0.4846

Mercury	Chromium	-5.5446*	1.81384	0.006	-9.3282	-1.7610
---------	----------	----------	---------	-------	---------	---------

According to Table 5, copper and zinc sediment levels varied greatly from one another, with copper levels being substantially lower than zinc levels. The remarkably low p-value of (0.000) and the mean difference of -10.3198 highlight the importance of this discrepancy. This significant difference is highlighted by the 95% confidence interval, which excludes zero. On the other hand, the levels of sediment for a number of other heavy metals, including copper-cadmium, copper-lead, and copper-mercury, do not significantly change. In these instances, greater p-values and confidence intervals that encompass zero suggest that the mean differences are not significant. Significant distinctions between zinc and a number of other heavy metals, such as lead, mercury, and chromium, are also shown by the research. The corresponding mean differences and low p-values show that the concentration of zinc in sediment is considerably higher than that of other heavy metals. Table 5: Analyze the impact of heavy metals and physio-chemical factors on the spread of benthic faunas.

Table 6: Linear Regression Analysis Outcome showing the effect of Physiochemical and Heavy metals on Benthic Faunas

	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
(Constant)	37.877	8.888		4.262	0.004
Physiochemical	-0.098	0.025	-0.847	-3.891	0.006
Heavy metals	0.106	0.263	0.088	0.405	0.698

Adjusted R-squared: 0.599 F-statistics: 7.729 P-value: 0.017

The findings of a linear regression analysis that was done to look into how heavy metals and physiochemical factors affected benthic fauna are shown in Table 6. The analysis provides proof of their interactions and environmental effects. When all other predictor variables are set to zero, the predicted value of benthic fauna is represented by the constant term. The model uses this initial value, which is predicted to be 37.877, as a baseline. The results of the investigation show that the distribution of benthic fauna is influenced by physiochemical parameters. The standardized coefficient (Beta) for physiochemical factors is -0.847, indicating a strong negative correlation, while the coefficient for these factors is -0.098. This implies that the benthic fauna is likely to decrease when physiochemical factors increase. Moreover, the statistical significance of this association at the 0.006 level of significance is indicated by the t-statistic of -3.891, which bolsters the evidence supporting the impact of physiochemical variables on benthic fauna.

However, the data reveals no meaningful connection between benthic species and heavy metals. The standardized coefficient (Beta) for heavy metals is 0.088, while the coefficient itself is 0.106. This suggests that although there is a correlation between benthic fauna and heavy metals, it is not very strong. The p-value of 0.698 indicates that the t-statistic of 0.405 is not statistically significant, indicating that heavy metals do not significantly affect benthic fauna in this particular situation. Statistical significance is demonstrated by the adjusted R-squared value of 0.599 for the entire regression model. This suggests that the combination of physiochemical parameters and heavy metals can account for about 59.9% of the variability observed in benthic fauna. The F-statistic of 7.729 with a p-value of 0.017 supports the overall significance of the model.

