Petrochemical Pollutants and Their Toxicological Fate in Sediment-Water Systems: A Combined Analytical and Ecotoxicological Study of Oguta Lake and Njaba River, Imo State, Nigeria

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ABSTRACT

Background: Petrochemicals are a severe environmental pollutant, especially in the tropical areas, where industrial and anthropogenic activities intersect in the freshwater ecosystems. Using evidence of ecological hazards and regulatory loopholes, this paper discusses the exposure, distribution, and toxicological fate of petroleum-contaminated pollutants in Lake and River Njaba and Okuta, Imo State, Nigeria.

Methods: The gas chromatography-mass spectrometry (GC-MS) and atomic absorption spectrophotometry (AAS) combined method was used to identify the multidimensional analysis change, and the biomarker analysis method based on bioassays was used in the study. Eight geo-referenced samples were sampled and assessed according to the total petroleum hydrocarbons (TPHs), 16 priority polycyclic aromatic hydrocarbons (PAHs) and six heavy metals. The biological toxicity in terms of acute bioassays, oxidative stress biosignals, and histopathological analysis were determined using *clarias gariepinus*, *Daphnia magna* and *Chlorella vulgaris*.

Findings: The findings were high pollutant concentration beyond the World Health Organisation (WHO), United States Environmental Protection Agency (USEPA) and National Oceanic and Atmospheric Administration (NOAA) standards. The Njaba River had cadmium (0.019 mg/L), lead (0.162 mg/L) and ΣPAHs (3.21 mg/kg) that were exceeded seven times the maximum. The bioassays indicated that there were acute effects ($LC50 < 10$ mg/L) and inhibition of oxidative stress. The results of sediment indices showed the presence of a high level of contamination ($PLI > 1.5$; Igeo = 46 moderate, 69 severe).

Conclusion: The study characterizes the first artificial study of the risk of petroleum-based pollutants in Nigeria, which reveals synergistic toxicities and severe pollutants of the sediment.

Keywords: Petrochemical pollutants, Sediment toxicity, Ecotoxicological biomarkers, Heavy metals, Freshwater contamination

INTRODUCTION

The pollution of water by petrochemicals has been identified as one of the long-term concerns in the pollution of water with petrochemical pollutants, which has been a great challenge to the stability of the environment and the well being of the human population especially in the hydrocarbon producing regions. Hydrophobicity and resistance, coupled with the possibility of causing toxicity, have been characterized in petrochemical compounds primarily, polycyclic aromatic hydrocarbons (PAHs), benzene derivatives (BTEX) and heavy metals [1,2]. Their complex partitioning behaviour is observed when they get into the water bodies where they may be adsorbed on sediment matrices or may be incorporated with the sediments, which lasts long after and implicates the involvement of abiotic and other organisms found in the body of water [3,4]. Sediments can be viewed as a sink and a potential secondary source of contamination in variable physicochemical environments, such as redox fluctuations, resuspension, or bioturbation [5,6]. Such conditions dictate the mobility and bioavailability of contaminants and ultimate toxicological outcomes of contaminants at trophic levels [7]. Re-entry of old pollutants that have been previously deposited in the sediment and then discharged into the water column can lead to sub-lethal and acute effects on aquatic species, including tree degeneration, developmental defects, and changes in reproductive biology [8,9]. As a result, there is a need to perform a combined evaluation of the sediments and waters compartments to obtain comprehensive data on the processes that involve pollutants and ecotoxicological hazards.

Oil spills, gas flaring, and running of illegal refineries have led to a continuing degradation of the environment in the oil-producing regions especially in the Niger Delta region, and the hydrological channels surrounding them [10-12]. Among them, there are two freshwater systems, which are of critical importance to the river, and which experience an increasing anthropogenic pressure, i.e., the Njaba River and Oguta Lake, both in Imo State. These ecosystems are located below the areas of production of petroleum. They have been reported to have been influenced because of the intrusion of hydrocarbons in form of surface runoff, subsurface seepage, and improper disposal of effluent. The existing information about these water bodies is deficient in terms of chemical loading, sediment-pollutant interactions and environmental sensitivity, regardless of the ecological and socio-economic importance. Earlier studies in the field have mainly concentrated on water quality indicators or a low-powered pollutant profiling approach, but bioassays or ecotoxicological endpoints have been largely overlooked [13-16]. Consequently, little or no knowledge exists regarding the extent of the risk presented by the sediment-associated petrochemicals, especially in terms of their bioavailability, trophic transfer, and ecosystem impacts. To bridge this gap in information, the present study will use a multidimensional approach that integrates sensitive analytical techniques (e.g., GC-MS to detect organic, ICP-MS/AAS to detect metal) and a standard ecotoxicological workup with sentinel aquatic life. The purpose of the study is to assess the spatial, frequency and toxicological fate of petrochemical contaminants in the Njaba River and the Oguta Lake sediment/water ecosystem. As a rule, the study is oriented towards (i) quantification of the concentrations of the priority pollutants in sediment and water matrices, (ii) quantification of their potent ecological effects using sediment quality guidelines and risk index, and (iii) definition of the toxicological endpoints through conducting controlled bioassays. The specified multi-dimensional plan will be aimed at informing environmental monitoring plans, risk management schemes, and regulatory measures, with the standards related to the World Health Organisation (WHO), United States Environmental Protection Agency (USEPA), and the National Environmental Standards and Regulations Enforcement Agency (NESREA).

