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# Insights into the quality index of surface water from the Okpare Olomu River, Southern Nigeria

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This study evaluated the physicochemical characteristics, heavy metal contamination, and water quality of the surface water from the Okpare Olomu River in Ughelli South, Delta State, Nigeria. Water samples from four stations were analysed for physicochemical parameters, heavy metals (Fe, Pb, Cd, Cr, Cu, Zn, Mn), and the total hydrocarbon content (THC). The pH ranged from 5.71 to 5.86, indicating slightly acidic water. Electrical conductivity (17.23–24.23 μS/cm), total dissolved solids (6.18–13.46 mg/L), and total suspended solids (71.20–75.20 mg/L) were low, while dissolved oxygen (5.12–6.24 mg/L) and biochemical oxygen demand (3.34–7.43 mg/L) reflected moderate water quality. Heavy metal concentrations followed the order: Fe (0.86–2.35 mg/L) > Pb (0.00–0.23 mg/L) > Cd (0.02–0.07 mg/L) > Cr (0.06–0.12 mg/L) > Cu (0.06–0.09 mg/L) > Zn (0.13–0.16 mg/L) > Mn (0.01–0.02 mg/L), with Fe, Pb, and Cd exceeding the permissible limits established by NESREA, USEPA, and the WHO. THC ranged 2.85–3.62 mg/L. The Water Quality Index (WQI: 136.21–1113.24) classified all stations as Grade E and unsuitable for drinking, while the Comprehensive Pollution Index (CPI: 0.66–2.20) indicated station 2 as severely polluted, stations 1 and 3 as moderately polluted, and station 4 as slightly polluted. Health risk assessment revealed non-carcinogenic risk due to arsenic exposure (HI > 1), and integrated carcinogenic risk suggested a high potential for cancer among consumers. These findings highlight the urgent need for mitigation strategies, continuous monitoring, and public health interventions to reduce heavy metal contamination and protect communities dependent on the Okpare Olomu River.

**Keywords:** the Okpare Olomu River, Water Quality Index (WQI), heavy metals, Comprehensive Pollution Index (CPI), health risk assessment

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## INTRODUCTION

Freshwater resources are essential for sustaining human health, supporting livelihoods, and maintaining ecological integrity. In Nigeria's Niger Delta region, rivers such as the Okpare Olomu River in Ughelli South serve as critical sources of water for domestic use, agriculture, and fisheries. However, these water bodies are increasingly threatened by anthropogenic pressures, including industrial effluents, oil exploration activities, sewage discharge, and agricultural runoff (Edward et al., 2013; Edori, Kpee, 2016; Edori, Marcus, 2019). Studies across the Niger Delta have documented significant alterations in physicochemical parameters and elevated heavy metal concentrations, highlighting the vulnerability of surface waters to pollution and their potential impact on public health and aquatic ecosystems (Kanu et al., 2011; Edori, Nna, 2018; Edori, Kieri, Festus, 2019). Despite these insights, systematic and integrative assessments of river water quality in the region remain limited.

The Okpare Olomu River exemplifies a freshwater system exposed to diverse pollution sources. It supports the livelihoods of local communities through fishing, farming, and domestic water use (Bankole et al., 2024). Previous studies in the Niger Delta have demonstrated the risks associated with untreated effluents and industrial discharges, including elevated concentrations of heavy metals and shifts in key physicochemical parameters (Edward et al., 2013; Edori, Nna, 2018; Edori, Kieri, Festus, 2019). Despite its ecological and socioeconomic importance, the Okpare Olomu River has received limited attention in terms of comprehensive water quality assessment using integrative tools. The Water Quality Index (WQI) is a widely recognised approach for evaluating the overall status of surface waters. By integrating multiple physicochemical parameters into a single value, the WQI provides a clear and quantitative measure of water quality that is easily interpretable by policymakers, stakeholders, and the public (Tyagi et al., 2020; Biose et al., 2024). Applying this tool to rivers under pressure from anthropogenic activities allows for identification of pollution hotspots, assessment of potential ecological and health risks, and support for informed water resource management decisions (Ojekunle et al., 2020).

Although several studies have characterised physicochemical and heavy metal contamination of the rivers in the Niger Delta (Edori, Kpee, 2016; Edori, Marcus, 2019; Edward et al., 2013), few have employed the WQI or combined it with multivariate statistical techniques to provide an integrative evaluation of water quality. Site-specific data for the Okpare Olomu River remain sparse, leaving a knowledge gap regarding spatial variation, pollution sources, and overall river health (Anyanwu et al., 2023). This study aims to fill this gap by assessing the water quality of the Okpare Olomu River using the WQI and multivariate analyses, thereby providing baseline data to inform sustainable water management strategies in the region.