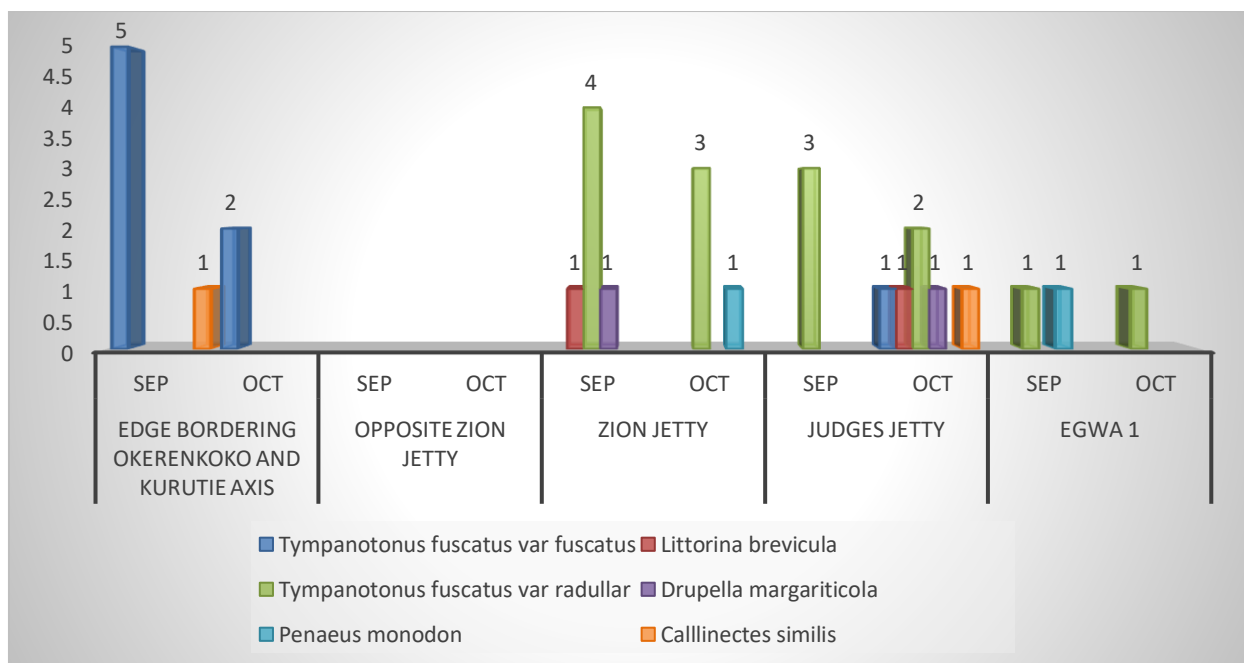


Figure 2: Bar Plot showing the distribution of Macro-benthic fauna.

Discussion

Macro-Benthic fauna community structure of Okerenkoko.

Under the influence of various complex factors such as seasonal variations, geographical location, environmental conditions on benthic-fauna distribution and the crucial interplay between physio-chemical parameters and heavy-metals. These has a great influence on aquatic invertebrates' composition, distribution and abundance level, as observed in this investigation. From the short-term coastal survey carried out in Okerenkoko estuary; benthic-fauna community, shown a great decline in their assemblage. A total of two Phyla, three Classes, four Orders, five Families, five Genera, six Species; amounting to a total of thirty individuals were observed. Table: 7 shows a summary of the Numerical Distribution of Macro Benthic-fauna constitution at the study stations, and the most dominant taxonomic group is comprehensively documented in this investigation, which reveal that Phyla Mollusca, Figure:3 shows the percentage class distribution in the month of September (88.2%), and percentage class distribution in October (88.6%). While, the percentage class distribution of macro benthic-fauna in the study area for Arthropods in Figure:3 shows the percentage class distribution for the months of September (11.8%) and (15.4%) October respectively. Phyla Arthropod constituted, individuals of the Class Crustacea: *Callinectes similis* and Class Malacostraca: *Penaeus monodon*. This group of benthos's scarcities may have resulted from their vulnerability to physiochemical alterations and anthropogenic stressors. The roots of mangrove plants accumulate sediments and absorb organic pollutants and oil spills, (hence in the long run; they suffocate and die off); these might have accounted for the low turn-out in the number of individuals (zero) in station two, as shown in Figure: 2, this may indicate also, that the study station is under stress, due to environmental pollution as observed in the silty-to-slimy characterization in the sediment type and because benthic-fauna are specific to sediment in nature, the sediment in station two may be devoid of oxygen due to oil-spills and anthropogenic contaminants in Okerenkoko estuary. This is basically linked, to artisanal activities; leading to the low species diversity, and distribution patterns of macro-benthic invertebrates turn-out in this study. Furthermore, stations with higher species richness and evenness such as station 3 and station 4 in September and October respectively, can be considered biodiversity hotspots within the study area, this aligns with previous observations; that points to the fact that environmental heterogeneity and substrate complexity (rocky, clay, sandy) bottoms promotes mollusks diversity. Bearing these in mind the composition and structure of the ecological communities of benthic-fauna can be shaped by the degree of heterogeneity in this study.

Table 7:1 A Summary of the Numerical Distribution of Macrobenthic -fauna at the study stations.

TAXA	Edge bordering Okerenkoko and Kurutie Axis	Opposite Zion Jetty	Zion Jetty	Judges Jetty	Egwa1	Total
<i>Tympanotonus fuscatus var fuscatus</i>	7	0	0	1	0	8
<i>Littorina brevicula</i>	0	0	1	1	0	2
<i>Tympanotonus fuscatus var radullar</i>	0	0	7	5	2	14
<i>Drupella margariticola</i>	0	0	1	1	0	2
<i>Penaeus monodon</i>	0	0	1	0	1	2
<i>Callinectes similis</i>	1	0	0	1	0	2
Total	8	0	10	9	3	30

The levels of dissolved oxygen in the water at all five stations met the requirements setup by the Federal Ministry of Environment (FME) and the Environmental Protection Agency (EPA) for live plants and animals (4.5–10 mg/l). Although the Department of Petroleum Resources (DPR) increased their standard from 10 to 30 mg/l, this can be linked to the regular pollution incidences in most aquatic media and the majority of petrochemical companies operating in the Niger Delta region causing intentional or unintentional spills. EPA, (2020).

