https://doi.org/10.48047/AFJBS.6.Si3.2024.3347-3369

AFJBS
African Journal of Biological Sciences
Journal homepage: http://www.afjbs.com
Research Paper
Open Access

Assessment and Distribution of Heavy Metal Toxicity in *Chrysichthys Nigrodigitatus* and the Water Quality of an Impacted River in Southern Nigeria

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ArticleInfo

Volume6, Issue Si 3,July2024

Received: 03 June2024

Accepted:31 June 2024

Published: 25 July 2024

doi:

10.48047/AFJBS.6.Si3.2024.3347-3369

ABSTRACT:

This study was carried out to determine the amounts of heavy metals in Silver Catfish and water samples collected from the Ogbogoro section of the new Calabar River in Nigeria. Measure key water quality parameters, such as pH, temperature, salinity, conductivity, total suspended solids, and Total dissolved solids. Dissolved oxygen levels were assessed using the Winkler method, turbidity was determined using a Secchi disc. Metals in fish tissue were analysed using a spectrophotometer, including copper, zinc, cadmium, chromium, nickel, lead, iron, and cobalt. These findings suggest that fish have increased levels of Pb, Cd, and Cr, posing possible ecological and human health hazards. Water quality measures such as pH, dissolved oxygen, and conductivity were also found to vary. To address these findings, it is recommended to establish regular monitoring programs, enforce strict environmental regulations, and implement mitigation measures to reduce heavy-metal inputs. This research contributes to the understanding of heavy metal contamination in Southern Nigeria and provides recommendations for policymakers, resource managers, and local communities to protect and sustainably regulate river ecosystems. Continuous monitoring and study are required to understand the long-term trends and possible effects of heavy-metal pollution caused by heavy metals.

Keywords: Heavy metals, Silver Catfish, *Ogbogoro axis*, Water quality

1. Introduction

The Niger Delta area of Nigeria is well known for its abundant natural resource deposits, notably oil and gas (Oluniyi, 2017). However, the exploration and extraction of these resources have had devastating consequences for the environment, notably in terms of water pollution. The aquatic ecosystem in the region faces considerable peril due to oil spills, gas flaring, and inadequate waste disposal methods, posing substantial risks to both water quality and various life forms (Reid *et al.*, 2019). The disposal of both household and industrial waste into rivers and other waterways has disturbed intricate nutrient equilibrium, leading to a decline in aquatic species (Bashir *et al.*, 2020). Pollution affecting the Niger Delta region has had severe consequences for the well-being and sustenance of the local community, which depends heavily on fishing and agriculture (WHO, 2011). Polluted water sources have contributed to an increase in waterborne illnesses and other health concerns.

Water pollution originates from diverse sources, with contaminants such as insecticides, pesticides, and oil spills identified as primary contributors. Among these pollutants, heavy metals have gained considerable attention because of their inherent toxicity even at low concentrations (Hojjati-Najafabadi*et al.*, 2022). The environment can be exposed to heavy metals through various pathways, including metal corrosion, atmospheric deposition, erosion of metal ions in the soil, leaching of heavy metals, and evaporation of metals from water sources into the soil and groundwater. The gradual build-up of heavy metals in aquatic environments raises significant concerns, as it can result in the bioaccumulation of these contaminants (Ali and Khan, 2018; Davies *et al.*, 2022). Bioaccumulation is a phenomenon in which the concentration of a pollutant gradually increases within a living organism over time, leading to higher levels of pollutants in the food chain (Odekina*et al.*, 2021).

The accumulation of heavy metals in fish and other aquatic organisms poses health and general health risks (Ali *et al.*, 2019). This is especially worrisome as heavy metals can enter the human food chain when people consume contaminated fish, thereby posing a substantial threat to public health (Ali and Khan, 2018; Sonone*et al.*, 2020). Fish tend to accumulate significant quantities of heavy metals in their tissues and membranes because of the ingestion of contaminated materials and their capacity to absorb these metals (Ezemonye*et al.*, 2019).

Consumption of contaminated fish has been linked to a variety of acute and chronic health effects in humans (Sharma and Singhvi, 2017). Cd, Pb, Cr, Cu, and Zn are particularly hazardous to the health of both fish and humans when present in high amounts (Chan *et al.*, 2021). Silver catfish (*Chrysichthysnigrodigitatus*) is a popular fish in Nigeria and a good source of protein (Aigberua*et al.*, 2021). However, concerns have been raised regarding the contamination of this fish species with heavy metals and its potential adverse effects on human health (Ali and Khan, 2018). Fish can absorb heavy metals through various pathways, including the gill surface and the gut wall (Rajeshkumar and Li, 2018). Therefore, it is critical to implement preventative measures to reduce heavy metal contamination and the danger of bioaccumulation in aquatic environments.

Metallic substances can affect enzymes and metabolic processes, resulting in stunted development, reproductive difficulties, and reduced immunological functions (Mishra *et al.*, 2019; Rehman*etal.*, 2021). They also cause oxidative stress, which causes cellular and tissue damage and can lead to chronic health issues such as cancer and organ damage (Kruk *et al.*, 2019). Furthermore, heavy metals can accumulate in fish tissues and pose health risks to humans when ingested (Vu *et al.*, 2017). This is especially concerning in communities in which fishing is a major source of food and money. To protect the environment and human health, it is critical to monitor and control heavy metal pollution in aquatic ecosystems. However, consumption of contaminated fish can cause various health issues, highlighting the importance of prevention.

Heavy metal contamination poses a significant environmental threat to aquatic ecosystems and fish species, including silver catfishes. The uptake of heavy metals by fish can negatively affect their health and development, leading to ecological consequences. The consumption of fish contaminated by humans can also result in adverse health effects (Zhong*et al*., 2016). Measures such as reducing industrial discharge, improving wastewater treatment, and promoting sustainable fishing practices are crucial to prevent contamination. Regular monitoring of heavy metal levels in fish is essential to mitigate bioaccumulation risks and ensure fish safety.

