

Determination of the Levels of Heavy Metals in Surface Water, Tilapia Fish (*Oreochromis Niloticus*) and Soil Within the Vicinity of Oil Production Facilities During Wet and Dry Season in Omoku, Rivers State

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Abstract

*This study determined the levels of heavy metals in surface water, tilapia fish (*Oreochromis niloticus*) and soil within the vicinity of oil production facilities during wet and dry seasons in Omoku, Rivers State, Nigeria. Samples of surface water, *Oreochromis niloticus* and soil were collected from Obrikom River (Onosi Ognu), Onosi Okpasimini and a control location during the wet and dry seasons. The samples were properly preserved, prepared and digested using standard analytical procedures, while the concentrations of lead (Pb), copper (Cu), chromium (Cr), cadmium (Cd), nickel (Ni) and iron (Fe) were determined using atomic absorption spectrophotometry. The data obtained were subjected to appropriate descriptive and pollution assessment indices, including bioaccumulation factor (BAF), contamination factor (CF) and pollution load index (PLI). The results showed that heavy metals occurred in all the investigated matrices, with generally higher concentrations during the dry season. In surface water, Pb concentrations ranged from 1.10 ± 0.00 – 2.49 ± 0.01 mg/L during the wet season and 1.24 ± 0.01 – 2.86 ± 0.01 mg/L during the dry season, while Fe ranged from 45.19 ± 0.23 – 72.58 ± 0.00 mg/L and 48.76 ± 0.21 – 79.64 ± 0.12 mg/L, respectively. In *O. niloticus*, Pb ranged from 1.18 ± 0.03 – 3.62 ± 0.08 mg/kg in the wet season and 1.39 ± 0.04 – 4.26 ± 0.11 mg/kg in the dry season, while Cd ranged from 0.08 ± 0.01 – 0.61 ± 0.03 mg/kg and 0.10 ± 0.01 – 0.76 ± 0.04 mg/kg, respectively. Soil Fe concentrations ranged from 421.58 ± 6.73 – 758.62 ± 9.17 mg/kg during the wet season and 458.72 ± 7.18 – 826.47 ± 10.26 mg/kg during the dry season. The BAF was highest for Cd, while PLI values indicated greater contamination at the oil-production-influenced locations, particularly during the dry season. The findings indicate heavy-metal contamination in the study area, with evidence of seasonal variation and accumulation of selected metals in *Oreochromis niloticus*. The study provides baseline information for environmental monitoring, pollution control and the protection of aquatic and terrestrial resources in Omoku, Rivers State.*

Keywords: *Heavy metals, surface water, soil, Oreochromis niloticus, atomic absorption spectrophotometry, bioaccumulation, pollution load index, seasonal variation, Omoku.*

Introduction

Environmental pollution remains a major global concern because of its adverse effects on ecological systems, human health and the sustainability of natural resources. Among the numerous environmental contaminants, heavy metals are of particular importance because of their persistence, toxicity, environmental mobility and ability to accumulate in living organisms. Heavy metals occur naturally in rocks, soils, sediments and water through geological processes such as weathering and erosion; however, anthropogenic activities can substantially increase their concentrations in environmental compartments. Petroleum exploration and production, industrial activities, agricultural practices, mining, waste disposal, combustion of fossil fuels and urbanization are among the major activities capable of increasing the environmental burden of heavy metals (Umeoguaju et al., 2023; Ogbogu & Nwoke, 2024).

Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), mercury (Hg), cobalt (Co) and arsenic (As) are frequently investigated in environmental pollution studies because of their potential ecological and toxicological significance. Some metals, including Fe, Zn, Cu and Mn, are essential micronutrients required for normal physiological and biochemical functions, but their presence at elevated concentrations may become toxic. Conversely, metals such as Pb, Cd and Hg are not required for normal biological functions and may cause adverse effects even at relatively low levels of exposure (Umeoguaju et al., 2023). Consequently, determining the concentration and distribution of metals in environmental media is essential for assessing ecological quality and potential health risks.

The environmental behaviour of heavy metals differs from that of many organic pollutants. Metals cannot be biologically degraded because they are elemental substances, although they may undergo changes in chemical form, oxidation state, partitioning and bioavailability. Once released into the environment, metals can remain for long periods and may be redistributed between water, soil, sediment and biological organisms. Their mobility and bioavailability are influenced by environmental characteristics such as pH, temperature, redox conditions, organic matter, clay content, ionic strength and the presence of competing ions. Therefore, heavy metals introduced into an aquatic or terrestrial environment may become deposited in soils and sediments, remain dissolved in water, or become incorporated into biological tissues (Umeoguaju et al., 2023).

Surface water is an important environmental compartment in the investigation of heavy-metal pollution because rivers, streams and creeks can receive contaminants originating from both natural and anthropogenic sources. Heavy metals may enter surface-water systems through industrial effluents, petroleum-related activities, agricultural runoff, atmospheric deposition, erosion, domestic wastewater and improper waste disposal. Once introduced into water, metals may exist in dissolved forms or become attached to suspended particles. They may subsequently be transported downstream, deposited in sediments or taken up by aquatic organisms. Consequently, the concentration of a metal in surface water at a particular sampling point represents only one component of the overall environmental contamination status.

The Niger Delta region of Nigeria is particularly important in relation to environmental contamination because it contains extensive freshwater ecosystems alongside intensive petroleum exploration and production activities. The region contains numerous rivers, creeks, wetlands, floodplains and other aquatic ecosystems that support fishing, agriculture, transportation and domestic activities. However, the proximity of these ecosystems to petroleum infrastructure and

other anthropogenic activities creates opportunities for the introduction of contaminants into environmental media. According to Umeoguaju et al. (2023), heavy-metal contamination of seafood is a significant environmental-health concern in the crude-oil-impacted Niger Delta. Their systematic review and meta-analysis evaluated 58 studies involving 2,983 seafood samples and reported measurable concentrations of As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn in seafood from the region. The presence of heavy metals in aquatic environments is of particular concern because aquatic organisms can accumulate these contaminants from their surroundings. Fish may absorb metals directly from water through their gills and skin or indirectly through ingestion of contaminated food, suspended particles and sediments. The extent of accumulation depends on several factors, including metal concentration, exposure duration, water chemistry, fish species, age, size, feeding behaviour and physiological condition. Metals may also accumulate preferentially in particular tissues such as the liver, kidney, gills and muscle. Therefore, fish tissue analysis can provide valuable information about the biological availability of contaminants in an aquatic ecosystem. The Nile tilapia, *Oreochromis niloticus*, is an important freshwater fish species that is widely consumed and cultivated in tropical and subtropical regions. It is of considerable nutritional and economic importance and is also relevant to environmental contamination studies because fish can accumulate contaminants from their surrounding environment and diet. Studies involving *O. niloticus* and other fish species have demonstrated the usefulness of fish as bioindicators of aquatic pollution. The accumulation of metals in fish tissues is particularly important where the organisms are consumed by local populations because contaminated fish may represent a direct pathway of human exposure to environmental contaminants.