The influence of Heavy-metals on benthic-fauna distribution:

However, the data reveals no meaningful connection between benthic-invertebrate species and heavy metals. But the fact still remains that heavy-metals bioaccumulates in sediments according to Hallegraff, (1993). And benthic-fauna are substratum specific in nature. Likewise, there is a highly significant variation in the quantities of heavy metals in the sediment at Stations two and five. The sediment at Station two has significantly lower amounts of heavy metals than the sediment at Station five; and the concentration of zinc in sediment is considerably higher than that of other heavy metals. As shown in Table 5: the analyzes of the impact of heavy metals and physio-chemical factors shows the compositional diversity of benthic-fauna, its well observed.

Human health risk associated with the consumption of benthic-fauna:

Higher concentrations of metallic ions are poisonous, due to their damaging nature, making their presence in the environment a major problem. Several human organs are impacted by the acute and long-term harmful effects of heavy metals. Human Complications are often recorded and the harmful effects of heavy metals include; birth defects, cancer, vascular damage, nervous system abnormalities, skin lesions, immune system dysfunction, and malfunctions of the digestive and kidney systems; simultaneous exposure to two or more metals may have cumulative effects, Fernandes et al, (2012); Cobbina et al, (2016); Costa, (2019); Gazwi et al (2020). A few of the most frequent heavy metals that are poisonous to the environment include: mercury, cadmium, chromium, zinc, copper, and lead. Outbreaks of biotoxins accumulated in aquatic sediments, according to Hallegraff, (1993). indicates that the consumption of undercooked or raw seafoods (primarily bivalve mollusks) that have accumulated pathogens or toxin-bearing from the environmental, further affects humans since human are the secondary consumers of these shellfishes, leading to paralytic, diarrheic, neurotoxic, and amnesic. Shellfish poisoning are all caused by biotoxins accumulated from heavy-metals in aquatic sediments.

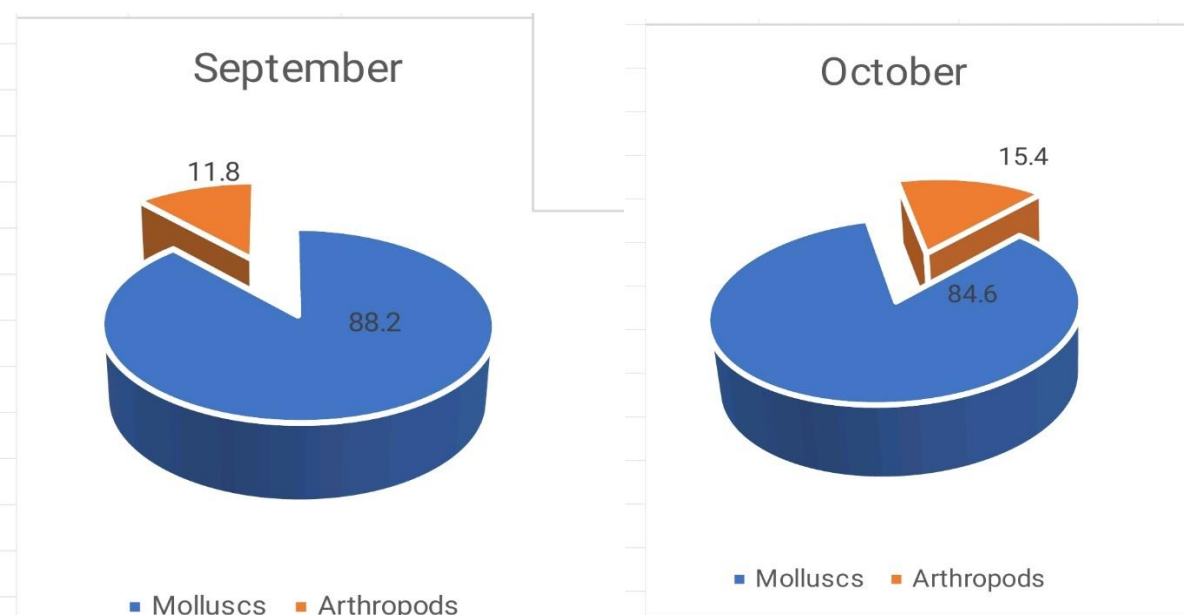


Figure 3: Macrobenthic fauna percentage distribution recorded in Okerenkoko community in the month of sept and oct.

Recommendation

- ☐ Policy Development: This is to inform environmental policies and regulations aimed at controlling industrial discharges and mitigating pollution activities in the maritime settlement.
- ☐ Environmental Monitoring: This is to Establish a long-term environmental monitoring program for the Okerenkoko region to track changes in water quality and benthic community health over time.
- ☐ Pollution Control: This is to recommend specific measures to reduce heavy metal contamination, such as implementing stricter waste management protocols for industries and communities' settlers in the area.
- ☐ Community Engagement: This is in order to engage local communities in awareness programs about the environmental impact of their activities and the importance of preserving the ecosystem for future generations.

Acknowledgements

A special thanks to the project consultant for their logistics support and providing the necessary materials for the research. We would also thank all the field and lab teams for the great job in the data collection and processing.