2. Materials And Method

Description of Study Area

This research was conducted on the Ogbogoro River, a tributary of the Upper New Calabar River in the Niger Delta region. The study area includes three sampling stations with specific coordinates (Station 1 is situated at 04º52'43.4″ N and 006º35'36.1″ E, Station 2 is located at 04º53'05.4″ N and 006º53'35.4" E, and Station 3 is positioned at 04º54'20.4″ N and 007º53'54.4″ E). The meander of the river is long and wide, with a shallow outer concave bank and sandy point bars. The depth and width varied slightly along its course, with a minimum width of 200 m and a maximum of 250 m. The river experiences a tidal influence during the dry season, with rapid water flow during the flood period (February to July 2020). However, during the peak of the dry season, the flow was slightly reversed owing to the rising tides. At full tide, flow became almost stagnant. The dominant vegetation along the Ogbogoro axis is mangrove forest, which includes species such as *R. harrisonii* (red mangrove), *Avicennia sp., Rhizophora sp., R. mangle, and Rhizophoraracemosa*. However, a significant portion of this mangrove vegetation has been lost because of industrialization and urbanization activities in the area.

Sampling Procedure

Figure 1 shows the locations of the sampling stations. Three stations were carefully chosen, each spaced at least 1000 metres down the river. Three specialized sample sites were established to capture the various characteristics and activities in the creek research area: Stations 1, 2, and 3. Water and biota samples were collected for analysis. To collect geographic coordinates, including longitudes and latitudes, for the sample region, all sites were carefully georeferenced using a portable global positioning system (GPS) receiver unit, namely the Magellan GPS 315. Sampling was performed on a monthly basis during the first week of each sample month.

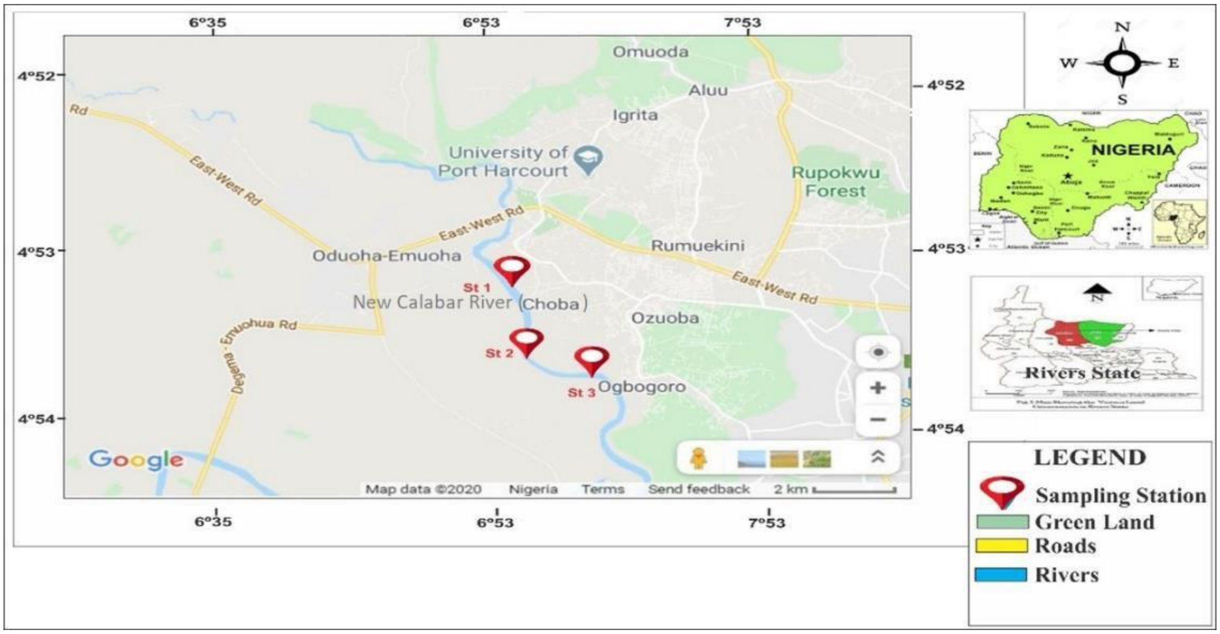

Figure 1: *Map Showing the Sampling Stations*

Fish sample collection (*Chrysichthysnigrodigitatus*)

Specimens of silver Catfish (*C. nigrodigitatus*) were captured using a cast net. The fish samples exhibited an average length of 10.6 ± 3.25 cm and a weight of 15.52 ± 0.03 g. Sampling activities were carried out monthly, spanning from February to July 2020, at three designated stations. The collected samples were carefully preserved with an ice pack before transportation to the Center for Marine Pollution Monitoring and Seafood Safety Laboratory (CMPM & SSL), University of Port Harcourt, Rivers State, Nigeria. Subsequently, heavy metal concentration analysis was performed on the samples using the Atomic Absorption Spectrometer (AAS) method, following the standards recommended by APHA (1999).

Water Samples

Surface water samples were collected from three designated sites using pristine 40 mL polyethylene screw-capped containers that had been meticulously cleaned, appropriately labelled, and rendered sterile. Before being dispatched to the laboratory, the collected water samples were acidified with 10 mL of a 1:1 mixture of nitric acid and deionized water.

Determination of Heavy Metals

Heavy metals, including copper (Cu), zinc (Zn), cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), iron (Fe), cobalt (Co), and manganese (Mn), were determined at standard wavelengths using the Atomic Absorption Spectrophotometer (AAS) method following the guidelines established by APHA (1999). The sample digestion process involved the use of concentrated Analar nitric acid, as described by Zhang (2007). Heavy metal concentrations were determined using an Atomic Absorption Spectrophotometer (Model PYE UNICAM SP9; Philips PyeUnicam Ltd., York Str., Cambridge CBl 2PX, England) equipped with an acetylene-air flame. This method adheres to established protocols, ensuring the accuracy and reliability of the heavy metal analysis.

Physico-Chemical Parameters Analysis

Surface water samples were acquired using Schott glass bottles. Subsequently, an in-situ Handheld Multimeter, comprising the Milwaukee Model pH600 and Laboratory Benchtop meter 860033-model, was employed to measure key water quality parameters, such as pH, temperature, salinity, conductivity, total suspended solids (TSS), and total dissolved solids (TDS). Dissolved oxygen (DO) levels were assessed using the Winkler method. Turbidity was determined using a 20 cm diameter Secchi disc. The total water hardness was assessed following the recommended procedure APHA 2340C, while the total alkalinity was determined according to the American Society for Testing and Materials (ASTM D 1067 B).