The food-safety implications of heavy-metal accumulation in fish are especially important in the Niger Delta, where seafood constitutes an important source of dietary protein and income for many communities. Umeoguaju et al. (2023) reported that seafood from the Niger Delta contained measurable levels of several metals and concluded that exposure to Cd, Pb and Co could present non-carcinogenic risks, while As and Cr could contribute to carcinogenic risks under certain exposure conditions. These findings demonstrate that heavy-metal contamination of aquatic ecosystems in the Niger Delta should be considered not only as an ecological issue but also as a potential public-health and food-safety concern. Soil represents another important environmental compartment in the assessment of heavy-metal pollution. It can function as a sink for contaminants introduced through atmospheric deposition, industrial emissions, oil spills, waste disposal, agricultural chemicals and other anthropogenic activities. Once metals enter soil, they may become associated with clay minerals, iron and manganese oxides, organic matter and other soil components. Depending on soil characteristics, metals may either remain relatively immobile or become mobilized and transported into surface water and groundwater. Thus, contaminated soil may serve as a long-term reservoir from which metals can enter other components of the environment. The relationship between soil and surface water is particularly important in the Niger Delta because of the region's high rainfall, extensive drainage systems and susceptibility to flooding. During rainfall events, contaminated soil particles can be eroded and transported into nearby water bodies. Heavy metals associated with these particles may subsequently become incorporated into sediments or remain suspended in the water column. Similarly, flooding can redistribute contaminated sediments and soil over large areas. This interaction means that contamination of terrestrial and aquatic environments should not necessarily be considered as separate processes. Heavy metals can move through environmental compartments and ultimately enter food chains. Soil-associated metals can be transported into water through runoff and erosion, while metals present in surface water can be absorbed by aquatic organisms. Fish can subsequently

transfer these contaminants to humans through consumption. This pathway can be conceptualized as **contaminated soil** → **runoff/surface water** → **aquatic organisms** → **human consumers**. In aquatic ecosystems, an additional pathway may involve the movement of metals from water to suspended particles and sediments and subsequently to fish through feeding. Assessment of only one environmental medium may therefore underestimate the overall extent of contamination.

The concentration of heavy metals in surface water may also vary according to season. During the rainy season, increased runoff can mobilize contaminants from surrounding soils and transport them into rivers and streams. At the same time, increased water volume can dilute dissolved contaminants. During the dry season, reduced water volume and limited dilution may result in relatively higher concentrations of some pollutants. Consequently, seasonal monitoring can provide a better understanding of the dynamics of heavy metals in aquatic systems. The interpretation of results should therefore take into account hydrological and environmental conditions at the time of sampling. Heavy-metal contamination is also important because different metals produce different biological and toxicological effects. Lead is a persistent environmental contaminant that can adversely affect the nervous system, blood-forming system, kidneys and other organs. Children are particularly vulnerable to the neurological effects of lead exposure. Cadmium is associated with kidney damage, skeletal effects and other chronic health outcomes following prolonged exposure. Mercury is of particular concern in aquatic ecosystems because methylmercury can accumulate in fish and become biomagnified through aquatic food webs. Arsenic exposure is associated with a range of adverse health outcomes, including skin lesions and cancers following prolonged exposure. Chromium toxicity depends substantially on its chemical form, with hexavalent chromium being of particular toxicological concern.

Essential metals can also become harmful when present at excessive concentrations. Iron is required for oxygen transport and several metabolic processes, while zinc and copper are essential for enzymatic and physiological functions. However, excessive intake or accumulation may cause adverse effects. Therefore, environmental monitoring should distinguish between the nutritional importance of certain metals and their potential toxicity at elevated concentrations. The presence of a metal in an environmental sample should not automatically be interpreted as contamination; rather, its concentration must be evaluated against appropriate environmental or food-safety standards. The potential for fish to accumulate heavy metals makes *O. niloticus* an appropriate organism for environmental monitoring. Fish are continuously exposed to their aquatic environment and can integrate contaminant exposure over time. Consequently, concentrations measured in fish tissue may provide evidence of the bioavailability of metals that may not be adequately represented by instantaneous measurements of dissolved metals in water. The use of fish alongside water and soil analyses can therefore provide a more comprehensive assessment of contaminant distribution. Despite the evidence of heavy-metal occurrence in Omoku soils, information linking heavy-metal concentrations in **surface water, soil and edible fish within the same study environment** remains important. Such information is necessary because the presence of metals in soil does not necessarily indicate the same concentration or bioavailability in surface water or fish. Similarly, the absence of elevated concentrations in surface water at a particular time does not necessarily eliminate the possibility of historical accumulation in soil or biological tissues. Integrated sampling is therefore necessary to determine the distribution and environmental significance of heavy metals. The determination of heavy metals in *O. niloticus* is also important because fish represent an interface between environmental contamination and human consumption. Where fish are harvested from local water bodies and consumed by members of the surrounding communities, contamination may have direct implications for food safety. Monitoring fish tissue

can therefore provide information about the extent to which environmental contaminants are entering the aquatic food chain. The results can also serve as baseline information for future environmental monitoring and health-risk assessments.

The present study is therefore designed to determine the levels of selected heavy metals in surface water, *Oreochromis niloticus* and soil in Omoku, Rivers State. By examining these three environmental compartments simultaneously, the study seeks to provide a more comprehensive understanding of the occurrence and distribution of heavy metals in the study environment. The findings will provide useful scientific information for assessing environmental quality, establishing baseline contamination levels, supporting pollution-control measures and contributing to the protection of aquatic ecosystems and human health.

Study Area

The study was conducted in Omoku, located in Ogba/Egbema/Ndoni Local Government Area (ONELGA) of Rivers State, Nigeria. The control point is Choba. Omoku is a prominent oil-producing community in the Niger Delta region and hosts several crude oil production facilities, including flow stations, oil wells, pipelines, and associated infrastructure operated by oil companies within OML 18 and surrounding leases. Geographically, Omoku lies within the tropical rainforest zone characterized by high rainfall, humid conditions, and rich biodiversity. The vegetation is predominantly lowland rainforest, although large portions have been modified due to human activities, particularly oil exploration and agricultural practices.

The area is drained by tributaries of the Orashi River system, which serves as a major water source for domestic, agricultural, and fishing activities. The hydrological network makes the area highly vulnerable to petroleum contamination, particularly from oil spills and produced water discharge. Economically, the inhabitants of Omoku are largely dependent on agriculture, fishing, and small-scale trading. These livelihoods are directly influenced by environmental quality, making the area highly sensitive to ecological disturbances caused by crude oil production activities (UNEP, 2011).

Methodology

Sample and Sampling Technique

A multistage sampling technique was adopted in this study. This involves purposive selection of communities in Omoku that are located near crude oil production facilities. These areas are selected based on their proximity to flow stations, pipelines, and gas flaring sites.

Water sample collection

Water samples were collected at 2 different points from Omoku River, within the vicinity of oil production facilities in Omoku, Rivers State during wet and dry season. The sampling period lasted for 6 months. Water samples were collected from a shallow point (approximately 2 m into the river) into clean sterilized 2.0 L amber glass bottle with Teflon lined top to prevent photochemical degradation. The samples were collected on seasonal basis once every month for a period of three months in the dry season (December-February) and three months in the wet season (March-May). The samples were carefully collected directly by hand (with gloves) into sampling bottles by pressing them under the water surface. The sampling bottles were twice partially filled, shaken well and emptied before the actual filling was done. 1 M HCL was added to the samples to prevent bacterial degradation. The bottles were put in ice-box and transported to the laboratory where they were kept in a fridge at 4°C prior to extraction.

Biota Sample Collection

Tilapia fish (*Oreochromis niloticus*) samples were collected via using a cast net at a point in the rivers. All the samples were kept in a cooler containing ice packs before transporting them to the laboratory and stored at -20°C until analysis.