## MATERIALS AND METHODS

### Study area

The study was carried out in Delta State, located in the Southern region of Nigeria, at latitude 5°30′0.00″N and longitude 6°00′0.00″E. Sampling locations along the Okpare Olomu River in Ughelli South were selected based on criteria such as population activity and post-oil spill incidents. Surface water and bottom sediment samples were collected from four designated stations along the river to capture spatial variability in water quality. Delta State covers a total land area of 16,842 km$^2$ (Ebewore, 2020) and is classified within the tropical rainforest zone, characterised by rich ecosystems supporting diverse aquatic and terrestrial flora and fauna. It is recognised as one of Nigeria's most ecologically sensitive regions (NDES, 1997; Uyigue and Agho, 2007; Ekpo et al., 2018).

### Climate

The region falls within the equatorial climate belt of the world and the tropical rainforest zone of Nigeria. It experiences a distinct wet and dry season pattern, with a mean annual rainfall of approximately 3,000 mm, predominantly between April and October (Agbaire, Emoyan, 2012; UNDP, 2006). The wet season, spanning April to October, is characterised by heavy rainfall, high relative humidity, and lower atmospheric temperatures, while the dry season, from November to March, is marked by lower humidity and higher atmospheric temperatures (Okumagba, Ozabor, 2014). Temperature variations in the area are generally moderate and fairly constant throughout the year. The average monthly temperature during the warmest months ranges from 28°C to 33°C, whereas the coolest months record average temperatures between 22°C and 26°C (Okumagba, Ozabor, 2014). Coupled with the region's ecological characteristics, these climatic conditions significantly influence hydrological processes, water quality, and the distribution of aquatic organisms in the Okpare Olomu River.

## Sample collection

Surface water samples were collected from four designated stations along the Okpare Olomu River in Ughelli South, Delta State. The geographic coordinates of each sampling station were recorded using a Global Positioning System (GPS) to ensure accurate spatial referencing. The sampling stations were as follows:

| | |
|---|---|
| Station 1/Ejeba Okpare | N05°27.795′ E005°54.409′ |
| Station 2/Uhrovwodo Okpare | N05°27.600′E005°53.980′ |
| Station 3/Ogbe Okpare | N05°27.115′E005°53.742′ |
| Station 4/Arovie Okpare | N05°25.859′ E005°53.569′ |

Sampling was conducted quarterly over a twelve-month period to capture seasonal variations in water quality. Surface water samples were carefully collected following standard protocols to prevent contamination and ensure representative measurements. The study area and sampling stations are illustrated in Figure.

Collection of water samples

Water samples for physicochemical analysis were collected in clean, sterilised 1-litre polyethylene bottles, tightly capped, placed in a cooler box, and transported to the laboratory for analysis. All physicochemical analyses were performed in a national certified laboratory,