Quality Assurance and Control

The experimental setup involved the utilization of atomic absorption standards for several heavy metals, all of which were buck-certified, to establish a calibration curve. To ensure the reliability of the measurements, a reagent blank was used after every ten samples to mitigate equipment drift. Recovery rates ranged from 82% to 110%. The assessment of metal levels in the water, sediment, and biota samples was conducted using atomic absorption spectrophotometry, employing the Model 210 VGP by Buck Scientific. The method employed, as well as the wavelength (nm), was aligned with the procedures outlined by Chris et al. (2023). All samples were subjected to duplicate analyses, and the reported values represent the mean of these measurements. This rigorous approach to quality assurance and control enhanced the accuracy and credibility of the obtained results. Analytical-grade reagents were used for all experiments.

Statistical Analysis

Data analysis was performed using the Statistical Package for Social Sciences (SPSS) version 23. Summary statistics such as means and standard deviations were calculated. Subsequently, one-way analysis of variance (ANOVA) was employed to identify statistically significant differences ($P < 0.05$) among the groups. To identify statistically distinct means, Duncan’s multiple range test was applied.

3. Result

The mean values of physicochemical parameters recorded at three locations along the Ogbogoro stretch of the New Calabar River in Rivers State are shown in Table 1. The mean water temperature ranged from 26.96 to 27.16oC, and the mean pH values ranging from 6.5 to 6.8 °C. There were no significant variations in temperature, pH, or total suspended solids (TSS) across the three locations ($P>0.05$), with mean TSS values ranging from 25.6 29.5. The conductivity values ranged from 36.0 to 55.83, with significant variations reported across the three locations (P0.05). TDS (total dissolved solids) were greatest at station 2 (4610.16265.56) and lowest at station 3 (52.333.90). TDS levels differed significantly across the three locations (P0.05). The salinity varied from 19.35 to 23.15.

Station 2 had the highest hardness (201.6712.43), whereas station 1 had the lowest (107.04.16). There were significant variations among the three stations (P0.05). The concentration of dissolved oxygen (DO) was highest at station 1 (4.360.58) and lowest at station 2 (3.950.11). However, no significant differences were found among the three stations ($P>0.05$). Station 2 had the highest turbidity value (2.880.21), while station 1 had the lowest (2.730.31). The mean total alkalinity levels varied from (1072.03) at station 1, to (172.8312.05) at station 2, with significant variations (P0.05) observed across the three locations.

Table 1: Spatial variation in the Physico-chemical features of the surface water

Parameters	**Site 1**	**Site 2**	**Site 3**	**WHO (2011)**
Temp (^{o}C)	27.2±0.24^{a}	26.9±0.34^{a}	27.0±0.12^{a}	30
pH	6.9±0.12^{a}	6.5±0.13^{a}	6.8±0.1^{a}	6.5-8.5
TSS (mg/L)	26.5±5.42^{b}	29.6±3.58^{a}	25.0±3.72^{b}	30
EC (µS/cm)	36.0±1.10 ^{c}	55.8±5.51^{a}	52.3±3.90 ^{a}	400
TDS (mg/L)	2869.2±3.84^{b}	4610.2±2.56^{a}	2422.5±2.20 ^{b}	2000
Salinity (mg/L)	19.4±1.35^{b}	22.3±2.18^{a}	23.2±2.52^{a}	600
TH (mg/L)	107.0±4.16^{c}	201.7±12.43^{a}	139.8±5.71^{b}	300
DO (mg/L)	4.4±0.58^{a}	3.95±0.11^{a}	4.1±0.35^{a}	3-5
Turbidity (NTU)	2.73±0.31^{a}	2.88±0.21^{a}	2.85±0.19^{a}	5
TA (mg/L)	107.5±2.03^{c}	172.83b±12.05^{a}	139.17±11.7^{b}	200

* The means of variables with different superscripts on the same row differ considerably.

Table 2 shows the mean values of the physicochemical parameters measured in the Ogbogoro stretch of the New Calabar River in the river state from February to July 2020. The highest mean water temperature was recorded in June (27.83±0.29), while the lowest was recorded in April (26.56±0.14). There were no significant changes across months (P>0.05).

Table 2.: Temporal Variation in Physico-chemical Parameters

Parameters	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**WHO (2011)**
Temp (^{o}C)	26.7± ±0.4^{a}	26.8± ±0.2^{a}	26.6± ±0.1^{a}	27.2± ±0.2^{a}	27.8± ±0.2^{a}	27.1± ±0.2^{a}	30
pH	6.6± ±0.3^{b}	6.7± ±0.2^{ab}	6.8± ±0.1^{a}	6.9± ±0.1^{a}	6.6± ±0.1^{b}	6.7± ±0.1^{ab}	6.5-8.5
TSS (mg/L)	14.2± ±2.2^{d}	15.8± ±1.8^{d}	25.2± ±2.4^{c}	38.7± ±2.0^{a}	35.0± ±2.1^{b}	33.3± ±1.2^{b}	30
EC (µS/cm)	37.7± ±2.9^{c}	40.7± ±5.3^{c}	56.0± ±9.8^{a}	55.0± ±8.0^{a}	49.7± ±7.9^{a}	49.3± ±7.6^{a}	400
TDS (mg/L)	3891.3± ±0.5^{a}	3926.7± ±0.6^{a}	3269.0± ±0.6^{b}	3026.0± ±0.6^{b}	2792.3± ±0.3^{c}	2898.3± ±0.2^{c}	2000
Salinity (mg/L)	17.4± ±0.5^{a}	16.1± ±0.4^{a}	17.9± ±0.2^{a}	27.1± ±1.9^{b}	25.5± ±1.8^{b}	25.6± ±2.1^{b}	600
TH (mg/L)	168.3± ±33.2^{a}	169.0± ±35.6^{a}	146.3± ±31.3^{a}	148.7± ±25.5^{a}	127.0± ±17.3^{a}	137.7± ±25.2^{a}	300
DO (mg/L)	5.4± ±0.6^{a}	4.6± ±0.5^{b}	4.1± ±0.2^{bc}	3.80± ±0.2^{bc}	3.4± ±0.2^{dc}	3.4± ±0.2^{dc}	3-5