Conclusion

The goal of the current study was to present a thorough understanding of the abundance of macrobenthos and how it relates to water variables in the Okerenkoko estuary, which is under constant threat from anthropogenic pollution

and oil spills from artisanal refining. The data observations clearly demonstrate that the study on physio-chemical parameters and heavy metals conducted, suggest that, as physio-chemical factors increases, the assemblage of macro-benthic fauna decreases. This suggests that physio-chemical parameters and heavy metals have a significant impact on the abundance, richness and the distribution patterns of macro-benthic fauna communities. The high number of *Tympanotonus fuscatus var fuscatus* found in this study indicates the adaptability of its spread and highlight its sensitive to changes in its habitat. Since Macro-benthic fauna organisms are substratum specific, the routine study and frequent monitoring of the state of this waterbody and analysis of the dynamic interplay among these components is highly vital for sustainable water quality management.

Reference

1. O.K Adeyemo, O.A Adedokun, K.K Yusuf, E.A Adeleye, Seasonal changes in physico-chemical parameters and nutrient load of river sediments in Ibadan city, Nigeria. *Global nest journal* 2008.10(3)326-336.
2. S. Ali, Z. Awan, S. Mumtaz, H.A. Shakir, F. Ahmad, M. Ulhaq, H.M. Tahir, M.S. Awan, S. Sharif, M. Irfan, M.A. Khan. Cardiac toxicity of heavy metals (cadmium and mercury) and pharmacological intervention by vitamin C in rabbits. 2020.
3. D. Aremu, F. Olawuyi, S. Metshitsuka, Sridhar, K. Heavy metal analysis of groundwater from Warri, Nigeria. *International Journal of Environmental Health* 2002. Resources 12: 61 – 72.
4. A.E.Greenberg, L.S.Clesceri, A.D. Eaton, , (eds) APHA; AWWA; WEF. *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association, (1992). 18th Edition.120-123.
5. H. Ali, E. Khan. Assessment of potentially toxic heavy metals and health risk in the water, sediments, and different fish species of river Kabul, Pakistan. *Hum. Ecol. Risk Assess. Int. J.* (2018), 8, 2101–2118
6. S.S. Ajayi. Refocusing the attention of the Federal Government of Nigeria on Ecology and Environment. Nigeria National Merit Award, 2018 Award Winners' Lecture delivered at the University of Ibadan, Nigeria. 44 – 70. (2018).
7. B.P. Naveen, D.M. Mahapatra, T.G. Sitharam, P.V. Sivapullaiah, T.V. Ramachandra Physico-chemical and biological characterisation of urban municipal landfill leachate *Environ. Pollut.*, 220 (2017), pp. 1-12. (2017).
8. A.K. Coker. *Ludwig's Applied Process Design for Chemical and Petrochemical Plants*. Volume 1, 4th Edn., Gulf Professional Publishers, UK., pp: 732-737. (2007).
9. S.J. Cobbina, Y. Chen, Z. Zhou, X. Wu, T. Zhao, Z. Zhang. Toxicity assessment due to sub-chronic exposure to individual and mixtures of four toxic heavy metals. *J. Hazard. Mater.* 294, 109–120. Doi: 10.1016/j.jhazmat.2015.03.057.
10. J.J. Coetzee, N Bansal, E.M.N. Chirwa. Chromium in environment, its toxic effect from chromite-mining and ferrochrome industries, and its possible bioremediation *Expo. Heal.*, 12 (1) (2020), pp. 51-62, 10.1007/s12403-018-0284-z.
11. M.Costa. Review of arsenic toxicity, speciation and polyadenylation of canonical histones. *Toxicol. Appl. Pharmacol.* 375, 1–4. Doi: 10.1016/j.taap.2019.05.006. (2019).
12. K. W. Dance, H.B.N Hynes. Some Effects of agricultural land use on stream Insect communities. *Environ Pollut Ser A*.1980: 22; 19 – 28. (1980).
13. C.A. Edokpayi, A.O. Olowoporoku, R.E Uwadiae. The hydrochemistry and macrobenthic fauna Characteristics of an urban draining creek. *Internat.J. Biodiver.Conserv.*2(8): 196-203. (2010).
14. C.A. Edokpayi, J.A. Nkwoji. Annual changes in the physico-chemical and macrobenthic invertebrate Characteristics of the Lagos lagoon Sewage dump site at Iddo, Southern Nigeria. *Ecol. Env. & Cons.* 13(1): 1318. (2007).
15. O.C. Eneh. A review on petroleum: Source, uses, processing, products and the environment. *J. Appl. Sci.*, 11: 2084-2091. (2011).
16. S.J. Ewutanure, F.E. Olaifa. Heavy metal concentrations in water and sediment of Gbalegbe River, Delta State, Nigeria. The 2nd SETAC Central/West Africa Regional Conference, Environmental sustainability and pollution control through science. Book of Abstract, 4 Pp. (2018).
17. S.J. Ewutanure, T.E. Binyotubo. Impacts of Anthropogenic Activities on the Fish Compositions and Diversity of Okerenkoko Estuarine, Delta State, Nigeria. *Proceedings of the Accra Bespoke Multidisciplinary Innovations Conference*. University of Ghana/Academic City University College, Accra, Ghana. December 2021. Pp 9-8 www.isteams.net/ghanabespoke2021. DOI <https://doi.org/10.22624/AIMS/ABMIC2021-V2-P2>.