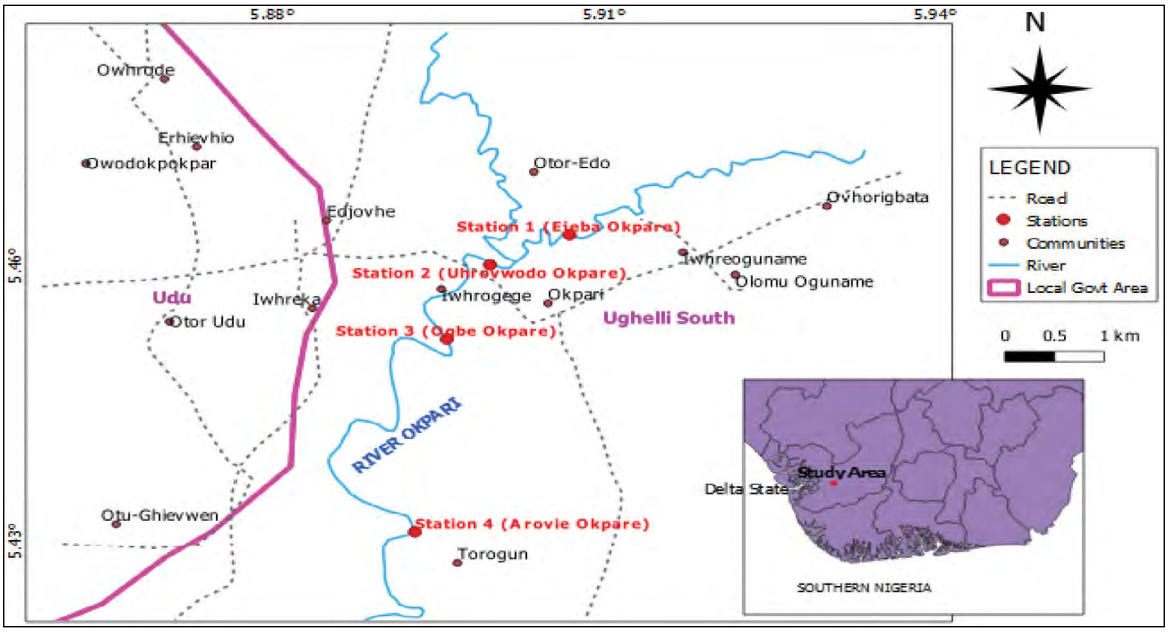

**Figure.** Map of Ughelli South showing water and sediment sampling stations (Source: ArcGIS Map) following standard quality assurance and quality control protocols (APHA, 2012).

### Sampling periodicity

The four sampling stations were visited quarterly from January to December 2020. A total of five field trips were conducted over the 12-month period, during which five sets of samples were collected from each station. Sampling was carried out between 7:00 a.m. and 11:00 a.m. (Nigerian time), proceeding sequentially from station 1 (upstream) to station 4 (downstream). Surface water and bottom sediment samples were collected concurrently at each station for the determination of various physicochemical parameters. Prior to use, all field equipment was checked and calibrated according to the manufacturer's specifications.

### Laboratory analysis

Physicochemical analyses of the water samples were carried out following standard protocols with appropriate quality assurance and quality control measures (APHA, 2012). True colour was measured in Pt-Co units using a HACH DR 2000 colorimeter at a wavelength of 455 nm, while in situ parameters, including water temperature, pH, and electrical conductivity, were determined using a Gilson mercury-in-glass thermometer, a digital pH meter (Hanna HI 1922 model), and a conductivity meter (Hanna HI96107 model), respectively. Surface turbidity was assessed in the laboratory using a HACH DR/920 colorimeter with a visible spectrophotometer at 420 nm. Total solids (TS) were determined gravimetrically by oven-drying 10 mL of the sample at 103–105°C for 2½ hours, and total dissolved solids (TDS) were measured using a conductivity meter, with total suspended solids (TSS) obtained as the difference between TS and TDS. Dissolved oxygen (DO) concentrations were fixed in the field using Winkler reagents and determined titrimetrically in the laboratory following the Azide Modification of the Winkler Method, while biochemical oxygen demand (BOD) was measured after a five-day incubation using the Winkler technique. Chemical oxygen demand (COD) was evaluated using the dichromate method with potassium dichromate, sulfuric acid, and silver sulphate under controlled heating. Total alkalinity was estimated titrimetrically with methyl orange as an indicator and 0.02 N $H_4SO_4$ as titrant, and total hardness was determined by titrating a buffered sample with EDTA using ManVer 2 indicator. Chloride concentrations were measured by Mohr's titration method with potassium chromate as the indicator, and exchangeable bases (potassium, sodium, calcium, and magnesium) were analysed using a pre-calibrated flame photometer (Technicon Auto Analyzer IV) with lithium as an internal standard. Sulphate, nitrate, and phosphate concentrations were determined colorimetrically using HACH reagents, and total hydrocarbon content (THC) was assessed following ASTM (2003) procedures through triple extraction with toluene and spectrophotometric measurement at 420 nm.

### Digestion and analysis of heavy metals

The concentrations of copper, iron, zinc, cadmium, lead, manganese, and chromium in the water samples were determined following standard laboratory procedures. Ten millilitres of each water sample were digested using an Aluminum Block Digester (BD 110) with the addition of 4 mL of perchloric acid, 20 mL of concentrated nitric acid, and 2 mL of concentrated sulfuric acid. The mixture was heated until the evolution of white fumes and a clear solution was obtained. The resulting clear solution was then analysed for metal content using an Atomic Absorption Spectrophotometer (Solar 969 Unicam Series Model). Heavy metal determinations were conducted in accordance with the methods outlined by the Association of Analytical Chemists (AOAC, 2000).

## Multivariate analysis

### Water quality assessment

The Water Quality Index (WQI) was employed to evaluate the suitability of the Okpare Olomu River water for domestic and consumption purposes. The WQI was calculated using the weighted arithmetic water quality index method, as described by Tyagi et al. (2013), Oboh and Agbala (2017), Egun and Ogiesoba-Eguakun (2018), Egun and Oboh (2021), and Biose et al. (2024) with the National Environmental (Surface and Groundwater Quality Control) Regulation guidelines (NESREA, 2011) serving as the reference standard. The WQI was determined using the expression:

$$WQI = \Sigma W_i Q_i / \Sigma W_i.$$

The quality rating scale ($Q_i$) for each parameter was calculated by using the following equation;

$$Q_i = 100\ [(V_i - V_0) / (S_i - V_0)]$$

where $V_i$ = estimated Concentration of the *i* th parameter of interest in the analysed water.