Turbidity (NTU)	3.4± $\pm0.6^{a}$	2.4± $\pm0.1^{b}$	2.4± $\pm0.2^{b}$	3.2± $\pm0.1^{a}$	2.8± $\pm0.2^{ab}$	2.8± $\pm0.2^{ab}$	5
TA (mg/L)	161.3± $\pm27.2^{a}$	160.7± $\pm26.7^{a}$	143.0± $\pm27.7^{b}$	135.7± $\pm15.5^{b}$	118.3± $\pm7.9^{c}$	120.0± $\pm12.1^{c}$	200

* Means of variables with different superscripts on the same row differ considerably

The highest pH value (6.90±0.15) was recorded in May, while the lowest (6.56±0.09) was recorded in June. There were no statistically significant changes across months ($P>0.05$). TSS (total suspended solids) reached its maximum point in May (38.66±2.02) and its lowest point in February (14.16±2.24). Significant variations were observed across months ($P<0.05$).

Conductivity measurements varied from 37.66±2.90 in February to 56.09.81 in April, with no significant changes observed ($P>0.05$). Total dissolved solids (TDS) were highest in March (3926.66±785.61) and lowest in June (2792.33±565.33). There was no significant change between months ($P>0.05$).

The maximum salinity was recorded in May (27.06±1.94) and the lowest in March (16.10±0.43), with a significant difference between the months (P0.05). The hardest month was March (169.0±35.64), while the softest month was June (127.0±17.34). There was no significant change between months ($P>0.05$).

Dissolved oxygen (DO) was highest in February (5.43±0.61) and lowest in July (3.400.20), with significant fluctuations over the month ($P<0.05$). Turbidity was highest in February (3.36±0.6) and lowest in July (2.760.2), with no statistically significant difference ($P>0.05$). The highest alkalinity value was 161.33±27.16 in February, and the lowest was 118.3±37.97 in June. Significant variations were observed across months ($P<0.05$).

Cadmium (Cd) levels ranged from 0.06±0.01 to 0.17±0.04, with a significant difference between the three sites ($P<0.05$). The mean values for chromium (Cr) were highest at station 2 (1.53±0.15) and lowest at station 1 (0.50±0.24), with a significant difference between the three stations ($P<0.05$). Copper (Cu) had the greatest mean value (0.550.11) and the lowest (0.26±0.03) at station 2. There were no significant differences between stations ($P>0.05$).

The mean levels of heavy metals recorded at three locations along the Ogbogoro stretch of the New Calabar River in Rivers State are shown in Table 3. The mean calcium (Ca) readings ranged from 3.52±0.24 to 5.91±0.29, with a significant difference ($P<0.05$) visible between the three locations. Zinc (Zn) mean values varied from 0.26±0.03 0.64±0.20, with no significant variation across stations ($P>0.05$). The mean lead (Pb) readings varied from 0.16±0.03 to 0.30±0.06, with no significant differences between the three locations ($P>0.05$).

For iron (Fe), station 2 had the greatest mean value (2.860.26) and station 1 had the lowest (1.22±0.09), with a significant difference ($P<0.05$) noted across the three stations. Station 2 had the highest mean value (0.3±0.04) for nickel (Ni), whereas station 1 had the lowest (0.16±0.02), with a significant difference between the three stations ($P<0.05$). Cobalt (Co) had the greatest value (0.42±0.06) at station 2 and the lowest (0.18±0.02) at station 1.

Table 3: Spatial Variation in Heavy Metals in Silver Catfish (Chrysichthysnigrodigitatus)

Metals	**Site 1**	**Site 2**	**Site 3**	**WHO (2011)**
Zn	0.26 ± 0.03^{c}	0.64 ± 0.20^{a}	0.32 ± 0.04^{b}	3.0
Pb	0.16 ± 0.03^{c}	0.30 ± 0.06^{a}	0.20 ± 0.03^{b}	0.01
Cd	0.06 ± 0.01^{b}	0.17 ± 0.04^{a}	0.07 ± 0.01^{b}	3.0
Cr	0.50 ± 0.24^{a}	1.53 ± 0.15^{b}	1.03 ± 0.24^{ab}	0.05

Cu	0.26±0.03^{c}	0.55±0.11^{a}	0.42±0.09^{b}	2
Fe	1.22±0.09^{c}	2.86±0.26^{a}	1.65±0.2^{b}	0.3
Ni	0.16±0.02^{b}	0.3±0.04^{c}	0.21±0.03^{a}	0.02
Co	0.18±0.02^{c}	0.42±0.06^{a}	0.25±0.03^{b}	0.005

*Means of variables with different superscripts on the same row are significantly different.

* World Health Organization (WHO, 2011).

Table 4 provides a representation of the mean values of heavy metals recorded from February to July 2020 for the Ogbogoro segment of the New Calabar River in Rivers State. The highest mean value (5.3±0.60) of Cu was observed in April, whereas the lowest (3.84±0.54) occurred in June. No significant differences were noted among the three stations (P>0.05).

Table 4.: The Temporal variation of The Heavy Metals in *Chrysichthysnigrodigitatus*

Metals	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**WHO (2011)/UNEP (2007)**
Zn	0.73± ±0.39^{a}	0.23± ±0.03^{e}	0.30± ±0.06^{d}	0.25± ±0.0^{e}	0.40± ±0.06^{c}	0.53± ±0.18^{b}	3.0
Pb	0.20± ±0.06^{a}	0.16± ±0.03^{b}	0.4± ±0.1^{c}	0.23± ±0.03^{a}	0.13± ±0.03^{b}	0.20± ±0.0^{a}	0.01
Cd	0.05± ±0.02^{c}	0.12± ±0.04^{b}	0.05± ±0.02^{c}	0.16± ±0.06^{a}	0.16± ±0.06^{a}	0.03± ±0.0^{c}	3.0
Cr	0.66± ±0.56^{c}	0.83± ±0.39^{b}	1.76± ±0.06^{a}	1.23± ±0.37^{b}	0.8± ±0.26^{b}	0.83± ±0.37^{b}	0.05
Cu	0.63± ±0.24^{a}	0.46± ±0.17^{ab}	0.43± ±0.03^{ab}	0.33± ±0.09^{b}	0.26± ±0.06^{c}	0.33± ±0.03^{b}	2
Fe	2.0± ±0.75^{b}	1.8± ±0.4^{c}	2.36± ±0.74^{a}	2.13± ±0.35^{ab}	1.86± ±0.35^{c}	1.3± ±0.45^{c}	0.3
Ni	0.3± ±0.06^{c}	0.23± ±0.03^{a}	0.3± ±0.06^{c}	0.23± ±0.03^{a}	0.13± ±0.03^{b}	0.16± ±0.03^{b}	0.02
Co	0.4± ±0.11^{c}	0.26± ±0.06^{b}	0.36± ±0.12^{a}	0.23± ±0.03^{b}	0.2± ±0.0^{c}	0.24± ±0.08^{b}	0.005