18. S.J. Ewutanure, F.E. Olaife. Effects of Effluents from Gbalegbe River, Delta State, Nigeria On the Breeding Performance of *Clarias Gariepinus* (Burchell, 1822). Proceedings of the Accra Bespoke Multidisciplinary Innovations Conference. University of Ghana/Academic City University College, Accra, Ghana. December 2021. Pp 163-178. 2021.
19. B. Fernandes Azevedo, L. Barros Furieri, F Peçanha, M. Wiggers, G. A. Frizera P. Vassallo, M. Ronacher Simões. Toxic effects of mercury on the cardiovascular and central nervous systems. *Biomed. Res. Int.* 2012, 949048. Doi:10.1109 (2012).6508156. (2012).
20. H. S. S. Gazwi, E. E. Yassien, H. M. Hassan. Mitigation of lead neurotoxicity by the ethanolic extract of *Laurus* leaf in rats. *Ecotoxicol. Environ. Safe* 192, 110297. Doi: 10.1016/j.ecoenv.2020.110297. (2020).
21. A.Ghorani-Azam, B. Riahi-Zanjani, M. Balali-Mood. Effects of air pollution on human health and practical measures for prevention in Iran. *J. Res. Med. Sci.*, 21, 65. Doi:10.4103/1735-1995.189646. (2016).
22. B. Gworek, W Dmuchowski, A.H. Baczewska-Dąbrowska. Mercury in the terrestrial environment: a review *Environ. Sci. Eur.*, 32 (1) (2020), 10.1186/s12302-020- 00401-x (2020).
23. M.T. Hayat, M. Nauman, N. Nazir, S. and Ali, N. Bangash Environmental hazards of cadmium: past, present, and future Cadmium Toxic. *Toler. Plants Physiol. Remediat.*, 163–183 (2018), 10.1016/B978-0-12-814864-8.00007-3 (2018).
24. J. A. Nkwoji a, S.I. Ugbana a, M.Y. Ina-Salwany b. Impacts of land-based pollutants on water chemistry and benthic macroinvertebrates community in a coastal lagoon, Lagos, Nigeria *Sci. Afr.* <https://doi.org/10.1016/j.sciaf.2019.e00220>. (2020).
25. J.A. Nkwoji, A. Yakub, G.E. Ajani, K.J. Balogun, K.O. Renner, J.K. Igbo, A.A. Ariyo, B.O. Bello. Seasonal variations in the hydrochemistry and benthic macroinvertebrates of a South Western Lagoon, Lagos, Nigeria *J. Am. Sci.*, 6 (3) (2010), pp. 85-92.
26. J.A. Nkwoji, C.A. Edokpayi. Hydrochemistry and community structure of benthic macroinvertebrates of lagoon, nigeri *Res. J. Pharm. Biol. Chem. Sci.*, 4 (1) (2013), pp. 1119-1131. (2013).
27. F. Naeem, M. Ayub, N. McGuire. Photoreceptor precursors derived from three-dimensional embryonic stem cell cultures integrate and mature within adult degenerate retina Published online 2013 Jul 21. Doi: 10.1038/nbt.2643. (2013).
28. J.A. Nkwoji, S.I. Awodeyi. Impacts of sediment mining on the hydrochemistry and macrozoobenthos community in a coastal lagoon, Lagos, Nigeria *Arch. Agric. Environ. Sci.*, 3 (3) (2018), pp. 209-215. (2018).