$V_0$ = the ideal value of the *i* th parameter in pure water.

$V_0 = 0$ (except pH = 7.0; and DO = 14.6 mg $l^{-1}$)

$S_i$ = recommended Standard value of the *i* th parameter (NESREA, 2011).

The unit weight ($W_i$) for each water quality parameter:

$$W_i = K/S_i$$

where $K$ = proportionality constant; $K = 1/\Sigma\ (1/S_i)$

The rating of water quality according to WQI is given in Table 1.

### Comprehensive Pollution Index (CPI)

Comprehensive Pollution Index (CPI) was applied to assess the pollution status of the river. CPI is calculated as the arithmetic mean of the single-factor pollution indices ($P_i$) of selected pollutants using the formula:

Table 1. **Water quality ratings according to the weighted arithmetic water quality index method (Tyagi et al., 2013)**

| Levels | Rating of Water Quality | Grading |
|---|---|---|
| 0–25 | Excellent water quality | A |
| 25–50 | Good water quality | B |
| 51–75 | Poor water quality | C |
| 76–100 | Very poor water quality | D |
| >100 | Unsuitable for drinking purposes | E |

$$CPI = \frac{1}{n}\sum_{i=1}^{n} P_i.$$

$P_i$ = the pollution index of pollutant *i*.

The PI (excluding DO) increases with the pollutant's concentration and its equation is as follows:

$$P_i = \frac{C_i}{S_i}.$$

$C_i$ = the measured concentration of the pollutant (mg $l^{-1}$)

$S_i$ = national water quality standard permissible limit for the pollutant in surface water (National Environmental Regulation guidelines, 2011).

$n$ = the number of chosen pollutants.

The water quality factor $P_i$ is classified into five grades, as listed in Table 2 (Li et al., 2010).

The pollution status of the water according to CPI is given in Table 3.

Table 2. **Standard grades for single-factor pollution index (PI) (Li et al., 2010)**

| Single factor pollution index (PI) | Pollution grades |
|---|---|
| Less than 0.4 | Non-pollutant |
| 0.4–1.0 | Slight pollutant |
| 1.0–2.0 | Medium pollutant |
| 2.1–5.0 | Heavy pollutant |
| More than 5.0 | Serious pollutant |

Table 3. **Standard surface water quality categories based on CPI (Li et al., 2010)**

| The comprehensive pollution index (CPI) | Level | Explanation of the water quality grades |
|---|---|---|
| Less than 0.2 | I | Cleanness |
| 0.21–0.4 | II | Sub-cleanness |
| 0.41–1.0 | III | Slight pollution |
| 1.01–2.0 | IV | Moderate pollution |
| More than 2.01 | V | Severe pollution |

## Human health risk assessment

Exposure to toxic heavy metals poses significant risks to humans living near contaminated aquatic ecosystems, particularly through oral ingestion of water. In this study, the chronic daily intake (CDI) of heavy metals via oral exposure was estimated using the equation proposed by USEPA (2012a):

$$CDI_{oral} = \frac{C_m \times IR \times EF}{B_w}$$

where $C_m$ is the mean concentration of element in water (mg/L)

*IR* – the ingestion rate of water (2 L/day for adults)

*EF* – the exposure factor

$B_w$ – the body weight (approximate average of 70 kg for adults)

$$\text{Exposure Factor } (EF) = \frac{E_{fr} \times IED}{AT}.$$

where $E_{fr}$ is the frequency of exposure (days/year, i.e., 365 days/year)

ED – exposure duration (conventional life expectancy of 70 years for adults)

AT – averaging time; for non-carcinogenic risk, AT is equal to ED × 365 days. While for carcinogenic risk, AT is the average life expectancy of people (USEPA, 2004). In Nigeria, average life expectancy for adults is 55 years.

### *Non-carcinogenic risk assessment*

The potential non-cancer risk of heavy metal concentrations in the surface water was characterised using the target hazard quotient (THQ) and hazard index (HI) (USEPA, 2012b)

Target hazard quotient (THQ):

$$THQ_{oral} = \frac{CDI_{oral}}{AT_{oral}}.$$

where RfD (mg/kg/day): reference dose level of a particular metal for oral exposure (USEPA, 2021).

Hazard index (HI):

$$\text{HI} = \sum THQ_{oral}.$$

The exposed population is considered safe to health risk where HI < 1.0; and when HI > 1.0, there may be a concern for potential non-cancer health effect (Tripathee et al., 2016; Saha, Paul, 2018).