Soil sample collection

Using a soil auger, soil samples were taken from the several sampling locations at a depth of 0 to 30 cm. The samples were then promptly transfer to the laboratory for analysis in labelled polythene bags.

Analysis of water samples

4ml of concentrated HCl (10M) was added to 250ml of each water sample placed in 600ml beaker, and evaporated to 25ml. The concentrate was then transferred to a 50ml volumetric flask and diluted to mark with deionised water. Prior to this process and further analysis, the solutions were filtered through Whatman number 42 filter paper in accordance with Owthoek et al., (2023).

Digestion of soil

The soil samples were air dried for 48 hours. The soil was ground and sieved with a mesh. The soil grains were digested as described by Jaijel et al. (2021). 2.0g soil sample was digested with a solution of 5.3 ml of conc. HNO₃ and 6.0mL of HCl to near dryness and allowed to cool, after which 20mL of 5M HNO₃ solution was added. The solutions were allowed to stay overnight and were filtered. The filtrates were transferred into a 100-ml volumetric flask and made up to the mark.

Digestion of tilapia fish samples

The method used to digest the fish in this study was based on a method from Muhammad et al. (2022). The present study would follow the wet digestion process with different concentrations and volumes of acids. A digestion plate was used for heating. Before analysis, the fish was thawed and dissected. The muscular tissues on the dorsal surface of each fish were taken out and homogenized and about 4 grams of the surface of the homogenized muscles (without skin) of each specimen were taken and placed in a 300-ml digestion tube. A digestion mixture containing 6.0 ml of high-purity HNO₃, 2 ml of HCL (10M) and 4 ml of H₂O₂ (35%) was then added to each tube. The samples were heated at 1300 °C by a heating digester with an air condenser until a clear solution was obtained. After cooling, the samples were filtered through Whatman filter paper, and the digested portion was diluted to a final volume of 50 mL using deionized water.

Determination of heavy metal concentrations in samples

The treated samples that were analyzed for heavy metal concentrations were water, soil and tilapia samples.

Analyzed heavy metals: The extractable heavy metals analysed were lead, copper, chromium, cadmium, nickel and chromium.

Instruments used for analysis: the determination of the heavy metal contents of each sample solution were analysed for the heavy metals, using Atomic Absorption Spectrophotometer, Shimadzu AA-6300 model.

Bioaccumulation Factor (BAF), Contamination Factor (CF) and Pollution Load Index (PLI)

Bioaccumulation Factor (BAF)

The bioaccumulation factor was used to determine the extent to which heavy metals present in the surface water accumulated in the tissues of *Oreochromis niloticus*. The BAF was calculated by dividing the concentration of each heavy metal in the fish tissue by its corresponding concentration in the surface water:

$$BAF = C_f / C_{fw}$$

Where C_f is the concentration of the heavy metal in fish tissue (mg/kg) and C_w is the concentration of the corresponding heavy metal in surface water (mg/L). A BAF value greater than 1 indicates that the metal concentration in the fish was higher than that in the surrounding water, suggesting accumulation of the metal in fish tissue.

Contamination Factor (CF)

The contamination factor was used to assess the degree of contamination of water and soil by individual heavy metals. It was calculated as the ratio of the measured concentration of a heavy metal to its corresponding reference or permissible concentration:

$$CF = C_i / C_{ref}$$

Where C_i is the measured concentration of the heavy metal and C_{ref} is the applicable reference or permissible concentration. A CF value less than 1 indicates low contamination relative to the reference value, whereas a value greater than 1 indicates enrichment or contamination above the reference level.

Pollution Load Index (PLI)

The Pollution Load Index was used to determine the overall level of heavy-metal pollution resulting from the combined effects of the metals investigated. The PLI was calculated as the geometric mean of the contamination factors:

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n)^{1/n}$$

Where (CF_1 , CF_2 to CF_n) are the contamination factors for the individual heavy metals and (n) is the number of metals assessed. A PLI value < 1 indicates no overall pollution, while a PLI value > 1 indicates an overall pollution load relative to the selected reference concentrations.

The BAF, CF and PLI values were calculated separately for the wet and dry seasons and for Obrikom River (Onosi Ognu), Onosi Okpasimini and Control station to evaluate spatial and seasonal variations in heavy-metal accumulation and pollution.

Results

Table 1: Heavy metal concentrations in water during wet season

Heavy metals (mg/L)	Obrikom River (Onosi Ognu)	Onosi Okpasimini	Control	DPR LIMIT
Pb	1.70±0.00	2.49±0.010	1.10±0.00	0.15
Cu	5.86±0.00	7.15±0.00	2.73±0.06	36
Cr	5.17±0.04	6.52±0.00	2.17±0.00	1.6
Cd	0.05±0.00	0.17±0.00	0.002±0.00	0.10
Ni	4.32±0.00	3.03±0.00	1.723±0.05	2.7
Fe	72.58±0.00	66.03±0.13	45.19±0.23	50

Table 2: Heavy metal concentrations in water during dry season

Heavy (mg/L)	Metals Obrikom (Onosi Ognu)	River (Onosi Okpasimini)	Control	DPR Limit
Pb	2.18 ± 0.02	2.86 ± 0.01	1.24 ± 0.01	0.15
Cu	6.73 ± 0.05	8.24 ± 0.03	3.18 ± 0.04	36
Cr	6.14 ± 0.03	7.31 ± 0.02	2.64 ± 0.01	1.6
Cd	0.08 ± 0.00	0.21 ± 0.01	0.003 ± 0.00	0.10
Ni	4.86 ± 0.02	3.57 ± 0.01	1.94 ± 0.04	2.7
Fe	79.64 ± 0.12	73.58 ± 0.15	48.76 ± 0.21	50

Table 3: Heavy metal concentration in Tilapia fish (*Oreochromis niloticus*) during Wet Season

Heavy (mg/kg)	Metals Obrikom (Onosi Ognu)	River Onosi Okpasimini	Control	DPR Limit
Pb	2.84 ± 0.06	3.62 ± 0.08	1.18 ± 0.03	0.30
Cu	4.76 ± 0.11	5.83 ± 0.14	2.21 ± 0.05	30.00
Cr	3.94 ± 0.09	4.87 ± 0.12	1.73 ± 0.04	1.00
Cd	0.46 ± 0.02	0.61 ± 0.03	0.08 ± 0.01	0.20
Ni	2.73 ± 0.07	3.18 ± 0.09	1.24 ± 0.04	1.00
Fe	48.63 ± 0.82	56.74 ± 0.96	32.18 ± 0.61	100.00

Table 4: Heavy metal concentrations in Tilapia fish (*Oreochromis niloticus*) during dry Season

Heavy (mg/kg)	Metals Obrikom (Onosi Ognu)	River Onosi Okpasimini	Control	DPR Limit
Pb	3.41 ± 0.08	4.26 ± 0.11	1.39 ± 0.04	0.30
Cu	5.38 ± 0.13	6.72 ± 0.16	2.54 ± 0.06	30.00
Cr	4.71 ± 0.11	5.68 ± 0.14	2.08 ± 0.05	1.00
Cd	0.57 ± 0.03	0.76 ± 0.04	0.10 ± 0.01	0.20
Ni	3.16 ± 0.08	3.79 ± 0.10	1.47 ± 0.04	1.00
Fe	54.72 ± 0.91	64.83 ± 1.04	35.46 ± 0.68	100.00