29. J.A. Nkwoji a, A.S. Yakub b, A.O. Abiodun b, and B.O. Bello. Hydrochemistry and community structure of benthic macroinvertebrates in Ilaje coastal waters, Ondo State, Nigeria *Reg. Stud. Mar. Sci.* <https://doi.org/10.1016/j.rsma.2016.08.009> (2016).
30. O. Ravera. Ecological monitoring for water body Management. Proceedings of Monitoring. Tailormade III. International Workshop on Information for Sustainable Water Management.157-167pp. (2000).
31. N. Rubalingeswari, D.Thulasimala, L. Giridharan, V. Gopal, Jayaprakash, Bioaccumulation of heavy metals in the water, sediment, and tissues of major fisheries from adyar estuary, southeast coast of India: An ecotoxicological impact of a metropolitan city. *Mar. Pollut. Bull.* 2021, 163, 111964. (2021).
32. J. Baiyu Zhang, Ethan, Matchinski, Bing Chen, Xudong Ye, Liang Jing, Kenneth Lee †. Marine oil spills oil pollution, sources and effects. <https://doi.org/10.1016/B978-0-12-805052-1.00024-3>. (2019).
33. B. IbangaL, J.A Nkwoji, A.I Useuse, I.C Onyema. Hydrochemistry and heavy metals concentrations in sediment of Woji creek and Bonny estuary, Niger Delta, Nigeria *Reg. Stud. Mar. Sci.* (2018).
34. E.O. Idowu, A.A. Ugwumba. Physical, chemical and benthic faunal characteristics of a Southern Nigeria Reservoir. *The Zoolog.* 3: 15-25. (2005).
35. R.B. Ikomi, F.O. Arimoro, O.K. Odihrin. Composition, Distribution and Abundance of Macroinvertebrates of the Upper Reaches of River Ethiope, Delta State, Nigeria. *The Zoologist*, 3, 68-81. (2005).
36. A.E. Ite, T.A Harry, C.O Obadimu, E.R. Asuaiko , and Inim I.J. Petroleum hydrocarbons contamination of surface water and groundwater in the Niger Delta region of Nigeria. *Journal of Environment Pollution and Human Health* 6(2):51-61. (2018).
37. N.S. Ifti, D. Ayas, M. Bakan. The comparison of heavy metal level in surface water, sediment and biota sampled from the polluted and unpolluted sites in the northeastern mediterranean sea. *Thalass. Int. J. Mar. Sci.* 2021, 37, 319–330. (2021).
38. Q. Xie, L. Qian, S. Liu, Y. Wang, D. Wang. Assessment of long-term effects from cage culture practices on heavy metal accumulation in sediment and fish. *Ecotoxicol. Environ. Saf.* 2020, 194, 110433. (2020).
39. N.A. Gashkina, T.I. Moiseenko, L.P. Kudryavtseva. Fish response of metal bioaccumulation to reduced toxic load on long-term contaminated lake Imandra. *Ecotoxicol. Environ. Saf.* 2020, 191, 110205. (2020)