*The means of variables with distinct superscripts on the same row exhibits substantial differences.

*The United Nations Environment Programme (UNEP, 2007) and the World Health Organisation (WHO, 2011)

For Zn, the mean values (0.73±0.39) reached their peak in February, and the lowest value (0.23±0.03) was observed in March. No significant differences were found among the three stations (P>0.05). The mean values of Pb (0.4±0.1) were highest in April and lowest in June (0.13±0.03), with a significant difference among the three stations (P<0.05).

Regarding Cd, the values (0.16±0.06) were highest in May and June, while the lowest value (0.03±0.03) was observed in July. No significant differences were observed between stations (P>0.05). The mean values of Cr (0.63±0.24) were highest in February and lowest (0.26±0.06) in June, with no significant difference across the stations (P>0.05). Cu had its highest mean value

(0.63±0.24) in February and the lowest (0.26±0.06) in June. No significant differences were observed between stations ($P>0.05$).
The highest mean values (2.36±0.74) for Fe were recorded in April, with the lowest (1.3±0.45) in July. A significant difference was evident among the three stations ($P<0.05$). Ni had its highest value (0.3±0.06) in February and April, while the lowest (0.13±0.03) was observed in June. No significant differences were found between the stations ($P>0.05$). The highest value (0.4±0.11) for Co was recorded in February, and the lowest (0.2±0.0) was observed in June. No significant differences were noted between stations ($P>0.05$).

4. Discussion

Spatial Variation in Physico-chemical Parameters

Table 1 presents the average values of different physical and chemical factors observed at three distinct stations within the Ogbogoro axis of the New Calabar River in Rivers State. These parameters are important indicators for assessing water quality and are used to evaluate their suitability for different purposes, such as drinking water or industrial use (Khan and Butt, 2022).

The results showed that water temperatures were relatively consistent across the three stations during the sampling period, indicating no significant fluctuations in temperature within the research area. The average water temperature falls within the normal range for tropical rivers and does not suggest thermal pollution or stress to aquatic life (Omer, 2019). Nevertheless, the average pH values suggest mildly acidic conditions while adhering to the safe drinking water quality standards established by the World Health Organization (WHO, 2011) and the Bureau of Indian Standards (BIS) (Verma*et al*., 2020). Acidic water can affect the nutrient availability for plants and potentially corrode metal pipelines (Das *et al*., 2013). Nevertheless, no significant changes in acidity were observed among the stations, as the pH values were similar.

It is important to note that these physicochemical parameters provide valuable insights into overall water quality and can serve as indicators of potential environmental impacts. To comprehensively evaluate water quality and its potential impact on aquatic ecosystems, a more extensive examination and interpretation of supplementary parameters, including conductivity, total dissolved solids (TDS), total suspended solids (TSS), alkalinity, hardness, and others are necessary. By examining these characteristics, researchers and stakeholders can better understand the current condition of the Ogbogoro Axis of the New Calabar River and make informed management and conservation decisions. Regular monitoring and research initiatives are crucial for consistently assessing water quality and ensuring the sustainable use of this important water resource.

TSS readings represent the volume of suspended matter in water and serve as a measure of turbidity. The mean TSS values obtained were relatively low, suggesting high water clarity and minimal turbidity. The similarity in the mean TSS values across the stations suggests little variation in the concentration of suspended solids within the research area. It is important to highlight that elevated TSS levels can hinder light transmission, reduce dissolved oxygen levels, and negatively impact aquatic life (Patel *et al*., 2022).

However, notable disparities in conductivity and total dissolved solids (TDS) were observed among the three locations, suggesting varying levels of dissolved mineral and salt compounds present in water. High conductivity and TDS levels can affect water taste, hardness, and corrosiveness and may indicate the presence of pollutants such as pesticides, fertilizers, or industrial effluents (Lemessa*et al*., 2023). The observed large fluctuations in TDS values among the stations suggest changes in the concentration of dissolved solids, potentially influenced by factors such as sediment composition, industrial discharge, or natural mineral deposits. Conductivity readings also provide information about the dissolved ion concentrations and represent the electrical permeability of the water. The significant differences in conductivity values between the three sites indicate changes in mineral composition or salt levels within the research area. These results highlight the importance of continuous monitoring of TSS, conductivity, and TDS as metrics for assessing water quality. They provide valuable information on the presence of dissolved salts, minerals, and suspended particles, which can impact the general well-being of aquatic ecosystems and potential human uses of water resources.

The average salinity readings varied among the three sites, suggesting the influence of evaporation or seawater intrusion on the river water. Salinity can affect the osmotic balance of aquatic organisms and limit their distribution (Bal*et al.*, 2022). Based on the measured salinity values, the research area exhibited a relatively low-to-moderate salinity range. The salinity levels at the stations were similar, indicating no regular freshwater or saltwater incursion.

The elevated values found at station 2 can be attributed to the presence of calcium and magnesium ions in the water and the low values at station 1, as indicated by the mean hardness results. The significantly different hardness readings among the three stations suggest variations in the mineral content or the presence of dissolved ions, which can influence water quality and aquatic life (Kanungo*et al.*, 2018). Hardness levels can also impact the soap lathering, scaling, and corrosion of pipes and appliances (Egbueri, 2022). Understanding changes in salinity and hardness is essential for evaluating water quality and the appropriateness of its use in several sectors, including agriculture, aquaculture, and potable-water provision.