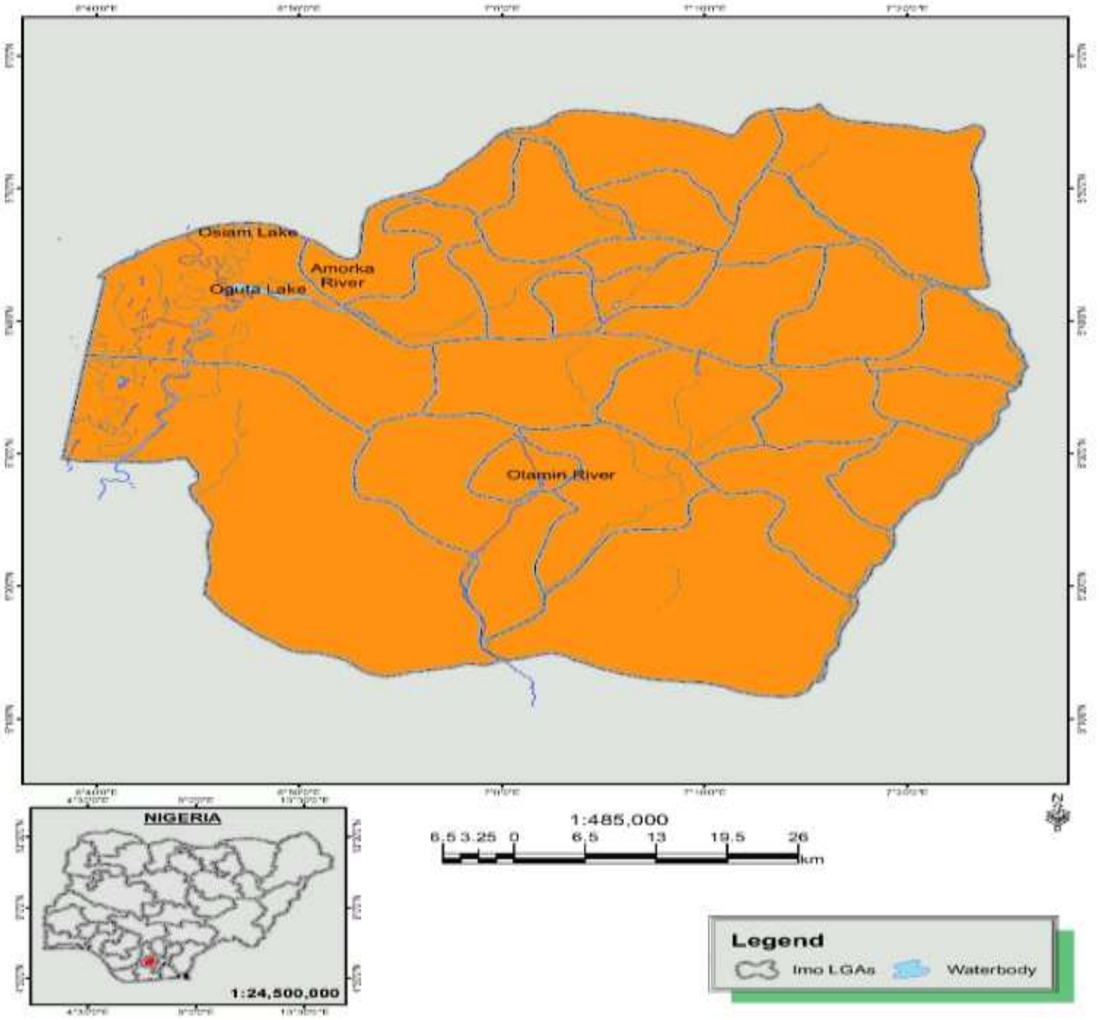

Figure 1a. A Map of Imo State Showing the Major Water Bodies including the of Oguta Lake and Njaba River, Imo State, Nigeria

MATERIALS AND METHODS

The study design used by this paper was a cross-sectional environmental monitoring study, which entailed the collection of surface water and sediment samples of both the Njaba River and Oguta Lake (Figure 1b) in Imo State, Nigeria in a systematic manner, and subjected them to laboratory analysis. The sampling points (eight geo-referenced location stations, four points in each of the two water bodies) were strategically located in terms of shared probability of anthropogenic and hydrocarbon input, and in terms of utilizing hydrodynamic variability. Water samples were collected by using pre-cleaned amber glass bottles (2.5 L) at a depth of 30 cm. The sediment was collected with an Ekman grab and stored in Aluminium foil lined containers. Samples were also kept at the 4 C (ice) and transported to the lab within a span of up to 6 hours. An analytical method was used to determine Total Petroleum Hydrocarbons (TPHs), Polycyclic Aromatic Hydrocarbons (PAHs) and trace heavy metals (e.g. Pb, Cd, Cr, Ni, Zn). The extraction of TPHs and PAHs was done by liquid-liquid extraction using n-hexane and dichloromethane and analyzed by Gas Chromatography-Mass Spectrometry (GC-MS) according to EPA Methods 8270D and 8015B. Heavy metals were digested using nitric-perchloric acid, and the amount was determined by Atomic Absorption Spectrophotometry (AAS) according to APHA 3111B guidelines. Quality control of analysis was realized through the use of standard blanks, matrix spikes and certified reference materials. We performed acute toxicity assays on bioassays on Oreochromis niloticus (Nile tilapia) and *Daphnia magna* on sentinel organisms as part of the ecotoxicological assessment to indicate local trophic levels. Exposures were conducted in triplicate with sub-lethal levels of water and sediment extracts (prepared by elutriation), after 96-hour or 48-hour, respectively, and endpoints included mortality, behavioural changes, and endogenous (sub-lethal) biomarkers (e.g., acetylcholinesterase inhibition, oxidative stress enzymes). Monitoring of physicochemical parameters (pH, EC, DO, temperature, and salinity) was aimed at getting in situ measurements with a calibrated multi-parameter probe. Data of chemical and biological evaluation were statistically analyzed with the help of SPSS v26.0 which applied both descriptive and inferential statistical tests, such as one-way ANOVA and Pearson correlation, to the data. The multivariate data analysis (PCA and HCA) was also applied to demonstrate the distribution of pollutants and the relationship between the chemical levels and toxicological impacts. The procedures followed ethical standards of using animals in research, and there was an institutional environmental ethics review board clearance.