40. S.K.Gao, R. Zhang, H. Zhang, S. Zhang. The seasonal variation in heavy metal accumulation in the food web in the coastal waters of Jiangsu based on carbon and nitrogen isotope technology. *Environ. Pollut.* 2021, 11, 118649. (2021)
41. A.E.Gbuvboro, E.O.R. Ulakpa. Licensing of modular refineries by Government in the Niger Delta region to stop artisanal refining of crude in the creeks. A review; *journal of environmental engineering and studies*. Volume- 8, iissu-2 May – August 2023. e-ISSN: 2582-3132. (2023).
42. M. Ibrahim, D.Oldham, M. Minghetti. Role of metal speciation in the exposure medium on the toxicity, bioavailability and bio-reactivity of copper, silver, cadmium and zinc in the rainbow trout gut cell line (rtgutgc). *Comp. Biochem. Physiol. Part C Toxicol. Pharmacol.* 2020, 236, 108816. (2020).
43. A.Jawed, V. Saxena, L.M.Pandey. Engineered nanomaterials and their surface functionalization for the removal of heavy metals: A Review. *Journal of Water Process Engineering*, 33,101009. (2020)
44. D.E.Kimbrough, Y. Cohen, A.M. Winer, L. Creelman, and C. Mabuni. A critical assessment of chromium in the environment *Crit. Rev. Environ. Sci. Technol.*, 29 (1) (1999), pp. 1-46, 10.1080/10643389991259164. (1999).
45. M.A.Khan, Z.Khan, M.Qamar. Waqas. The uptake and bioaccumulation of heavy metals by food plants, their effects on plants nutrients, and associated health risk: a review *Environ. Sci. Pollut. Res.*, 22 (18) (2015), pp. 13772-13799, 10.1007/s11356-015-4881-0. (2015).
46. N. Loh, H-P. Loh, L.K. Wang, M.-H.-S. Wang Health effects and control of toxic lead in the environment *Nat. Resour. Control Process.*, 233–284 (2016), 10.1007/978-3-319-26800-2_5 (2016).
47. L.Luo, B.Wang, J.Jiang, Q.Huang, Z.Yu Li. Heavy metal contaminations in herbal medicines: determination. Comprehensive risk assessments. *Front. Pharmacol.* 11, 595335. Doi:10.3389/fphar.2020.595335. (2020)
48. A.A.Kadafa. Oil Exploration and Spillage in the Niger Delta of Nigeria. *Civil and Environmental Research*, 2, No. 3. (2012).
49. Environmental impacts of oil exploration and exploitation in the Niger Delta of Nigeria *Glob. J. Sci. Front. Res. Environ. Earth Sci.* (2012).
50. M.S.Khan, M.Javed, M.T.Rehman, M.Urooj, M.I.Ahmad. Heavy metal pollution and risk assessment by the battery of toxicity tests. *Sci. Rep.* 2020, 10, 16593. (2020).
51. S.Kabari, A.Onyena, J.E. Ochuko, Felix Eze. Water quality evaluation using water quality index and pollution model in selected communities in Gbaramatu Kingdom, Niger Delta, Nigeria. <https://doi.org/10.21203/rs.3.rs-2831196/v1>. Preprint version 2023.
52. K.N. Kouadio, D. Diomandé, A. Ouattara, Y.J.M. Koné, G. Gourène Taxonomic diversity and structure of benthic macroinvertebrates in Aby lagoon (Ivory coast, west Africa) *Pak. J. Biol. Sci.*, 11 (18) (2008), pp. 2224-2230. (2008).
53. K.N. Kouadio, D. Diomandé, Y.J.M. Koné, K.Y. Bony, A. Ouattara, and G. Gourène Distribution of benthic macroinvertebrate communities in relation to environmental factors in the Ebrié lagoon (Ivory coast, west Africa) *Vie et milieu-Life Environ.*, 61 (2) (2011), pp. 59-6. (2011).
54. P.Kumar, P.Sivaperumal, V.Manigandan, R.Rajaram, M.Hussain. Assessment of potential human health risk due to heavy metal contamination in edible finfish and shellfish collected around ennore coast, India. *Environ. Sci. Pollut. Res.* 2021, 28, 8151–8167. (2021).
55. E.Lampsey, K.A. Armah. Factors affecting macro benthic fauna in a tropical hypersaline coastal lagoon in Ghana, West Africa *Estuaries Coasts*, 31 (2008), pp. 1006-1019. (2008).
56. Li-Hua Lee a b, Hsing-Juh Lin. Effects of an oil spill on benthic community production and respiration on subtropical intertidal sandflats. *Mar Pollut Bull.* 2013 Volume 73, Issue 1. 15 August 2013, Pages 291-299. <https://doi.org/10.1016/j.marpolbul.2013.05.006>
57. S. Mitra, A. Rauf, A.M. Tareq, S. Jahan, T.B. Emran, T.G. Shahriar, K. Dhama, F.A. Alhumaydhi, A.S.M. Aljohani, M. Rebezov, M.S. Uddin, P. Jeandet, Z.A. Shah, M. A and Shariati, K.RR. Rengasamy Potential health benefits of carotenoid lutein: An updated review *Food Chem. Toxicol.*, 154 (2021), p. 112328, 10.1016/j.fct.2021.112328 (2021b).
58. S. R.Mousavi, M.Balali-Mood, B.Riahi-Zanjani, H.Yousefzadeh, M. Sadeghi, Concentrations of mercury, lead, chromium, cadmium, arsenic and aluminum in irrigation water wells and wastewaters used for agriculture in Mashhad, northeastern Iran. *Int. J. Occup. Environ. Med.* 4 (2 April), 80–86. (2013).
59. G. Nabulo, C.R. Black, and S.D. Young. Trace metal uptake by tropical vegetables grown on soil amended with urban sewage sludge *Environ. Pollut.*, 159 (2) (2011), pp. 368-376, 10.1016/j. (2011).
60. D.W.O'Connell, C.Birkinshaw, T.F.O'Dwyer. Heavy metal adsorbents prepared from the Modification of cellulose: A review. *Bioresource Technology*, 99(15), 6709–6724. (2008).