The average dissolved oxygen (DO) levels at the three sites indicated poor water quality and limited support for aquatic life. Dissolved oxygen (DO) levels are subject to several factors, including temperature, organic matter, photosynthesis, and respiration. The changes detected in dissolved oxygen (DO) values suggest that there are differences in oxygen levels among the different stations. These variations can substantially impact the respiratory and survival capabilities of aquatic organisms (Null *et al.*, 2017). In addition, the average turbidity values were low across all three sites, indicating reduced light penetration and water visibility. Turbidity is influenced by factors such as total suspended solids (TSS), algal content, water color, and depth (Adhar*et al.*, 2021).

The discrepancies in turbidity values suggest varying degrees of water purity at different stations, which can affect light penetration and impact the growth and productivity of aquatic plants. The ability of water to withstand pH fluctuations caused by acid inputs was demonstrated by the mean alkalinity values, which were higher at station 2 and lower at station 1. Alkalinity serves as a buffer against acidic contaminants, protecting aquatic life from pH variation (Lawson, 2011). The significantly different alkalinity values among the three stations suggest variations in buffering ability and carbonate and bicarbonate concentrations, which can influence the pH stability and dynamics in aquatic ecosystems.

Temporal Variation in Physico-chemical Variables

The mean values of different physical and chemical variables for the Ogbogoro axis of the new Calabar River in Rivers State for the period of February to July 2020 are provided in Table 2. The findings show that water temperature was highest in June and lowest in April, reflecting seasonal changes and external factors, such as weather conditions and solar radiation. These temperature variations can affect the metabolic rates, reproduction, and behavior of aquatic organisms (Zhang et al., 2018). Furthermore, fluctuations in temperature can affect dissolved oxygen levels, biological activity, and chemical processes occurring in water (Espinosa-Díaz*et al.*, 2021).

In the Ogbogoro segment of the New Calabar River, the pH values indicate a slightly acidic environment, ranging from 6.56 6.90. These pH levels have the potential to impact the survival and growth of aquatic organisms and can influence the availability of nutrients, metals, and contaminants in water (Davies and Ekperusi, 2021). The highest pH reading was recorded in May, while the lowest occurred in June; this variation may be attributed to natural factors or fluctuations in organic matter or pollutant inputs (Madhav*et al.*, 2020). It is crucial to monitor the pH levels because of their capacity to negatively affect aquatic organisms and disrupt ecosystem processes when extreme values are present (Espinosa-Díaz*et al.,* 2021).

TSS values provide an indication of the quantity of suspended particles present in the water, which can have implications for water clarity, turbidity, and the extent to which light can penetrate the water column (Tomperi*et al.*, 2022). The TSS values were highest in May and lowest in February. The significant difference observed between the months indicated variations in the number of suspended particles in the water (Cox *et al*., 2019). Higher TSS levels in May may be associated with increased sediment runoff or the presence of algal blooms (Zhang et al., 2018). TSS can affect water clarity, light penetration, and nutrient availability, thus impacting aquatic plants and animals (Sulistiawati*et al.*, 2020). Seasonal changes in rainfall, runoff, erosion, and sedimentation can contribute to these variations (Davies and Ekperusi, 2021).

The conductivity values quantify the capacity of water to facilitate the flow of electric current, and their magnitude is contingent on the quantity and composition of dissolved ions (Rusydi, 2018). April exhibited the highest recorded conductivity value, while February had the lowest recorded conductivity value. The relatively stable conductivity values across the months suggest a certain level of stability in mineral content or salinity levels (Davies *et al*., 2021b). The low conductivity values, ranging from 37.66 to 56.0 µS/cm, indicate low salinity and low mineral content in the Ogbogoro axis of the new Calabar River. However, higher conductivity may indicate the influence of dissolved salts or other ions in the water (Davies and Ekperusi, 2021).

TDS measurements showed the highest values in March, reaching their lowest levels in June. This pattern may be attributed to variations in the concentration of dissolved solids, which are notably affected by runoff, agricultural activities, or industrial discharges (Sabha*et al*., 2019). TDS levels can affect water quality, taste, and suitability for specific uses (Cox *et al.*, 2019). The TDS values, ranging from 2792.33 to 3926.66 mg/L, indicate high salinity and high mineral content (Islam and Guha, 2013). However, the TDS values did not vary significantly across months, suggesting a stable dissolved solid composition.

Salinity reflects the amount of salt in water and can affect osmoregulation, metabolism, and distribution of aquatic organisms (Ramaglia*et al*., 2018). May had the highest reported salinity value, while the lowest recorded value was observed in March. The monthly variations in salinity levels suggest temporal changes in saltwater intrusion or freshwater input. Salinity levels can affect the osmotic balance and distribution of aquatic organisms and their distribution (Bal*et al.*, 2022). The salinity values, ranging from 16.10 to 27.06 ppt, indicating a brackish water body around the Ogbogoro River with a mixture of fresh and saltwater sources.

Hardness measures the concentration of calcium and magnesium ions in water and can affect scaling, corrosion, and soap formation (Egbueri, 2022). March had the highest recorded hardness rating, while June displayed the lowest observed value. The absence of significant differences across the months suggests a relative stability in mineral content. The hardness values, ranging from 127.0 to 169.0 mg/L as $CaCO_3$, indicate a moderate level of hardness. Hardness levels do not vary significantly, indicating stable water quality in terms of hardness level.

The measurement of dissolved oxygen (DO) values is crucial in assessing the quantity of oxygen present in water, playing a vital role in aerobic respiration and decomposition processes (Espinosa-Díaz*et al*., 2021).

Spatial Variation in Heavy Metals in Silver Catfish (*Chrysichthysnigrodigitatus*)

The mean values of heavy metals at the three stations along the Ogbogoro axis of the new Calabar River, located in the river state, are reported in Table 3. The mean concentrations of calcium (Ca) exhibited notable variations among the three sites and were below the permissible thresholds for potable water as defined by the World Health Organization (WHO, 2011).