Table 5: Heavy metal concentrations in soil during wet Season

Heavy (mg/kg)	Metals Obrikom (Onosi Ognu)	River (Onosi Okpasimini)	Control	DPR Limit
Pb	18.42 ± 0.31	24.67 ± 0.42	8.36 ± 0.18	85
Cu	21.36 ± 0.27	28.54 ± 0.35	12.18 ± 0.21	36
Cr	31.74 ± 0.46	38.62 ± 0.51	16.43 ± 0.29	100
Cd	0.72 ± 0.04	1.08 ± 0.06	0.21 ± 0.02	0.80

Heavy Metals (mg/kg)	Obrikom River (Onosi Ognu)	Onosi Okpasimini	Control	DPR Limit
Ni	17.63 ± 0.32	22.48 ± 0.39	9.72 ± 0.17	35
Fe	684.35 ± 8.42	758.62 ± 9.17	421.58 ± 6.73	1000

Table 6: Heavy metal concentrations in soil during dry Season

Heavy Metals (mg/kg)	Obrikom River (Onosi Ognu)	Onosi Okpasimini	Control	DPR Limit
Pb	22.76 ± 0.38	29.83 ± 0.47	9.64 ± 0.21	85
Cu	25.84 ± 0.32	33.76 ± 0.41	13.47 ± 0.24	36
Cr	36.82 ± 0.51	44.73 ± 0.58	18.76 ± 0.33	100
Cd	0.86 ± 0.05	1.27 ± 0.07	0.25 ± 0.02	0.80
Ni	20.48 ± 0.36	26.73 ± 0.43	10.84 ± 0.19	35
Fe	742.63 ± 9.14	826.47 ± 10.26	458.72 ± 7.18	1000

Table 7: Bioaccumulation Factor (BAF) of Heavy Metals in *Oreochromis niloticus* During Wet Season

Heavy Metals	Obrikom River (Onosi Ognu)	Onosi Okpasimini	Control
Pb	1.67	1.45	1.07
Cu	0.81	0.82	0.81
Cr	0.76	0.75	0.80
Cd	9.20	3.59	40.00
Ni	0.63	1.05	0.72
Fe	0.67	0.86	0.71

Table 8: Bioaccumulation Factor (BAF) of Heavy Metals in *Oreochromis niloticus* During Dry Season

Heavy Metals	Obrikom River (Onosi Ognu)	Onosi Okpasimini	Control
Pb	1.56	1.49	1.12
Cu	0.80	0.82	0.80
Cr	0.77	0.78	0.79
Cd	7.13	3.62	33.33
Ni	0.65	1.06	0.76
Fe	0.69	0.88	0.73

Table 9: Contamination Factor (CF) and Pollution Load Index (PLI) of Heavy Metals in Water During Wet Season

Heavy Metals Obrikom River (Onosi Ognu) Onosi Okpasimini Control			
Pb	11.33	16.60	7.33
Cu	0.16	0.20	0.08
Cr	3.23	4.08	1.36
Cd	0.50	1.70	0.02
Ni	1.60	1.12	0.64
Fe	1.45	1.32	0.90
PLI	1.38	1.80	0.45

Table 10: Contamination Factor (CF) and Pollution Load Index (PLI) of Heavy Metals in Water During Dry Season

Heavy Metals Obrikom River (Onosi Ognu) Onosi Okpasimini Control			
Pb	14.53	19.07	8.27
Cu	0.19	0.23	0.09
Cr	3.84	4.57	1.65
Cd	0.80	2.10	0.03
Ni	1.80	1.32	0.72
Fe	1.59	1.47	0.98
PLI	1.70	2.08	0.54

Table 11: Contamination Factor (CF) and Pollution Load Index (PLI) of Heavy Metals in Soil During Wet Season

Heavy Metals Obrikom River (Onosi Ognu) Onosi Okpasimini Control			
Pb	0.22	0.29	0.10
Cu	0.59	0.79	0.34
Cr	0.32	0.39	0.16
Cd	0.90	1.35	0.26
Ni	0.50	0.64	0.28
Fe	0.68	0.76	0.42
PLI	9.88	12.75	4.81

Table 12: Contamination Factor (CF) and Pollution Load Index (PLI) of Heavy Metals in Soil During Dry Season

Heavy Metals Obrikom River (Onosi Ognu) Onosi Okpasimini Control			
Pb	0.27	0.35	0.11
Cu	0.72	0.94	0.37
Cr	0.37	0.45	0.19

Heavy Metals Obrikom River (Onosi Ognu) Onosi Okpasimini Control			
Cd	1.08	1.59	0.31
Ni	0.59	0.76	0.31
Fe	0.74	0.83	0.46
PLI	11.59	14.88	5.44

Heavy Metal Concentrations in Water, Tilapia Fish and Soil

The results presented demonstrate clear spatial and seasonal variations in the concentrations of heavy metals in surface water, *Oreochromis niloticus* and soil within the study area. The metals investigated were lead (Pb), copper (Cu), chromium (Cr), cadmium (Cd), nickel (Ni) and iron (Fe). In general, the concentrations recorded at Onosi Okpasimini were higher than those observed at Obrikom River (Onosi Ognu), whereas the Control station generally recorded the lowest concentrations. This spatial pattern suggests that the two impacted locations are exposed to greater inputs or accumulation of metal contaminants than the Control location. The finding is environmentally important because recent investigations in Nigerian aquatic ecosystems have similarly demonstrated substantial spatial heterogeneity in heavy-metal concentrations among sampling stations, with locations influenced by anthropogenic activities generally recording greater contamination than reference locations (Ujah et al., 2025).

Heavy Metals in Surface Water During Wet Season

Table 4.9 shows that Pb concentrations during the wet season ranged from 1.10 ± 0.00 mg/L at the Control station to 2.49 ± 0.010 mg/L at Onosi Okpasimini, while Obrikom River recorded 1.70 ± 0.00 mg/L. All three stations therefore exceeded the stated DPR limit of 0.15 mg/L. Onosi Okpasimini recorded approximately 16.6 times the stated limit, while Obrikom River and the Control station recorded approximately 11.3 and 7.3 times the limit, respectively. The particularly elevated Pb concentration at Onosi Okpasimini indicates that Pb represents one of the major contaminants of concern in the surface water. The elevated concentration may be associated with anthropogenic inputs such as petroleum-related activities, vehicular emissions, industrial discharges, waste disposal, corrosion of metallic materials and runoff from contaminated areas. Lead is persistent in aquatic systems and may be transported in dissolved form or associated with suspended particles before eventually becoming incorporated into bottom deposits.

The present Pb concentrations are notably high when compared with a recent investigation of Biu Reservoir, Nigeria, where Wakil et al. (2025) reported Pb concentration of 0.016 mg/L in reservoir water and identified the elevated Pb concentration as a potential environmental and health concern. The Pb concentrations in the present study are therefore considerably higher than those reported for Biu Reservoir, suggesting a comparatively stronger Pb burden in the studied water bodies. Similarly, Boma and Nwoke (2026), in a recent investigation of the Bonny River in Rivers State, reported a mean Pb concentration of 3.23 ± 1.11 mg/L in surface water and classified Pb as exhibiting a very high degree of contamination based on contamination-factor assessment. The Pb concentrations observed in the present study, particularly at Onosi Okpasimini, are therefore within the same broad order of magnitude as those recently reported from another Niger Delta aquatic system. This similarity strengthens the interpretation that Pb contamination remains an important environmental issue in petroleum-influenced aquatic ecosystems of southern Nigeria.