61. I.C.Onyema, J.A.Nkwoji. The Water Chemistry and Plankton Dynamics of a Tropical High Energy Erosion Beach in Lagos. *Journal of American Science*, 2009, 5 (7). (2009)
62. K.M. Rice, E.M. Walker, M. Wu, C. Gillette, and E.R. Blough Environmental mercury and its toxic effects *J. Prev. Med. Public Heal.*, 47 (2) (2014), pp. 74-83, 10.3961/jpmph.2014.47.2.74 (2014).
63. M.Mahamood, M.Javed, S.S.Alhewairini, F.Zahir, M.I.Ahmad, A .Labeo rohita. bioindicator for water quality and associated biomarkers of heavy metal toxicity. *NPJ Clean Water* 2021, 4, 17. (2021).
64. M.Mokarram, A.Saber, R.Obeidi. Effects of heavy metal contamination released by petrochemical plants on marine life and water quality of coastal areas. *Environ. Sci. Pollut. Res.* 2021, 28, 51369–51383. (2021).
65. A.P.Onyena. Composition, Distribution, and Diversity of Benthic Macroinvertebrate from Creeks Around Lagos Lagoon, Nigeria Copyright: Copyright © 2019 <https://dx.doi.org/10.4314/jasem.v23i5.14> (2019).
66. A. P.Onyena, S.Kabari . A review of the threat of oil exploitation to mangrove ecosystem: Insights from Niger Delta, Nigeria. <https://doi.org/10.1016/j.gecco.2020.e00961>.(2020)
67. O.W.Obot, S.M.Ibanga. The Impact of Noise Pollution on Productivity: A Case Study of University of Uyo, Nigeria. *Indian Journal of Computer Science and Engineering*, 5, 9-14. (2014).
68. P.M.R.Nejadhashem, A. P.Herman. A review of macroinvertebrate- and fish-based stream health indices.<https://doi.org/10.1016/j.ecohyd.2015.04.00>. (2015).
69. J.A.Nkwoji. Impact of Hypoxia on the Community Structure of Benthic Macroinvertebrates of Lagos Lagoon, Nigeria May 2016*Journal of Applied Sciences and Environmental Management* 20(1):121 DOI:10.4314/jasem. v20i1.15. (2016).
70. J.S.Nworu, OJO . Wilberforce Application of nanotechnology for enhancing oil recovery (EOR) in oil and gas industry: a review Publication date 2019 Source IOSR Journal of Applied Chemistry Volume 12, Issue 2: Pages 32-42. (2019).
71. S.Pegg, N.Zabbey. Oil and water: the Bodo spills and the destruction of traditional livelihood structures in the Niger Delta. *Community Development Journal* 48(3):391–405. (2013).
72. D.Sah, P.K.Verma, M.K.Kandikonda, A.Lakhani. Pollution characteristics, human health risk through multiple exposure pathways, and source apportionment of heavy metals in PM10 at Indo-Gangetic site. *Urban Climate* 27:149-62. (2019).
73. K.Sam, N.Zabbey, A.P.Onyena. Implementing contaminated land Remediation in Nigeria: Insights from the Ogoni remediation Project. *Land Use Policy* 115:106051. (2022).
74. K.Sam, N.Zabbey. Contaminated Land and Wetland Remediation in Nigeria: Opportunities for Sustainable Livelihood Creation, *Science of the Total Environment* Elsevier B.V (2018), 10.1016/j.scitotenv.2018.05.266 (2018).
75. Sahara report Copyright 26th of September, 2016 © 2006–2023 Sahara Reporters, Inc. All rights reserved. Privacy Policy Powered by Drutopia
76. T.H.Trevizani, M.A.V.Petti, A.P.Ribeiro, T.N. Corbisier, R.C.L.Figueira. Heavy metal concentrations in the benthic trophic web of Martel Inlet, Admiralty Bay (King George Island, Antarctica). *Mar. Pollut. Bull.* 2018, 130, 198–205. (2018).
77. G.G. Schwartz, D. Il'yasova, A. Ivanova Urinary cadmium, impaired fasting glucose, and diabetes in the NHANES III Diabetes Care, 26 (2) (2003), pp. 468-470, 10.2337/diacare.26.2.468n (2003).
78. M.Zhao, Y.Xu, C.Zhang, H.Rong, G.Zeng. New trends in removing heavy metals from Wastewater. *Applied Microbiology and Biotechnology*, 100(15), 6509–6518. (2016).
79. X. Zhang, L. Yang, Y. Li, H. Li, W. and Wang, B. Ye. Impacts of lead/zinc mining and smelting on the environment and human health in China *Environ. Monit. Assess.*, 184 (4) (2012), pp. 2261-2273, 10.1007/s10661-011-2115-6. (2012).
80. World Health Organization. National systems to support drinking-water: Sanitation and hygiene: Global status report: UN-Water global analysis and assessment of sanitation and drinking water: GLAAS 2019 report. World Health Organization. (2019).
81. Warri South West (Local Government Area, Nigeria) – Population Statistics, Charts, Map and Location
82. Z.Wang, K.W.Yeung, G.J.Zhou, M.M.Yung, C.E.Schlekat, E.R.Garman, F.Gissi, J.L.Stauber, E.T.Middleton, Y.Y.Wang, K.M.Leung. Acute and chronic toxicity of nickel on freshwater and marine tropical aquatic organisms. *Ecotoxicology and Environmental Safety* 206:111373. (2020).
83. O.A.F.Wokoma, K. U. Njoku. Physical and Chemical Characteristics of the Lower Sombreiro River, Niger Delta, Nigeria October 2017 2017DOI: 10.15192/PSCP.ASR.2017.20.1.1116. (2017).
84. O.J.A. Bayode, E.A. Adewunmi, S. Odunwole. Environmental implications of oil exploration and exploitation in the coastal region of Ondo state, Nigeria: A regional planning appraisal. *J. Geogr. Regional Plann.*, 4: 110-121. (2011).

85. Hallegraff, G.M. 1993. A review of harmful algal blooms and their apparent global increase. *Phycologia* 32:79-99.