Davies and Oghenetekevwe (2023) found no significant variation in average zinc levels across different stations, suggesting uniform levels of this heavy metal in the research region. The concentrations of zinc in water samples range from 0.26 to 0.64 mg/L, within the World Health Organisation's permissible limits for drinking water. This indicates a consistent Zn concentration in the water quality. However, excessive Zn levels can lead to toxicity and negatively impact the taste of water, as noted by Omer (2019). However, it is important to monitor Zn levels over time because higher concentrations can be detrimental to aquatic organisms and may indicate pollution from industrial or agricultural sources (Davies and Ekperusi, 2021).

Lead is a hazardous metallic element known for its potential to cause neurological, circulatory, renal, and reproductive problems in aquatic organisms and humans (Collin *et al*., 2022). The mean Pb values showed no significant differences among the three stations. The recorded levels of Pb within the designated study region were comparatively low; however, they were above the permissible threshold for drinking water as defined by the World Health Organization (2011), which is 0.01 mg/L. Lead is a hazardous metallic element known to induce neurological and cardiovascular complications. However, Pb values did not vary significantly across the three stations, suggesting that the water quality was uniformly contaminated with Pb.

The presence of Cd in water poses a significant health hazard to both aquatic organisms and human beings. This toxic metal has been linked to numerous adverse effects including kidney damage, bone loss, cancer, and various other health complications (Akoto*et al*., 2019). Cd levels span from 0.06 to 0.17 mg/L, exceeding the permissible limit for drinking water set by the World Health Organization in 2011, which is 0.003 mg/L. The variations in Cd levels among the three sites can be attributed to differences in industrial or agricultural activities and discharge of wastewater effluents (Davies *et al*., 2021a). These observations may suggest regional disparities in pollution prevalence or sources of this specific heavy metal (Davies *et al*., 2021b). Nonetheless, it is essential to acknowledge that elevated Cd concentrations can adversely affect aquatic life, serving as an indicator of pollution originating from industrial operations or improper waste disposal practices (Davies *et a*l., 2021a). Odekina*et al*. (2021) recommend regular monitoring as a necessary step to identify potential hazards and implement appropriate mitigation measures.

Chromium is a nutrient necessary for humans when present in trace quantities; however, it can also lead to skin irritation, allergic reactions, lung damage, and cancer in both aquatic organisms and humans (Akankali*et al*., 2019). The levels observed across the stations exceeded the permissible limits for drinking water set by the WHO in 2011, which are 0.05 mg/L for total chromium and 0.01 mg/L for hexavalent chromium, the most toxic form. Among the three stations, there was a significant disparity in the average Cr values, with Station 2 exhibiting the highest mean values and Station 1 the lowest. The difference in Cr levels indicates variations in the sources or contamination of this heavy metal across the study area (Davies *et al*., 2021b) and could also be due to differences in mining, metallurgical activities, or natural sources (Šajn*et al*., 2022). However, higher Cr concentrations can have detrimental effects on aquatic ecosystems and human health (Anyanwu and Chris, 2023). Therefore, monitoring and managing Cr levels are essential to prevent pollution and minimize potential risks.

Copper is an essential nutrient for aquatic organisms and humans but can also cause gastrointestinal distress, liver damage, and kidney failure at high doses (Akankali*et al*., 2019). The Cu values ranged between stations within the acceptable limit for drinking water according to the WHO (2011), which is 2 mg/L. The values varied significantly across the three stations, suggesting that the water quality was stable in terms of copper content. However, the highest mean value of Cu was recorded at station 2 and the lowest was observed at station 1, with no significant difference across the stations. The observed Cu levels were consistent across the study area. However, it is important to note that elevated concentrations can be toxic to aquatic organisms, indicate pollution from various sources, and continue monitoring to ensure that they remain within acceptable limits is essential (Bosch *et al*., 2016). Station 2 had the highest mean values, whereas Station 1 had the lowest, and there were significant differences between the three stations. This suggests spatial variation in the sources or inputs of this heavy metal (Davies *et al*., 2021a).

Higher Iron (Fe) concentrations can impact water quality and have implications for aquatic life (Šajn*et al*., 2022). Therefore, monitoring Fe levels is crucial for assessing potential risks and ensuring appropriate management of water resources. Fe is an essential nutrient for aquatic organisms and humans but can also cause staining, turbidity, and taste problems in water (Madhav*et al*., 2020). The Fe values range between 1.22 and 2.86 mg/L, which are above the acceptable limit for drinking water according to the WHO (2011), which is 0.3 mg/L. The Fe values varied significantly across the three stations, which could be due to differences in soil erosion, corrosion, or natural sources.

The average values of Ni quantify the concentration of nickel present in water, a hazardous metal known to induce dermatitis, respiratory ailments, and cancer in both aquatic creatures and people (BökeÖzkoç&Arıman, 2023). The maximum concentration of Ni was observed at Station 2, whereas the lowest concentration was reported at Station 1. Notably, there was a substantial disparity in the Ni levels across the three sites. The observed discrepancies in Ni levels across the three locations may be ascribed to disparities in industrial or municipal activity as well as natural sources. According to the World Health Organization (2011), the concentration of Ni in drinking water exceeds the permissible threshold of 0.02 mg/L. According to Santana *et al*. (2020), elevated Ni concentrations can be harmful to aquatic organisms, and may result from industrial activities or natural mineral deposits. Variations in Ni levels indicate spatial variations in the contamination or inputs of this heavy metal (Bing *et al*., 2019). Regular monitoring is essential to identify potential risks and implement appropriate mitigation measures.

Station 2 recorded the highest Co levels, whereas station 1 had the lowest. The observed variations in Co levels suggest differences in the contamination or sources of this heavy metal (Amangelsin*et al*., 2023). Elevated Co concentrations can adversely affect aquatic ecosystems and indicate pollution from various sources (Santana *et al*., 2020). Regular assessment of Co levels is essential to safeguard water quality and the well-being of aquatic organisms.

The Temporal Variation of The Heavy Metals in *Chrysichthysnigrodigitatus*

The average concentrations of heavy metals in the Ogbogoro portion of the New Calabar River in Rivers State from February to July 2020 are presented in Table 4. The observed concentrations exhibited both temporal and geographical fluctuations, indicating the influence of many sources and mechanisms on the dispersion and fate of pollutants in aquatic ecosystems. Overall, the levels of Cu, Zn, Pb, Cd, Cr, Ni, and Co in surface water were below the permissible thresholds set by the WHO (2011) and FEPA (1991) recommendations. However, it should be noted that the concentration of Fe was above the established limits at specific stations during particular months. Among the many heavy metals analyzed, only lead (Pb) displayed a discernible disparity across the three designated sites. Specifically, elevated concentrations of lead were observed at Station 1 compared to those at sites 2 and 3. This discrepancy suggests the possibility of a localized pollution source in close proximity to station 1.