### *Carcinogenic risk assessment*

The potential carcinogenic risk of heavy metals in the water were estimated using the incremental or excess individual lifetime cancer risk. Carcinogenic risk (CR) is the product of daily exposure dose (CDI) and cancer slope factor (CSF).

$$CR_i = \text{CDI}_i \times \text{CSF}_i$$

where $CR_i$ is the carcinogenic risk of heavy metals through oral or dermal absorption,

$CDI_i$ is the daily exposure dose of carcinogenic pollutants,

$CSF_i$ is the cancer slope factor of carcinogenic pollutants.

The integrated carcinogenic risk (ICR) can also be identified as the sum of carcinogenic risks exposure by various pollutants via different pathways, with the assumption that there is no antagonism and synergism between pollutants:

$$ICR = \sum_{i=1}^{n} CR_i.$$

USEPA (2005) believes that carcinogenic risk value for humans is acceptable within $1 \times 10^{-4}$, while the maximum acceptable risk value recommended by the International Commission on Radiological Protection (ICRP) is $5 \times 10^{-5}$ (Zeng et al., 1998).

For clarity of risk evaluation results, risk classification based on the Delphi method, assessment criteria of USEPA and ICRP was carried out in this study as shown in Table 4 (Yuan et al., 2011; Liu et al, 2015; Li et al., 2017).

## Statistical Analysis

Descriptive statistics were used to summarise and analyse the water quality data, including measures of central tendency and variability. All computations for the Water Quality Index (WQI) and Comprehensive Pollution Index (CPI) were performed using Microsoft Excel 2013, providing a basis for evaluating spatial and temporal variations in river water quality.

## RESULT AND DISCUSSION

### Physico-chemical characteristics of water samples from the Okpare Olomu River

Water plays a critical role in the economy, industry, agriculture, and overall human activities. However, anthropogenic pollution continues to threaten freshwater bodies worldwide. The physicochemical parameters of rivers provide essential information about water quality and its suitability for humans and aquatic organisms (Animesh, Saxena, 2011; Marimuthu, Rajendran, 2017). Numerous studies have documented that freshwater systems are increasingly impacted by human activities, which induce changes in hydrologic regimes, water quality, and biodiversity (Patil et al., 2012; Dessu et al., 2014; Garabaa, Zielinski, 2015).

The physicochemical parameters measured in this study (Table 5) highlight the water quality status and variability along the stretch of the Okpare Olomu River. The pH values were relatively consistent across all four sampling stations, ranging from moderately acidic to slightly acidic, with average means of 5.71, 5.71, 5.86, and 5.85 at stations 1, 2, 3, and 4, respectively. The minimal variation between stations suggests a uniform acidic nature along the river. Nevertheless, these values were below the recommended range of 6.5–8.5 for drinking water as stipulated by NESREA (2015), USEPA, and the WHO (2008). pH is a key parameter influencing the solubility and mobility of heavy metals in water and sediment, and the slightly acidic nature observed in the Okpare Olomu River is comparable to findings reported by Iyama et al. (2019) in the Sagbama Creeks. Electrical conductivity (EC) reflects the ability of a material, whether liquid or solid, to conduct electricity, and it is influenced by the presence of dissolved ions such as $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $Cl^{-}$, and other charge-carrying particles in water or sediment (Nazir et al., 2015; Edori et al., 2019). In this study, the average mean EC values were 22.54, 17.23, 17.28, and 24.23 µS/cm at stations 1, 2, 3, and 4, respectively. Comparatively, Edori and Nna (2018) recorded lower.

Table 4. **Carcinogenic risk evaluation and classification based on the Delphi method (Yuan et al., 2011; Liu et al., 2015; Li et al., 2017)**

| Risk grades | | Range of risk value | Acceptability |
|---|---|---|---|
| Grade I | Extremely low risk | $<10^{-6}$ | Completely accept |
| Grade II | Low risk | $(10^{-6}, 10^{-5})$ | Not willing to care about the risk |
| Grade III | Low-medium risk | $(10^{-5}, 5 \times 10^{-5})$ | Do not mind about the risk |
| Grade IV | Medium risk | $(5 \times 10^{-5}, 10^{-4})$ | Care about the risk |
| Grade V | Medium-high risk | $(10^{-4}, 5 \times 10^{-4})$ | Care about the risk and willing to invest |
| Grade VI | High risk | $(5 \times 10^{-4}, 10^{-3})$ | Pay attention to the risk and take action to solve it |
| Grade VII | Extremely high risk | $>10^{-3}$ | Reject the risk and must solve it |