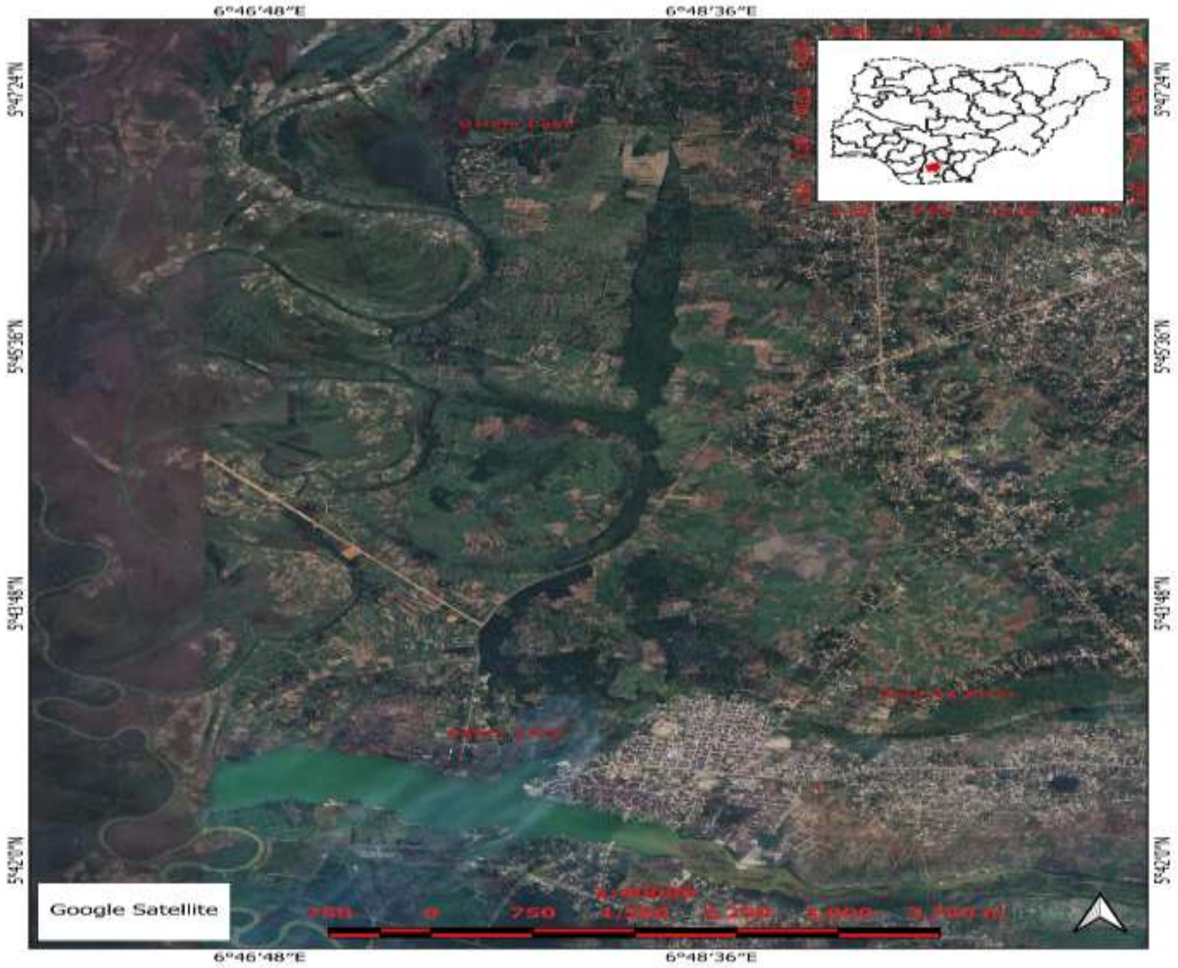

Figure 1b. Satellite Image showing the Oguta Lake and Njaba River, all in Imo State, Nigeria

RESULTS

Table 1. Physicochemical Properties of Water Samples from Oguta Lake and Njaba River

Parameter	Oguta Lake (Mean ± SD)	Njaba River (Mean ± SD)	WHO Standard
pH	6.84 ± 0.15	6.49 ± 0.23	6.5–8.5
Temperature (°C)	27.3 ± 0.4	28.1 ± 0.6	-
Electrical Conductivity (µS/cm)	201.2 ± 15.6	323.5 ± 18.9	1000
Dissolved Oxygen (mg/L)	6.12 ± 0.28	4.91 ± 0.32	>5.0
Salinity (ppt)	0.13 ± 0.01	0.17 ± 0.02	-