Copper concentrations during the wet season ranged from 2.73 ± 0.06 mg/L at the Control station to 7.15 ± 0.00 mg/L at Onosi Okpasimini, with Obrikom River recording 5.86 ± 0.00 mg/L.

Although the concentrations were considerably higher at the impacted stations than at the Control station, all values remained below the stated DPR limit of 36 mg/L. The approximately 2.6-fold difference between Onosi Okpasimini and the Control station indicates substantial spatial enrichment even though the concentrations did not exceed the regulatory benchmark. Copper may originate from both natural weathering and anthropogenic sources, including industrial activities, petroleum operations, metallic infrastructure, domestic wastewater and surface runoff. The fact that Onosi Okpasimini recorded the highest concentration suggests that localised sources may be contributing to Cu loading in that location. Chromium concentrations ranged from 2.17 ± 0.00 mg/L at the Control station to 6.52 ± 0.00 mg/L at Onosi Okpasimini, while Obrikom River recorded 5.17 ± 0.04 mg/L. All measured concentrations were substantially higher than the stated DPR limit of 1.6 mg/L. Onosi Okpasimini therefore recorded approximately four times the regulatory value, whereas Obrikom River recorded more than three times the limit. The elevated Cr concentrations may reflect inputs from industrial activities, petroleum-related processes, metal-containing wastes and weathering of chromium-bearing materials. Chromium is particularly important from an environmental-health perspective because its toxicity depends strongly on its chemical form, with hexavalent chromium generally being substantially more toxic than trivalent chromium. Therefore, where only total chromium was analysed, the present results should be interpreted as evidence of total Cr contamination rather than as direct evidence of Cr(VI) toxicity. The wet-season Cd concentration was 0.05 ± 0.00 mg/L at Obrikom River, 0.17 ± 0.00 mg/L at Onosi Okpasimini and 0.002 ± 0.00 mg/L at the Control station. Onosi Okpasimini consequently exceeded the stated DPR limit of 0.10 mg/L, while Obrikom River remained below the limit. The very low concentration at the Control station provides additional evidence of a spatially localised Cd input. Cadmium is particularly significant because it is non-essential to biological systems and can accumulate in aquatic organisms. The recent Bonny River study by Boma and Nwoke (2026) also reported Cd in surface water and classified Cd as exhibiting a very high degree of contamination. The similarity is particularly relevant because the Bonny River and the present study area are both situated within the Niger Delta environmental setting.

Nickel concentrations ranged from 1.723 ± 0.05 mg/L at the Control station to 4.32 ± 0.00 mg/L at Obrikom River, with Onosi Okpasimini recording 3.03 ± 0.00 mg/L. Obrikom River and Onosi Okpasimini exceeded the stated DPR limit of 2.7 mg/L, whereas the Control station remained below the limit. The distribution differs slightly from Pb, Cu, Cr and Cd because Obrikom River recorded the highest Ni concentration rather than Onosi Okpasimini. This suggests that the sources and environmental behaviour of Ni may differ from those of the other metals. Nickel can enter aquatic environments through petroleum activities, industrial discharges, combustion processes, metal corrosion and natural mineral weathering.

Iron recorded the highest absolute concentrations among all metals investigated, with values of 72.58 ± 0.00 mg/L at Obrikom River, 66.03 ± 0.13 mg/L at Onosi Okpasimini and 45.19 ± 0.23 mg/L at the Control station. The concentrations at Obrikom River and Onosi Okpasimini exceeded the stated DPR limit of 50 mg/L, while the Control station was slightly below the limit. The relatively high Fe concentration may partly reflect natural geochemical contributions because iron is abundant in many soils and sediments; however, the higher concentrations at the impacted locations indicate that anthropogenic contributions cannot be excluded. Ujah et al. (2025) similarly observed substantial Fe concentrations in the River Niger ecosystem and reported that the highest Fe concentration in water was associated with the site that also showed the highest Fe accumulation in fish.

The wet-season water results show that Pb and Cr were consistently elevated at all sampling locations relative to the stated DPR limits, while Cd and Ni showed exceedances at selected impacted stations and Fe exceeded the stated limit at the two main study stations. Cu was the only metal among those investigated that remained below the stated regulatory limit at all locations. This pattern indicates that the water body is subject to multiple-metal contamination rather than contamination by a single element.

Heavy Metals in Surface Water During Dry Season

The dry-season results in Table 4.10 show a general increase in the concentrations of most metals compared with the wet-season results. Pb increased from 1.70 to 2.18 mg/L at Obrikom River, from 2.49 to 2.86 mg/L at Onosi Okpasimini and from 1.10 to 1.24 mg/L at the Control station. These represent increases of approximately 28.2%, 14.9% and 12.7%, respectively. The continued exceedance of the DPR limit at all stations indicates persistent Pb contamination throughout the year rather than a short-lived wet-season phenomenon. The dry-season increase in Pb is environmentally plausible because reduced river flow and lower dilution during the dry period can increase the concentration of contaminants in the water column. Furthermore, continued inputs from anthropogenic sources during periods of reduced rainfall can result in greater apparent concentrations. Similar spatial and environmental variability has been reported in recent Nigerian aquatic studies, where heavy-metal concentrations varied considerably among sites according to the intensity and proximity of contaminant sources (Ujah et al., 2025; Yusuf et al., 2025). Copper increased during the dry season to 6.73 ± 0.05 mg/L at Obrikom River, 8.24 ± 0.03 mg/L at Onosi Okpasimini and 3.18 ± 0.04 mg/L at the Control station. Although these concentrations remained below the stated DPR limit of 36 mg/L, the consistent increase relative to the wet-season values indicates seasonal concentration of Cu. The highest dry-season concentration at Onosi Okpasimini further confirms that this location experienced greater metal loading than the Control station.

Chromium increased from 5.17 to 6.14 mg/L at Obrikom River, from 6.52 to 7.31 mg/L at Onosi Okpasimini and from 2.17 to 2.64 mg/L at the Control station. Consequently, Cr remained above the stated regulatory limit at all three locations. The persistence of elevated Cr in both seasons indicates that chromium contamination is not merely a consequence of rainfall-driven runoff but may also involve continuous or residual sources within the catchment.

Cadmium increased from 0.05 to 0.08 mg/L at Obrikom River and from 0.17 to 0.21 mg/L at Onosi Okpasimini, while the Control concentration increased only slightly from 0.002 to 0.003 mg/L. The dry-season Cd concentration at Onosi Okpasimini was therefore more than twice the stated DPR limit. The strong difference between the impacted and Control locations suggests that Cd is particularly associated with local anthropogenic inputs. This observation agrees with the 2026 Bonny River investigation, which identified Cd as one of the metals contributing substantially to water contamination in the Niger Delta. Nickel increased at Obrikom River from 4.32 to 4.86 mg/L and at the Control station from 1.723 to 1.94 mg/L, whereas Onosi Okpasimini increased from 3.03 to 3.57 mg/L. The dry-season concentrations remained above the stated DPR limit at Obrikom River and Onosi Okpasimini. Iron also increased from 72.58 to 79.64 mg/L at Obrikom River, from 66.03 to 73.58 mg/L at Onosi Okpasimini and from 45.19 to 48.76 mg/L at the Control station. Thus, the dry-season Fe concentrations at the two impacted stations remained above the stated limit. The overall dry-season results therefore demonstrate a stronger heavy-metal burden than during the wet season. This seasonal pattern is important because it indicates that periods of reduced dilution may increase the exposure of aquatic organisms to dissolved and suspended metals. However, seasonal variation should not be attributed solely to dilution; changes in runoff,

sediment resuspension, pH, redox conditions, organic matter and metal partitioning between water and solid phases may also influence the measured concentrations.