Table 5. **Summary of physico-chemical characteristics of the water from the Okpare Olomu River**

| | **Station 1** | **Station 2** | **Station 3** | **Station 4** | | | |
|---|---|---|---|---|---|---|---|
| **Parameters** | **$\bar{x}$ ± SD (min-max)** | **$\bar{x}$ ± SD (min-max)** | **$\bar{x}$ ± SD (min-max)** | **$\bar{x}$ ± SD (min-max)** | ***p*-value** | **NESREA 2015** | **USEPA/WHO 2004/2011** |
| Colour | Pale yellow | Pale yellow | Pale yellow | Pale yellow | | | |
| pH | 5.71 ± 0.30<br>(5.47–6.20) | 5.71 ± 0.19<br>(5.40–5.93) | 5.86 ± 0.48<br>(5.37–6.65) | 5.85 ± 0.61<br>(5.36–6.92) | $p > 0.05$ | 6.5–8.5 | 6.5–8.5 |
| EC (us/cm) | 22.54 ± 5.09<br>(16.00–26.80) | 17.23 ± 6.47<br>(10.80–24.20) | 17.28 ± 4.26<br>(12.40–21.60) | 24.23 ± 4.01<br>(17.14–27.00) | $p > 0.05$ | 1000 | 500<br>1000 |
| Turbidity (NTU) | $8.03^{a} \pm 0.11$<br>(7.95–8.15) | $7.03^{b} \pm 0.48$<br>(6.50–7.51) | $7.71^{a} \pm 0.33$<br>(7.35–7.96) | $7.09^{b} \pm 0.31$<br>(6.75–7.32) | $p < 0.01$ | < 5.0 | 0.5–1.0<br><5.0 |
| TDS (mg/L) | $8.00^{b} \pm 0.71$<br>(7.00–9.00) | $6.46^{c} \pm 0.48$<br>(6.10–7.30) | $6.18^{c} \pm 0.46$<br>(5.90–7.01) | $13.46^{a} \pm 0.42$<br>(13.20–14.22) | $p < 0.01$ | 500 | 500 |
| TSS (mg/L) | $74.00^{b} \pm 0.71$<br>(73.00–75.00) | $71.20^{d} \pm 1.10$<br>(70.00–72.00) | $72.60^{c} \pm 0.89$<br>(71.00–73.00) | $75.20^{a} \pm 0.45$<br>(75.00–76.00) | $p < 0.01$ | 500 | 500 |
| TS (mg/L) | $82.00^{b} \pm 0.71$<br>(81.00–83.00) | $77.66^{d} \pm 0.86$<br>(76.30–78.30) | $78.78^{c} \pm 0.43$<br>(78.01–79.00) | $88.66^{a} \pm 0.55$<br>(88.20–89.30) | $p < 0.01$ | 500 | 500<br>1000 |
| DO (mg/L) | 5.54±0.58<br>(5.00–6.40) | 5.12±1.07<br>(4.30–7.00) | 5.46±2.44<br>(4.11–9.80) | 6.24±0.90<br>(4.70–6.80) | $p > 0.05$ | | 7.5–10 |
| BOD (mg/L) | 6.70±2.90<br>(4.50–11.35) | 6.46±2.90<br>(4.20–10.90) | 3.34±0.83<br>(2.18–4.40) | 7.43±4.97<br>(3.60–16.15) | $p > 0.05$ | 30 | 4.0–7.5 |
| COD (mg/L) | $40.20^{a} \pm 15.01$<br>(32.00–67.00) | $30.80^{a} \pm 7.43$<br>(26.00–44.00) | $25.20^{b} \pm 1.79$<br>(22.00–26.00) | $42.40^{a} \pm 6.39$<br>(34.00–52.00) | $p < 0.01$ | | 10.0 |
| Alkalinity (mg/L) | $8.37^{b} \pm 1.47$<br>(6.20–10.20) | $7.42^{b} \pm 2.13$<br>(6.10–11.00) | $6.92^{b} \pm 0.68$<br>(6.00–7.90) | $11.12^{a} \pm 1.50$<br>(9.20–12.40) | $p < 0.01$ | | 100<br>100 |
| Hardness ($mgCaCO_3/L$) | $9.16^{b} \pm 2.49$<br>(7.01–12.40) | $7.16^{b} \pm 0.83$<br>(5.82–8.01) | $8.02^{b} \pm 1.61$<br>(7.01–10.80) | $15.49^{a} \pm 2.10$<br>(14.27–19.22) | $p < 0.01$ | 100 | 150<br>75 |
| Chloride (mg/L) | $6.92^{b} \pm 1.50$<br>(5.80–9.45) | $4.77^{c} \pm 0.90$<br>(3.90–6.30) | $3.54^{d} \pm 1.28$<br>(2.70–5.65) | $9.35^{a} \pm 1.33$<br>(7.22–10.65) | $p < 0.01$ | 250 | 250<br>100 |
| Potassium (mg/L) | $1.61^{b} \pm 0.23$<br>(1.26–1.92) | $1.35^{b} \pm 0.26$<br>(1.14–1.65) | $1.32^{b} \pm 0.29$<br>(0.98–1.67) | $2.49^{a} \pm 0.39$<br>(2.15–3.11) | $p < 0.01$ | 10 | 10 |
| Sodium (mg/L) | $1.20^{a} \pm 0.11$<br>(1.14–1.40) | $0.83^{c} \pm 0.17$<br>(0.60–0.99) | $1.03^{b} \pm 0.11$<br>(0.86–1.16) | $1.29^{a} \pm 0.15$<br>(1.12–1.51) | $p < 0.01$ | 200 | 200<br>200 |
| Calcium (mg/L) | $1.87^{b} \pm 0.74$<br>(0.98–2.98) | $1.27^{b} \pm 0.02$<br>(1.26–1.30) | $1.75^{b} \pm 0.34$<br>(1.17–1.96) | $3.76^{a} \pm 0.87$<br>(3.12–5.13) | $p < 0.01$ | | 7.50 |
| Magnesium (mg/L) | $0.46^{c} \pm 0.24$<br>(0.17–0.78) | $1.06^{a} \pm 0.47$<br>(0.24–1.38) | $0.55^{b} \pm 0.21$<br>(0.27–0.78) | $1.19^{a} \pm 0.61$<br>(0.14–1.56) | $p < 0.01$ | | 200<br>250 |
| Sulphate (mg/L) | 3.05 ± 0.88<br>(2.45–4.58) | 3.55 ± 1.77<br>(2.28–6.50) | 2.64 ± 0.30<br>(2.16–2.86) | 2.43 ± 0.45<br>(2.02–3.19) | $p > 0.05$ | 100 | 250<br>200 |
| Phosphate (mg/L) | 0.66 ± 0.71<br>(0.05–1.80) | 0.22 ± 0.16<br>(0.02–0.36) | 0.39 ± 0.37<br>(0.03–0.98) | 0.40 ± 0.54<br>(0.01–1.34) | $p > 0.05$ | 5.0 | 3.5<br>10.0 |
| Nitrate (mg/L) | 1.94 ± 0.73<br>(1.22–2.83) | 1.91 ± 0.70<br>(1.37–2.88) | 2.46 ± 0.82<br>(1.32–3.61) | 2.87 ± 0.93<br>(1.49–3.86) | $p > 0.05$ | 50 | 10<br>11 |
| Nitrogen (mg/L) | $0.58^{bc} \pm 0.21$<br>(0.33–0.79) | $0.33^{c} \pm 0.11$<br>(0.19–0.49) | $1.28^{a} \pm 0.06$<br>(1.20–1.33) | $0.55^{bc} \pm 0.22$<br>(0.19–0.77) | $p < 0.01$ | | |