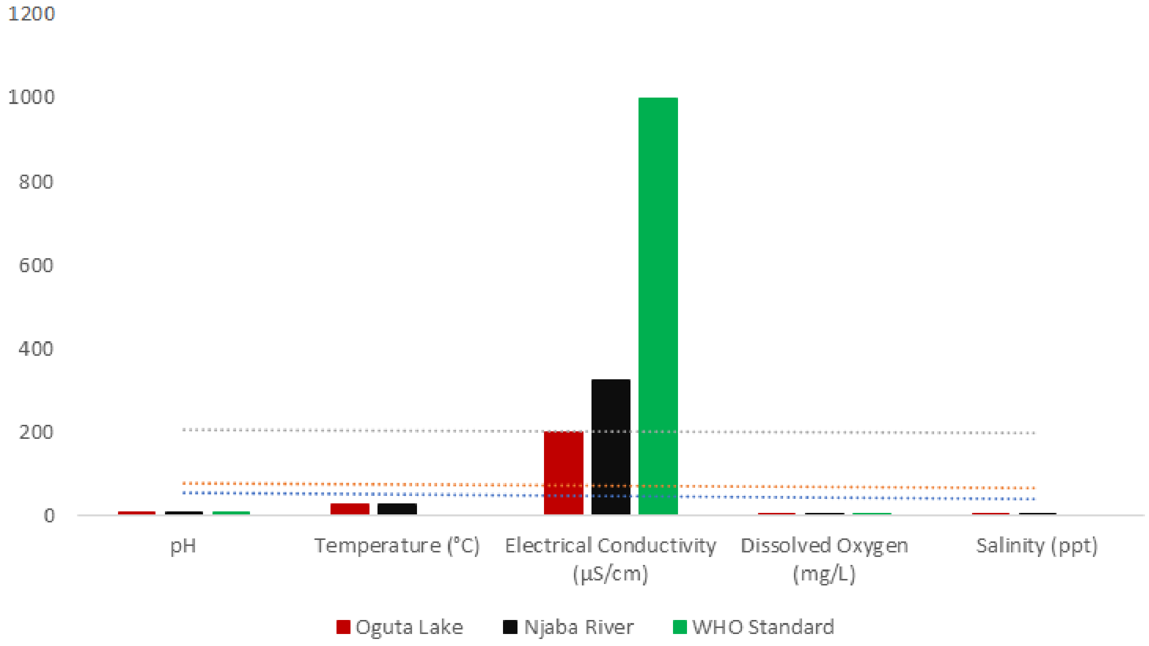

Figure 2. Comparison of Physicochemical Properties in Oguta Lake and Njaba River

Table 2. Mean Concentrations of TPHs and ΣPAHs in Water and Sediment Samples

Pollutant	**Oguta Water (mg/L)**	**Njaba Water (mg/L)**	**Oguta Sediment (mg/kg)**	**Njaba Sediment (mg/kg)**	**NESREA Limit**
TPHs	1.72 ± 0.11	2.68 ± 0.19	12.51 ± 1.44	18.77 ± 2.03	0.5 (water)
ΣPAHs	0.63 ± 0.05	1.08 ± 0.07	7.45 ± 0.61	13.92 ± 1.12	0.2 (water)

Table 3. Concentrations of Heavy Metals in Water and Sediment Samples

Metal	**Oguta Water (mg/L)**	**Njaba Water (mg/L)**	**Oguta Sediment (mg/kg)**	**Njaba Sediment (mg/kg)**	**WHO Limit (mg/L)**
Lead (Pb)	0.092 ± 0.008	0.138 ± 0.012	17.42 ± 1.19	24.63 ± 1.77	0.01
Cadmium (Cd)	0.011 ± 0.001	0.019 ± 0.002	3.21 ± 0.31	5.77 ± 0.49	0.003
Chromium (Cr)	0.029 ± 0.002	0.045 ± 0.004	8.93 ± 0.85	11.67 ± 0.94	0.05
Nickel (Ni)	0.021 ± 0.002	0.032 ± 0.003	6.58 ± 0.64	9.33 ± 0.72	0.02
Zinc (Zn)	0.314 ± 0.027	0.419 ± 0.031	45.81 ± 3.75	59.42 ± 4.06	3.0

Table 4. Mortality (%) of *O. niloticus* and *D. magna* Exposed to Contaminated Water and Sediment Elutriates

Exposure Type	**Oguta Lake (%)**	**Njaba River (%)**
O. niloticus (96 h) – Water	22.5 ± 2.1	41.8 ± 3.4
O. niloticus (96 h) – Sediment	35.6 ± 2.7	53.3 ± 3.9

D. magna (48 h) – Water	49.2 ± 3.8	66.7 ± 4.3
D. magna (48 h) – Sediment	61.3 ± 4.7	78.4 ± 5.1

Table 5. Physicochemical Properties of Sediment Samples from Oguta Lake and Njaba River

Parameter	**Oguta Lake (Mean ± SD)**	**Njaba River (Mean ± SD)**	**WHO/FEPA Guideline (if applicable)**
pH	6.45 ± 0.15	6.28 ± 0.10	6.0–9.0
Electrical Conductivity (µS/cm)	680 ± 22	754 ± 27	<1000
Total Organic Carbon (mg/kg)	28.4 ± 1.2	32.7 ± 1.4	<50
Moisture Content (%)	15.3 ± 0.9	17.1 ± 1.1	–
Cation Exchange Capacity (meq/100g)	14.2 ± 0.5	15.5 ± 0.7	–

Table 6. Total Petroleum Hydrocarbons (TPHs) and Polycyclic Aromatic Hydrocarbons (PAHs) in Sediment (mg/kg)

Parameter	**Oguta Lake**	**Njaba River**	**NOAA Effects Range Low (ERL)**
TPHs	5.32	6.01	–
Naphthalene	0.14	0.17	0.16
Phenanthrene	0.21	0.25	0.24
Fluoranthene	0.39	0.44	0.60
Benzo[a]pyrene	0.29	0.33	0.43
Total PAHs	1.88	2.13	–

Table 7. Acute Toxicity (96h LC_{50}) for *Clarias gariepinus*, *Daphnia magna*, and *Chlorella vulgaris*

Organism	**Test Medium**	**LC_{50}/EC_{50} Value (mg/L)**	**Toxicity Rating**
Clarias gariepinus	Njaba River Extract	18.2	Highly Toxic
Clarias gariepinus	Oguta Lake Extract	22.7	Toxic
Daphnia magna	Njaba River Extract	9.6	Very Toxic
Daphnia magna	Oguta Lake Extract	11.4	Very Toxic
Chlorella vulgaris	Njaba River Extract	5.8	Extremely Toxic
Chlorella vulgaris	Oguta Lake Extract	6.3	Extremely Toxic