Heavy Metal Concentrations in *Oreochromis niloticus* During Wet Season

The results for tilapia in Table 11 demonstrate that heavy metals present in the water were also reflected in fish tissues. Pb concentrations were 2.84 ± 0.06 mg/kg at Obrikom River, 3.62 ± 0.08 mg/kg at Onosi Okpasimini and 1.18 ± 0.03 mg/kg at the Control station. All three values exceeded the stated DPR limit of 0.30 mg/kg. Onosi Okpasimini therefore recorded approximately 12 times the stated limit, while Obrikom River recorded approximately 9.5 times the limit. The elevated Pb concentration in fish is particularly important because fish occupy an important position in aquatic food webs and may transfer accumulated contaminants to human consumers.

The present finding is consistent with recent research in Nigeria. Wakil et al. (2025), studying Biu Reservoir, detected Pb and Cd contamination in fish and reported Cd in *O. niloticus* gills above the applicable safety limit. Similarly, Boma and Nwoke (2026), working in the Bonny River, reported Pb and Cd concentrations in tilapia above applicable limits. The agreement between these studies and the present results provides strong evidence that Pb accumulation in edible or biologically relevant fish tissues remains a significant concern in Nigerian aquatic systems.

Copper concentrations in the tilapia ranged from 2.21 ± 0.05 to 5.83 ± 0.14 mg/kg, with all values below the stated permissible limit of 30 mg/kg. Although Cu did not exceed the fish-tissue limit, the concentration at Onosi Okpasimini was more than twice that of the Control station. This spatial pattern suggests uptake from the surrounding aquatic environment. Copper is an essential trace element at low concentrations but can become toxic when environmental exposure is excessive.

Chromium concentrations ranged from 1.73 ± 0.04 mg/kg at the Control station to 4.87 ± 0.12 mg/kg at Onosi Okpasimini. All three stations exceeded the stated limit of 1.00 mg/kg. The elevated Cr concentrations indicate that the contamination observed in the water was accompanied by transfer into fish tissue. Recent research by Ogunbanwo et al. (2025) specifically investigated heavy-metal bioaccumulation in *O. niloticus* and *Chrysichthys nigrodigitatus* from Sagbo Koji, Lagos, demonstrating the usefulness of fish tissues as indicators of aquatic heavy-metal contamination. Cadmium showed particularly notable accumulation in tilapia, with concentrations of 0.46 ± 0.02 mg/kg at Obrikom River and 0.61 ± 0.03 mg/kg at Onosi Okpasimini, compared with only 0.08 ± 0.01 mg/kg at the Control station. The two impacted locations therefore exceeded the stated permissible limit of 0.20 mg/kg. The substantially higher Cd concentration in fish from Onosi Okpasimini corresponds with its higher Cd concentration in water, demonstrating an apparent environmental transfer relationship.

Nickel concentrations in fish were 2.73 ± 0.07 mg/kg at Obrikom River, 3.18 ± 0.09 mg/kg at Onosi Okpasimini and 1.24 ± 0.04 mg/kg at the Control station. All three concentrations exceeded the stated limit of 1.00 mg/kg. The highest Ni concentration occurred at the same station that generally recorded the greatest fish contamination, namely Onosi Okpasimini.

Iron concentrations ranged from 32.18 ± 0.61 to 56.74 ± 0.96 mg/kg, and all remained below the stated permissible limit of 100 mg/kg. The high Fe concentration in fish nevertheless demonstrates that Fe is actively present in the aquatic environment and is being incorporated into fish tissue. Ujah et al. (2025) reported a comparable pattern of substantial Fe accumulation in fish from the River Niger, where Fe in fish tissue reached 47.12 ± 0.785 mg/kg at the most affected site. The present concentrations at Obrikom River and Onosi Okpasimini are therefore broadly comparable with recent River Niger observations.

Heavy Metal Concentrations in *Oreochromis niloticus* During Dry Season

The dry-season fish results in Table 12 generally show higher concentrations of Pb, Cu, Cr, Cd, Ni and Fe than the corresponding wet-season values at most stations. Pb increased to 3.41 ± 0.08 mg/kg at Obrikom River and 4.26 ± 0.11 mg/kg at Onosi Okpasimini, while the Control station recorded 1.39 ± 0.04 mg/kg. All three values exceeded the stated limit of 0.30 mg/kg. The highest Pb concentration in the dry season therefore occurred at Onosi Okpasimini, consistent with the water results. Copper concentrations were 5.38 ± 0.13 , 6.72 ± 0.16 and 2.54 ± 0.06 mg/kg at Obrikom River, Onosi Okpasimini and Control, respectively. These values remained below the stated fish limit of 30 mg/kg, although the impacted stations continued to show higher concentrations than the Control station. Chromium increased during the dry season to 4.71 ± 0.11 mg/kg at Obrikom River and 5.68 ± 0.14 mg/kg at Onosi Okpasimini, while the Control station recorded 2.08 ± 0.05 mg/kg. All values remained above the stated 1.00 mg/kg limit. This persistence of elevated Cr in fish across both seasons suggests sustained environmental exposure. Cadmium recorded 0.57 ± 0.03 mg/kg at Obrikom River and 0.76 ± 0.04 mg/kg at Onosi Okpasimini, compared with 0.10 ± 0.01 mg/kg at the Control station. The two impacted stations therefore exceeded the stated Cd limit of 0.20 mg/kg. This is particularly significant because Cd is a non-essential metal capable of accumulating in organisms following chronic environmental exposure. Nickel also remained above the stated fish limit at the two impacted stations, recording 3.16 ± 0.08 mg/kg at Obrikom River and 3.79 ± 0.10 mg/kg at Onosi Okpasimini. Iron increased to 54.72 ± 0.91 and 64.83 ± 1.04 mg/kg, respectively, but remained below the stated limit of 100 mg/kg. The general dry-season increase in fish-tissue concentrations corresponds with the increase observed in the surface-water concentrations. This relationship is consistent with the ecological principle that fish can accumulate metals from the surrounding water, suspended particles, sediments and food. Recent research emphasizes that the degree of metal accumulation in freshwater fish is influenced not only by ambient concentration but also by species characteristics, age, sex, parasites, tissue type and environmental conditions (Brázová et al., 2025). Consequently, the higher concentrations observed in *O. niloticus* from Onosi Okpasimini should be interpreted as evidence of greater environmental exposure rather than as proof that water concentration alone determines tissue accumulation.

Heavy Metal Concentrations in Soil During Wet Season

The wet-season soil results in Table 14 show that Onosi Okpasimini recorded the highest concentrations of Pb, Cu, Cr, Cd, Ni and Fe. Pb ranged from 8.36 ± 0.18 mg/kg at the Control station to 24.67 ± 0.42 mg/kg at Onosi Okpasimini, while Cu ranged from 12.18 ± 0.21 to 28.54 ± 0.35 mg/kg. Chromium ranged from 16.43 ± 0.29 to 38.62 ± 0.51 mg/kg, whereas Cd ranged from 0.21 ± 0.02 to 1.08 ± 0.06 mg/kg. Nickel and Fe showed similar spatial patterns, with maximum values of 22.48 ± 0.39 and 758.62 ± 9.17 mg/kg, respectively, at Onosi Okpasimini.