x ± SD = average mean generated from values across the months per station, ± standard deviation; min–max = minimum and maximum values for each parameter per station; post hoc = values with different superscripts (a > b > c > d) are significantly different ($p < 0.05$ or 0.01), while values with same superscript are not significantly different ($p > 0.05$). * $p < 0.05$ (significant difference), ** $p < 0.01$ (highly significant difference); NESREA, National Environmental Standard, Regulation and Enforcement Agency Guidelines and standards for water quality in Nigeria (2015); WHO, World Health Organization Guidelines for Drinking Water Quality (2011); USEPA, United State Environmental Protection Agency National recommended water quality criteria (2004).

Comparatively, Edori and Nna (2018) recorded lower EC values (11.60–15.61 µS/cm) for effluents discharged into the New Calabar River along the Rumuolumeni Axis, while Nnoli et al. (2021) reported higher EC values of 117.01 µS/cm in Goi Creek, Ogoni Land. Statistical analysis indicated no significant difference ($p > 0.05$) in EC across the sampling stations. Overall, the EC levels observed in the Okpare Olomu River were considerably below the recommended limits for drinking water of 1000 µS/cm (NESREA, 2015; WHO, 2008) and 500 µS/cm (USEPA, 2008), suggesting low ionic content and minimal risk of salinity-related water quality issues. Turbidity, which measures the clarity or opaqueness of water, is largely determined by suspended particles of organic or inorganic origin (Edori, Kpee, 2016; Okorafor et al., 2014). In this study, average turbidity values were 8.03, 7.03, 7.71, and 7.09 NTU at stations 1, 2, 3, and 4, respectively. Elevated turbidity levels may be linked to bunkering activities, oil spills, and frequent dredging in Okpare Olomu Kingdom. Similar observations were reported by Okorafor et al. (2014), who recorded turbidity of 12.83 and 12.52 NTU upstream and downstream of the Lower Qua Iboe River in Akwa Ibom State, and by Nnoli et al. (2021), who reported 9.43 NTU in Goi Creek. High turbidity reduces light penetration, impairs photosynthetic activity, alters aquatic habitats, and can degrade water aesthetic quality, while also facilitating the proliferation of microorganisms, phytoplankton, and zooplankton (Gupta et al., 2017; Edori, Kpee, 2016; Edori, Nna, 2018; Edori et al., 2019).