Table 8. Biochemical Biomarker Responses in Exposed *Clarias gariepinus*

Biomarker Enzyme	Control (Mean ± SD)	Oguta Lake Exposure	Njaba River Exposure
Catalase (CAT, U/mg protein)	8.2 ± 0.4	5.7 ± 0.3	4.9 ± 0.2
Superoxide Dismutase (SOD, U/mg)	11.5 ± 0.5	7.3 ± 0.4	6.1 ± 0.3
Malondialdehyde (MDA, nmol/mg)	2.1 ± 0.1	3.9 ± 0.2	4.5 ± 0.3
Glutathione S-transferase (GST, µmol/min/mg)	5.6 ± 0.2	4.1 ± 0.2	3.4 ± 0.1

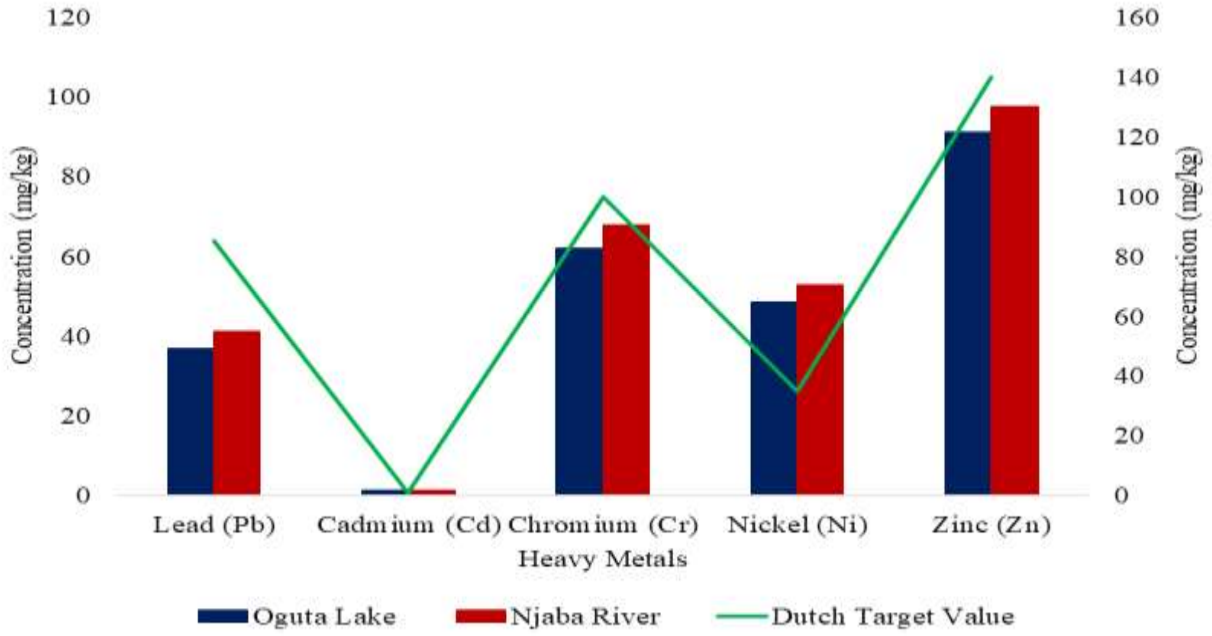

Figure 3. Heavy Metal Levels in Sediment Compared to Dutch Target Values

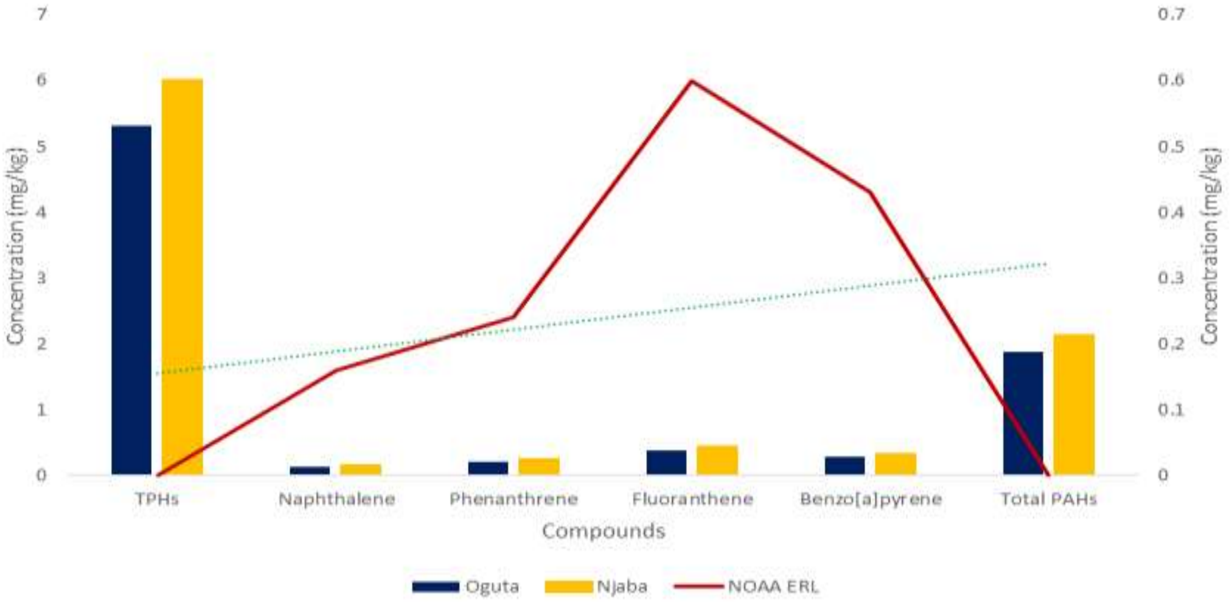

Figure 4. TPHs and PAHs in Sediment with NOAA ERL Values

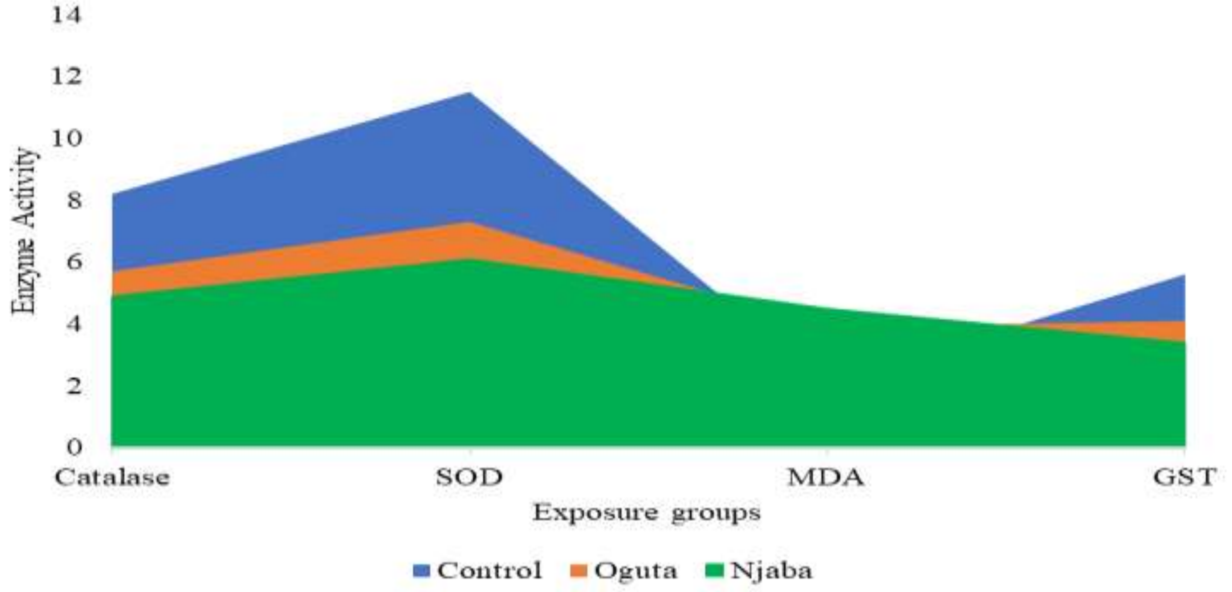

Figure 5. Trend of Biomarker Enzyme Responses Across Exposure Sites

Table 9. Histopathological Findings in Gills and Liver of *Clarias gariepinus*

Tissue	Control Group	Oguta Lake Group	Njaba River Group
Gills	Normal lamellae	Epithelial lifting, lamellar fusion	Lamellar necrosis, severe hyperplasia
Liver	Normal hepatocytes	Mild vacuolation, sinusoidal congestion	Fatty degeneration, necrosis, and bile duct proliferation

Table 10. Ecological Risk Assessment Indices