With the exception of Cd at Onosi Okpasimini, the concentrations remained below the stated DPR limits. The relatively high Fe concentration is not unexpected because Fe is naturally abundant in soils and sediments. However, the consistent enrichment of all metals at Onosi Okpasimini compared with the Control suggests an additional anthropogenic contribution. Soil or sediment can act as a long-term reservoir for heavy metals because metals may become associated with clay minerals, iron and manganese oxides, organic matter and other particulate phases.

This relationship between water, solid phases and fish is particularly important for interpreting the present findings. Heavy metals introduced into aquatic systems do not necessarily remain dissolved in the water column. They may adsorb onto suspended particles, settle into bottom

deposits and subsequently become available to benthic organisms and fish through food-web transfer. A recent Nigerian study in the River Niger similarly found site-specific variation in heavy metals across water, sediment and fish, demonstrating the interconnected behaviour of metals across environmental compartments (Ujah et al., 2025).

Heavy Metal Concentrations in Soil During Dry Season

The dry-season soil concentrations generally increased relative to the wet-season values. Pb increased to 22.76 ± 0.38 mg/kg at Obrikom River and 29.83 ± 0.47 mg/kg at Onosi Okpasimini, while Cu increased to 25.84 ± 0.32 and 33.76 ± 0.41 mg/kg, respectively. Chromium increased to 36.82 ± 0.51 mg/kg at Obrikom River and 44.73 ± 0.58 mg/kg at Onosi Okpasimini. Cadmium recorded 0.86 ± 0.05 mg/kg and 1.27 ± 0.07 mg/kg at the two impacted locations, respectively, exceeding the stated limit of 0.80 mg/kg.

Nickel increased to 20.48 ± 0.36 mg/kg at Obrikom River and 26.73 ± 0.43 mg/kg at Onosi Okpasimini, while Fe increased to 742.63 ± 9.14 and 826.47 ± 10.26 mg/kg, respectively. The consistent increase in soil concentrations during the dry season corresponds with the seasonal increase observed in water and fish.

The dry-season enrichment may result from reduced dilution, increased exposure of contaminated surfaces, changes in redox conditions and concentration of previously deposited materials. It may also reflect the remobilisation of metals from contaminated particulate material. Recent research on heavy-metal contamination in aquatic environments continues to demonstrate the importance of examining water, sediment and biota together rather than considering any single environmental compartment in isolation. For example, the 2026 Bonny River study assessed water, sediment and *O. niloticus* simultaneously and found substantial contamination in water together with Pb and Cd exceedances in tilapia.

Bioaccumulation of Heavy Metals in *Oreochromis niloticus*

The bioaccumulation factor results provide important evidence concerning the ability of *Oreochromis niloticus* to accumulate metals from its surrounding aquatic environment. A BAF greater than 1 generally indicates that the concentration of a contaminant in an organism exceeds its concentration in the environmental medium used for the calculation, suggesting significant accumulation, whereas values below 1 indicate comparatively limited accumulation from that medium. The present results show that Pb and particularly Cd had the strongest accumulation tendencies in *O. niloticus*. During the wet season, the BAF for Pb was 1.67 at Obrikom River, 1.45 at Onosi Okpasimini and 1.07 at the control. All three values were above unity, indicating that *O. niloticus* accumulated Pb at all sampling locations. The dry-season BAF values of 1.56, 1.49 and 1.12 at Obrikom River, Onosi Okpasimini and the control, respectively, also remained above 1. This finding is particularly important because Pb concentrations in fish were simultaneously above the stated DPR limit of 0.30 mg/kg at both impacted locations. The results therefore demonstrate that elevated environmental Pb availability is being reflected in fish tissues.

The BAF of Cu was below 1 at all locations during both seasons, ranging from 0.80 to 0.82 during the dry season and from 0.81 to 0.82 during the wet season. This indicates relatively limited bioaccumulation of Cu in relation to the water concentration used in the calculation. The result may partly reflect the physiological regulation of essential metals such as Cu by fish. Although Cu is essential for normal biological functions, organisms can regulate its internal concentration more effectively than non-essential toxic metals under certain exposure conditions.

Chromium also showed BAF values below 1, ranging from 0.75 to 0.80 during the wet season and 0.77 to 0.79 during the dry season. This suggests relatively limited accumulation of Cr compared with its concentration in the environmental medium. Nickel showed a similar pattern, with wet-season BAF values of 0.63, 1.05 and 0.72 and dry-season values of 0.65, 1.06 and 0.76 at Obrikom River, Onosi Okpasimini and the control, respectively. The slightly greater-than-one values for Ni at Onosi Okpasimini indicate that this location may provide conditions favouring Ni uptake by *O. niloticus*. The most striking BAF results were observed for Cd. During the wet season, Cd BAF values were 9.20 at Obrikom River, 3.59 at Onosi Okpasimini and 40.00 at the control. During the dry season, the values were 7.13, 3.62 and 33.33, respectively. These values indicate strong accumulation of Cd by *O. niloticus*, particularly at the control location where the concentration of Cd in water was extremely low. The very high BAF at the control should, however, be interpreted carefully because BAF is a ratio, and a very low denominator can produce an exceptionally high value even where the absolute concentration of Cd in fish is comparatively low. Thus, the BAF should be interpreted alongside the actual fish concentration rather than as evidence that the control site necessarily represents the greatest absolute Cd pollution.

The BAF results are broadly consistent with recent Nigerian research. Ogunbanwo et al. (2025) reported significant uptake of heavy metals by *O. niloticus* and other fish species from water and sediment in the Sagbo Koji Riverine Community. Their findings showed that Fe and Pb were among the metals displaying notable bioaccumulation, demonstrating the importance of fish as biomonitoring organisms. Similarly, Wakil et al. (2025) detected heavy metals in *O. niloticus* tissues from Biu Reservoir and reported particular concern regarding Pb and Cd. A recent study of *O. niloticus*, *Synodontis clarias* and *Clarias gariepinus* from Kiri Reservoir also demonstrated species- and season-related differences in heavy-metal accumulation, emphasizing that fish uptake depends on both environmental conditions and biological characteristics (British Journal of Multidisciplinary and Advanced Studies, 2025).

Contamination Factor and Pollution Load Index of Water

The contamination-factor results provide further evidence of the degree to which individual metals contribute to the overall pollution status of the water. During the wet season, Pb recorded very high CF values of 11.33 at Obrikom River and 16.60 at Onosi Okpasimini, while the control site recorded 7.33. These values indicate that Pb was the dominant contributor to water contamination at all locations. Cr also showed elevated CF values of 3.23 and 4.08 at the two impacted sites, while Ni recorded values of 1.60 and 1.12. Fe showed CF values of 1.45 and 1.32. In contrast, Cu had low CF values of 0.16 and 0.20, while Cd recorded 0.50 and 1.70 at Obrikom River and Onosi Okpasimini, respectively. The dry-season results show a further deterioration in the contamination status of the water. Pb CF increased to 14.53 at Obrikom River and 19.07 at Onosi Okpasimini, while Cr increased to 3.84 and 4.57, respectively. Ni also increased to 1.80 at Obrikom River and 1.32 at Onosi Okpasimini. The CF of Cd increased to 0.80 at Obrikom River and 2.10 at Onosi Okpasimini. These increases agree with the higher measured concentrations during the dry season and reinforce the conclusion that contaminant concentration is intensified during periods of reduced hydrological dilution. The PLI values provide an integrated assessment of the combined effect of the investigated metals. The wet-season PLI values were 1.38 at Obrikom River, 1.80 at Onosi Okpasimini and 0.45 at the control. The impacted locations therefore had PLI values greater than 1, indicating an overall polluted condition, whereas the control location had a value below 1, indicating comparatively low overall pollution. During the dry season, the PLI increased to 1.70 at Obrikom River and 2.08 at Onosi Okpasimini, while the control remained below unity at 0.54.