The average concentrations of Cu, Zn, Pb, Cd, Cr, Ni, and Co decreased from February to July 2020, whereas that of Fe exhibited an increasing trend. These trends could be ascribed to seasonal variations influenced by factors such as rainfall, runoff, sedimentation, biogeochemical cycles, and the biological uptake of these metals (Chen *et al.*, 2021). The highest mean concentration was recorded in April, whereas the lowest was noted in June, with no substantial variance among the three stations for most of the heavy metals. The Cu levels remained relatively stable throughout the study period (Akankali*et al*., 2018). However, it is important to monitor Cu levels over time to ensure that they remain within acceptable limits, as elevated concentrations can be toxic to aquatic organisms and can indicate pollution from various sources (Onyemesili*et al.*, 2022).

The average concentrations of Zn were highest in February and lowest in March, with no statistically significant variation observed across the three sampling locations. The lack of significant differences in the Zn levels suggests relatively consistent concentrations of this heavy metal during the study period. However, continuous monitoring is necessary because higher concentrations can be detrimental to aquatic organisms and may indicate pollution from industrial or agricultural sources (Chris and Anyanwu, 2022).

The average levels of Pb ranged between 0.4±0.1 (highest in April) and 0.13±0.03 (lowest in June), with a significant difference observed across the three stations. The significant difference in Pb levels indicated spatial variations in contamination or sources of this heavy metal. The elevated concentrations of Pb and the significant differences across the three stations suggest the presence of Pb contamination in Ogbogoro Creek, posing potential health risks to humans and ecological risks to the aquatic ecosystem (Onyemesili*et al*., 2022).

The Cd concentrations peaked in May and June and reached their lowest levels in July, with no notable differences detected among the stations. The consistent Cd levels within the study period are in line with WHO's (2011) findings on heavy metals in marine fish meat and consumer health (Bosch *et al.*, 2016). Nevertheless, it is essential to maintain regular monitoring because of the potential toxicity of increased Cd concentrations in aquatic life, which might serve as an indicator of pollution originating from diverse sources (Saha*et al*., 2016).

The average concentrations of chromium (Cr) varied between 0.63±0.24 (highest in February) and 0.26±0.06 (lowest in June), with no statistically significant variation found across the sampling sites. The absence of statistically significant variations in Cr levels suggests stable concentrations of this heavy metal during the investigation (Akankali*et al.*, 2019). However, higher concentrations of Cr can negatively affect human health and aquatic ecosystems, emphasizing the importance of tracking its levels over time (Mishra *et al.*, 2019).

April had the highest average concentrations of Fe, while July displayed the lowest reported levels, with a significant difference observed between the three stations. The significant differences in Fe levels indicate spatial variations in the sources or inputs of this heavy metal (Liang *et al*., 2017). Higher concentrations of Fe can affect water quality and have implications for aquatic life. Monitoring Fe levels is crucial for assessing potential risks and ensuring appropriate management of water resources (Gaber*et al*., 2013).

The highest concentrations of Ni were recorded in February and April, whereas the lowest value was observed in June, with no significant difference across the stations. The consistent Ni levels during the study period indicated relatively stable concentrations of this heavy metal (Song *et al*., 2014). However, continued monitoring is necessary because higher concentrations of Ni can have adverse effects on aquatic ecosystems and indicate pollution from various sources (Yoon *et al*., 2020).

Cobalt (Co) is crucial as a trace nutrient but can lead to adverse effects at elevated doses. The highest concentration of Co was recorded in February, whereas the lowest concentration was observed in June; no notable distinctions were evident among the stations. The significant variation in Co levels across the three stations can be attributed to differences in anthropogenic or natural sources (Zhang *et al*., 2018). Consistent Co levels during the study period indicate relatively stable concentrations. However, Co levels exceeded the acceptable limit for drinking water according to WHO (2011), emphasizing the need for continued monitoring to ensure that concentrations remain within acceptable limits (Saha*et al*., 2016; Bosch *et al.*, 2016). The observed disparities in heavy metal concentrations, in terms of both location and time, indicate potential pollution sources or natural factors affecting water quality (Gaber*et al*., 2013).

5. Conclusion

This study provides insights into the physicochemical parameters and heavy metal concentrations in the Ogbogoro section of the New Calabar River in Rivers State. Although water quality parameters vary across months and stations, most values remain within acceptable limits. However, specific parameters, such as pH, dissolved oxygen, and turbidity, raise concerns for aquatic life and human applications. Heavy metal concentrations generally fall below acceptable limits, except for iron (Fe), which can exceed these limits in certain cases. Pb contamination at Station 1 suggests a localized pollution source. Regular monitoring, mitigation measures, point source identification and control, public awareness initiatives, collaboration, and stakeholder involvement are recommended to protect the river from preservation and long-term use.

Declaration

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors". All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Conflict of Interest

The authors have no competing interests to declare that are relevant to the content of this article.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author upon reasonable request.

Consent to participate

Not applicable

Author Contributions

Conceptualization, Davies Ibienebo Chris, Okechukwu Kenneth Wokeh; methodology, Davies Ibienebo Chris; formal analysis, Okechukwu Kenneth Wokeh, FathurrahmanLananan, NooraBarzkar, Mohamad Nor Azra; investigation, Mohamad Nor Azra; data curation, Davies Ibienebo Chris, Mohamad Nor Azra, FathurrahmanLananan; writing—original draft preparation, Davies Ibienebo Chris, Okechukwu Kenneth Wokeh, Lee Seong Wei; writing—review and editing, Mohamad Nor Azra; visualization, NooraBarzkar, Olga Babich, StansilavSukhikh, Davies Ibienebo Chris, Okechukwu Kenneth Wokeh, Lee Seong Wei. All authors have read and agreed to the published version of the manuscript.

Funding

No funding was obtained for this study.

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