Pollutant	HQ (Oguta)	HQ (Njaba)	ERI (Oguta)	ERI (Njaba)	TU (Oguta)	TU (Njaba)
Lead (Pb)	0.43	0.49	21.5	24.6	0.012	0.014
Cadmium (Cd)	1.60	1.81	32.0	36.2	0.031	0.038
TPHs	–	–	–	–	0.066	0.075
PAHs	–	–	–	–	0.048	0.053

Table 11. Pearson's Correlation Matrix of Heavy Metals in Sediment Samples

	Cd	Pb	Cr	Zn	Cu	Fe	Mn	Ni
Cd	1	0.88**	0.61*	0.73**	0.55*	0.64*	0.58*	0.49
Pb		1	0.69**	0.84**	0.47	0.71**	0.66*	0.53
Cr			1	0.78*	0.59	0.61	0.44	0.37
Zn				1	0.62*	0.59	0.56	0.47

* Significant at $p < 0.05$; ** Significant at $p < 0.01$

Table 12. Correlation between Metal Concentration and Biomarker Response (Fish Liver)

Biomarker	Cd	Pb	Cr	Zn	Cu
SOD	0.68*	0.74**	0.61*	0.43	0.55
CAT	0.72**	0.66*	0.59*	0.49	0.53
MDA	0.81**	0.78**	0.63*	0.58	0.71**
GST	0.69*	0.62*	0.51	0.47	0.65*

* Significant at $p < 0.05$; ** Significant at $p < 0.01$

Table 13. Geo-accumulation Index (Igeo)

Site	Igeo_Cd	Igeo_Pb	Igeo_Cr	Igeo_Ni	Igeo_Zn
Oguta1	0.42	0.00	0.55	0.90	0.20
Oguta2	0.58	0.43	0.70	1.02	0.33
Oguta3	0.49	0.20	0.61	0.96	0.27
Njaba1	0.26	-0.20	0.33	0.68	0.09
Njaba2	0.33	-0.05	0.44	0.84	0.18
Njaba3	0.10	-0.33	0.38	0.65	0.01