The increase in PLI during the dry season demonstrates that the combined metal burden was greater during the dry period than during the wet period.

The consistently highest CF and PLI values at Onosi Okpasimini indicate that this station represents the most contaminated of the investigated water locations. This agrees with the concentration results, where Onosi Okpasimini generally recorded the highest concentrations of Pb, Cu, Cr and Cd. Recent research has also demonstrated the usefulness of pollution indices in identifying aquatic pollution hotspots. A 2026 study of the Bonny River system in Nigeria reported very high contamination factors for Pb, Cd and Cr in water and demonstrated clear differences in contamination between environmental compartments (Boma & Nwoke, 2026).

Contamination Factor and Pollution Load Index of Soil

The soil CF results present a different picture from the water results. During the wet season, all CF values at Obrikom River were below 1, ranging from 0.22 for Pb to 0.90 for Cd. At Onosi Okpasimini, Cd recorded a CF of 1.35, while Cu, Ni, Fe, Cr and Pb recorded values below 1. During the dry season, Cd increased to 1.08 at Obrikom River and 1.59 at Onosi Okpasimini, while the other metals remained below 1. This indicates that Cd is the most important individual contaminant in the soil compartment based on the calculated CF values.

The PLI values provided in the study, however, indicate a much greater overall pollution burden in soil than might be suggested by the individual CF values. The reported wet-season PLI values were 9.88 at Obrikom River, 12.75 at Onosi Okpasimini and 4.81 at the control, while dry-season values increased to 11.59, 14.88 and 5.44, respectively. Based on these reported values, Onosi Okpasimini had the highest overall soil pollution burden, followed by Obrikom River and then the control. The increase from wet to dry season indicates an intensified soil contamination burden during the dry season. The high soil PLI values should be interpreted together with the actual concentrations and CF values rather than independently. In particular, the relatively low individual CF values for most metals indicate that the overall index is strongly influenced by the mathematical treatment and reference values used in its calculation. Recent research has continued to employ PLI as an integrated indicator for identifying areas with multiple-metal contamination and pollution hotspots (Lai et al., 2025). The use of PLI is particularly useful where several metals occur simultaneously because it provides an overall indication that may not be apparent from examining individual metals separately. Taken together, the results demonstrate a clear environmental linkage among water, soil and *O. niloticus*. The impacted locations generally recorded higher heavy-metal concentrations in water and soil than the control, while fish collected from these locations also showed higher concentrations of several metals. For example, the wet-season Pb concentration in fish increased from 1.18 mg/kg at the control to 2.84 mg/kg at Obrikom River and 3.62 mg/kg at Onosi Okpasimini. During the dry season, the values increased further to 3.41 mg/kg and 4.26 mg/kg at the two impacted locations, compared with 1.39 mg/kg at the control. This parallel pattern strongly suggests that the elevated environmental availability of Pb is contributing to its accumulation in fish.

The same relationship was observed for Cd. Wet-season Cd concentrations in fish were 0.46 mg/kg at Obrikom River and 0.61 mg/kg at Onosi Okpasimini, compared with 0.08 mg/kg at the control. During the dry season, these values increased to 0.57 mg/kg and 0.76 mg/kg, respectively, compared with 0.10 mg/kg at the control. Thus, the higher Cd concentrations in water and soil at the impacted locations corresponded with higher Cd burdens in fish.

The findings are consistent with the conceptual model in which heavy metals enter aquatic systems through anthropogenic and natural sources, become distributed between the water column and

particulate or sediment phases, and subsequently become available to aquatic organisms. Fish may absorb metals directly from water through the gills and body surfaces or indirectly through ingestion of contaminated food, suspended particles and sediments. Recent Nigerian research has provided similar evidence of interconnected contamination among water, sediment and fish. Ogunbanwo et al. (2025) found heavy-metal contamination across water, sediments and fish tissues in the Sagbo Koji Riverine Community, while Wakil et al. (2025) demonstrated that Pb and Cd contamination in a Nigerian reservoir could extend from water and sediment to fish tissues.

The results indicate that Onosi Okpasimini represents the principal contamination hotspot, followed by Obrikom River, while the control location consistently showed the lowest concentrations and pollution indices. Pb was the most prominent contaminant in the water based on its high CF values, while Cd showed the strongest tendency for bioaccumulation in *O. niloticus*. Fe was the most abundant metal in both water and soil, although its CF values were considerably lower than those of Pb in water. The dry season generally produced higher concentrations, higher contamination factors and higher PLI values than the wet season, suggesting that reduced dilution and concentration effects contribute substantially to seasonal metal enrichment.

The ecological significance of these findings is strengthened by the fish results. The BAF values above unity for Pb and Cd indicate that *O. niloticus* can accumulate these metals from its environment. This is particularly important because the measured Pb and Cd concentrations in fish at the impacted sites exceeded the stated DPR limits. Recent studies in Nigeria continue to report similar concerns regarding heavy-metal accumulation in edible fish and emphasize the importance of fish monitoring as a component of aquatic pollution assessment (Ogunbanwo et al., 2025; Wakil et al., 2025). Consequently, the combined evidence from metal concentrations, BAF, CF and PLI indicates that the aquatic ecosystem is experiencing measurable heavy-metal pressure, with Pb and Cd requiring particular attention. The higher contamination observed at Onosi Okpasimini suggests that pollution-control and monitoring efforts should prioritize this location. The transfer of metals from environmental media to *O. niloticus* also has implications for aquatic ecosystem health and human exposure where fish from the river are consumed. This interpretation is supported by recent studies from Nigerian aquatic environments that have identified heavy-metal contamination across multiple environmental compartments and recommended continuous monitoring because of the potential ecological and food-chain implications (Boma & Nwoke, 2026; Ogunbanwo et al., 2025; Wakil et al., 2025).

Conclusion

The study established that heavy metals were present in the surface water, *Oreochromis niloticus* and soil within the vicinity of oil production facilities in Omoku, Rivers State. The concentrations of several metals, particularly Pb, Cr, Cd and Fe, were higher at the oil-production-influenced locations than at the control site, with generally higher concentrations recorded during the dry season. The elevated bioaccumulation factors observed for Cd indicate its greater tendency to accumulate in *O. niloticus*. The pollution indices further indicated varying degrees of contamination, particularly in the soil and surface water around Onosi Okpasimini. The findings suggest that oil production activities and associated anthropogenic pressures may contribute to heavy-metal contamination of the study environment, with potential implications for aquatic ecosystems, soil quality and human health through consumption of contaminated fish.

Recommendations

Based on the findings of this study, the following recommendations are made:

1. Heavy metal monitoring should be strengthened in water, soil and fish, with particular attention to Pb, Cr and Cd because of their potential toxicity and capacity to accumulate in biological tissues. Periodic testing of locally consumed fish should be undertaken to identify increasing contamination before it becomes a significant food-safety concern.
2. The BAF, CF and PLI indices should be incorporated into routine environmental assessment programmes. These indices provide useful information on metal bioaccumulation, contamination severity and the combined pollution burden and can assist regulatory agencies in identifying locations requiring priority intervention.

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