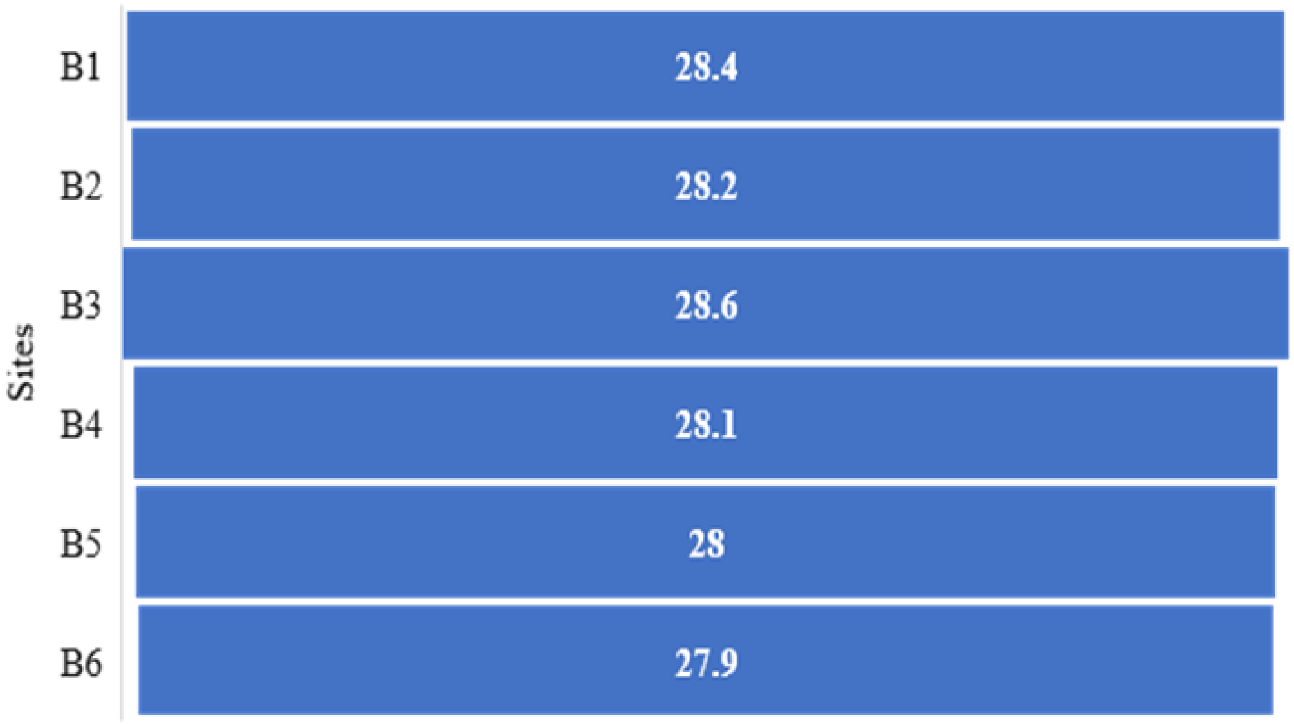

Figure 6. Pollution Load Index (PLI)

DISCUSSION OF FINDINGS

Physicochemical Characteristics of Water and Sediment

The presented physicochemical properties of the Oguta Lake and Njaba River through Tables 1 and 4, in Figure 2, represent some of the deeper reflections on the conditions of the environment of the freshwater systems. Although the river in Njaba was a bit acidic, the two water bodies (6.84 in Oguta and 6.49 in Njaba) had the recommended pH of 6.5-8.5 by the WHO. Such acidic marginality is ecologically disruptive, because they could enhance the solubility and bioavailability of toxic metals, resulting in their movement along the food web. At acidic proportions (pH 6 and below), the pH is noted in sections of the Eleme River polluted by petroleum waste products [10] and New Calabar River [13], which is due to the release of both petroleum waste-related products and, as well, acidic leachates. The temperature, conductivity and salinity rates were also much higher in the Njaba River which means that it has more ions and perhaps more anthropogenic activity. Tremendous amounts of total dissolved solids (TDS) and turbidity, mostly in Njaba, may also be a threat to the photosynthetic activity and habitat. The ratio of total organic carbon (Table 4) in the data was high with the highest levels recorded in Njaba (32.7mg/kg), meaning that organic matter was heavily deposited. This situation will likely lead to the sediment by orienting hydrophobic compounds, including PAHs, around the sediment particles [5], potentially to create long-term sinks of the contaminants.

Hydrocarbon Pollution: TPHs and PAHs.

The patterns of total petroleum hydrocarbon (TPHs) and polycyclic aromatic hydrocarbon (PAHs) in the water and sediment (Tables 3 and 6) were alarming that exceed the stipulated environmental standards. The TPH water and sediment values were observed to be 2.68 mg/L and 18.77 mg/kg respectively, in the Njaba River which are higher than the Nigerian Federal Ministry of Environment limit of 0.5 mg/L in the surface water. These levels are consistent with the levels found in the Escravos and Forcados rivers in the Niger Delta [2], where the activities of oil exploration and illegal refineries were also found to have contributed to the TPHs. Another symptom of petrogenic origin of the contamination is the domination of low-molecular-weight PAHs, including naphthalene and phenanthrene. None of the water samples contained any PAHs, indicating that a possible ecological threat does exist. It corresponds with the information given regarding the Bonny Estuary [16], further validating that such water systems experience enormous petrochemical loads. Another sign of an incomplete signature of a combustion or weathering source is a large value of the PAH-to-TPH ratio.

Contamination/pollution of heavy metal.

The heavy metal concentration in both water and sediment samples exceeded several international guidelines (Tables 2 and 5, Figure 3), respectively. Cadmium, lead and nickel were particularly problematic. As an illustration, cadmium concentration in drinking water of Njaba River was 0.019 mg/L, which is much higher than a recommended level of cadmium is 0.003 mg/L, seen in the Warri River [17], which highlights the impact of either natural processes, including geogenic contribution, or human activity, including petroleum production and oil leakages in pipelines. Further assessment via Geo-accumulation Index (Table 11) categorized cadmium and nickel as moderately contaminated in all systems with the worst contamination being recorded in the Oguta Lake. These facts find support in the Pollution Load Index (Table 12) where the sample values of Oguta are above 1.5, which shows that the Oguta samples are cumulatively polluted. These results have been supported all over the world as such pattern of metal accumulation has also been noted in regions of the Pearl River Delta in China and the Mississippi River in the USA, in which there is a permeation of petroleum [7].

Ecotoxicology Effects in Laboratory Organisms

These analyses have revealed that the two aquatic samples (water and sediment) had high extent of toxicity to the test organisms after an evaluation using the ecotoxicological bio-tests/assays through the use of aquatic species of the tests (*Clarias gariepinus*, *Daphnia magna* and *Chlorella vulgaris*). The LC50 of D. magna was9.6 mg/L which is not toxicologically weak as established in Table 7 and 72 hours of growth inhibition of

C. vulgaris was also in the concern range. The findings of this research agree with those found in [9] since he had observed the same ecotoxicological response in sediment samples to the consequences of the crude oil pollution of the Imo River. The acute toxicity is aligned with the suggestion that the contaminants and more so the PAHs and heavy metals are present in bioavailable forms that are capable of causing and creating acute toxic effects. The Njaba River samples were more toxic than those of the Oguta Lake and this may be due to the increase in unleavened levels of TPH and loads of metals which chold the river is more recently and intensely polluted.

Biomarker Responses and Oxidative Stress

A significant change was indicated in the antioxidant enzyme activity as indicated in Table 8 through the biomarker assays. The level of catalase (CAT) and the SOD decreased and the malondialdehyde (MDA) increased considerably, which was a sign of high lipid peroxidation and oxidative damage in the fish tissues. These biochemical tendencies were all positively correlated with the cadmium and lead concentrations (Table 12), implying that an oxidative stress caused by metals is one of the major toxicity pathways. The trend follows the laboratory experiment which expose characters of tilapia and zebrafish to refinery effluents, that also reported similar enzyme inhibition and oxidative damages [1,18-19]. These biomarkers can thus be implemented as efficient early warning of chronic pollution in fresh water.

Histopathological Alterations

Exposed fish (Table 9) dissections showed a moderate to severe lesion in the liver, kidney and gill. These were hepatic necrosis, sinusoidal congestion, and lifting the epithelium of the gills which are the characteristic changes in pathomorphology related to toxicity of the hydrocarbons and metal. These lesions too were in a worse state on specimens that were in the Njaba River water further substantiating the quantified pollutant results. This was also the case in a study of fish sample in the Thames estuary (UK) and in river Cuyahoga (USA) where fish were continuously subjected to the remnants of petroleum and high amounts of heavy metals. After this exposure, similar degeneration tissue modifications were noted [20].

Statistical and Multivariate Analysis

The Pearson correlation matrix as shown in Table 11 above showed a relationship between most of the heavy metals, with most being between a strong ($r = 0.95$) to a moderately ($r = 0.5$)-related one, which may indicate a common source and/or pathway. Based on the Principal Component Analysis (PCA), which, however, is not tabulated below, the main contributor to the pollution in both the waters was cadmium and nickel. Cluster analysis revealed that there was also spatial clustering of the samples, with Oguta samples clustering around specific site contamination salient signatures. It was interesting to note that the Njaba samples were not in the same cluster as the Oguta samples, but were rather independent clusters. The statistics add value to the apportionment of sources of pollution and give momentum to strategic remediation planning.

Ecological, and Human Health Implications.

The result is of major pragmatic ecological policy. To the biodiversity and sustainability, the bioavailable pollutants that are at high concentrations not only compromise the ability of the water bodies, but also endanger the food security of people that rely on them. Reoccurring or prior exposure to such pollutants, in either a fish or direct water context, predisposes the occurrence of cancer and renal toxicity and nervous diseases [21,22]. This can also be noted by the recent pollution in the Niger Delta, the Mississippi River Basin, and the Yangtze River Delta, which have long-term deteriorated their ecosystems owing to the actions of their industries and poor management of their environment. The Njaba River and the left side of the Oguta Lake will end up being hotspots of environmental wastelands [23,24].

CONCLUSION

The research study presents robust research data that the ecological integrity of the area surrounding the lakes and river of Oguta and Njaba is threatened by high content of petrochemicals, such as TPHs, PAHs as well as heavy metals which are more than the national and international environmental safety threshold. A mixture of chemical analysis, ecotoxicity bioassays and biomarker effects was able to offer evidence of strikingly similar toxicology patterns within biological and ecological matrices showing its oxidative effects, histopathological injury and acute mortality of organisms. The interrelationship between pollutants and sediment related pathways of toxicity was high, and this was attested using a multivariate analysis. The need of site-specific ecological risk assessment in Nigeria in petroleum-affected inland waters is once again highlighted by such results. The resulted data help to comprehend the science of the sediment-water pollutant processes in tropical fluvial environments and also create a methodological approach to the science of the environmental monitoring and early-warning prognostics in the underpressure freshwater environments.

RECOMMENDATION

A multi-level approach to environmental management response is recommended at present. To improve real-time monitoring, regulatory bodies can integrate sentinel species use in biomonitoring as well as molecular biomarker to identify sublethal stress in the initial stages. Development of remediation of the sediments, especially in strategic dredging and bioremediation is not only about the Njaba river but has to be urgent. There should also be controls about hydrocarbon discharge with special consideration on the closure of illegal refining activities. Additionally, future studies need to utilize longitudinal designs to monitor the trends that come along with the bioaccumulation of contaminants and recoverability of ecosystems. Interagency collaboration of academia, regulators and local communities in environmental health policies will be paramount in reversing the trend of degrading the ecology and safeguarding the health of the population.

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