Total dissolved solids (TDS) provide a measure of the total concentration of dissolved substances in water and are indicative of pollution levels in aquatic systems (NRCC, 2011; Edori et al., 2019). The average mean TDS values in this study were 8.00, 6.46, 6.18, and 13.46 mg/L at stations 1, 2, 3, and 4, respectively. TDS influences water taste, color, odor, and light penetration, and elevated levels may render water unsuitable for drinking (NRCC, 2011; Edori et al., 2019). The TDS values observed at stations 2 and 3 are comparable to those reported by Okorafor et al. (2014), while stations 1 and 4 exhibited slightly higher values than the 6.09 and 5.62 mg/L recorded in the Lower Qua Iboe River, likely due to local influences such as river flow and effluent inputs. These values are consistent with those reported in the upper reaches of the Orashi River (Davies et al., 2018) and stretches of the New Calabar River (Dienye, Woke, 2014; Edori et al., 2019). Overall, TDS levels in the Okpare Olomu River remain well below the recommended limits for drinking water (500 mg/L) and domestic use (2000 mg/L) as prescribed by NESREA (2015), USEPA (2008), and the WHO (2008), indicating that dissolved solids are not a major concern in the study area. The variability of total suspended solids (TSS) and total solids (TS) in water samples from the Okpare Olomu River was relatively consistent across all sampling stations. The average mean concentrations of TSS were 74.00, 71.20, 72.60, and 75.20 mg/L, while TS values were 82.00, 77.66, 78.78, and 88.66 mg/L at stations 1, 2, 3, and 4, respectively. These values are considerably lower than the TSS values reported by Okorafor et al. (2014), who recorded 724.60 and 652 mg/L upstream and downstream of the Lower Qua Iboe River in Akwa Ibom State, attributing the higher levels to seasonal influences. Conversely, Edori et al. (2019) reported lower TSS concentrations (17.78 mg/L) in the surface waters of the Silver River in Bayelsa State. Elevated TSS generally increases water turbidity, and factors affecting TSS include farming practices, construction activities, mining, and seasonal variations (wet or dry), all of which expose soil surfaces, promoting runoff and erosion that transport particulate matter into rivers (Edori et al., 2019). Suspended particles are predominantly natural and are mainly composed of algae, silt, and sediment. Elevated TSS levels provide insight into the extent of water contamination and contribute to organoleptic properties such as odour and colour (Edori, Kpee, 2016; Edori, Nna, 2018; Edori et al., 2019).

Dissolved oxygen (DO) is a critical indicator of water quality, ecological status, and overall health of aquatic ecosystems (Linden, Palsson, 2013). In this study, average DO concentrations were 5.54, 5.12, 5.46, and 6.24 mg/L at stations 1, 2, 3, and 4, respectively. These values are consistent with findings from polluted waters reported by Edori and Nna (2018) but differ from the higher DO levels observed in Sagbama Creeks by Iyama et al. (2019). Lower DO levels, particularly in upstream and midstream areas, may result from high organic loads that demand oxygen for chemical oxidation and decomposition processes, a phenomenon previously documented by Morenikeji and Raheem (2008), Chukwu et al. (2008), Okorafor et al. (2012), and Andem et al. (2012). Additionally, visible oil waste from bunkering activities and leaking pipelines likely contributes to reduced oxygen levels in the Okpare Olomu River.

Biochemical oxygen demand (BOD) reflects the oxygen required to biologically decompose organic material in water (Sawyer, 1994; Edori et al., 2019). In this study, average BOD values were 6.70, 6.46, 3.34, and 7.43 mg/L at stations 1, 2, 3, and 4, respectively. According to the WHO (2005), water is considered clean at BOD levels of 1–2 mg/L, fairly clean at 3 mg/L, doubtful at 5 mg/L, and polluted above 10 mg/L. BOD values in this study suggest moderate organic pollution, with station 3 potentially reflecting self-purification processes of the river, as BOD below 4 mg/L indicates natural recovery (Radojevic, Bashkin, 1999; Ayobahan et al., 2014). These values are higher than those reported by Okorafor et al. (2014), who recorded 2.80 and 0.32 mg/L upstream and downstream of the Lower Qua Iboe River, but lower than the heavily polluted Silver River, where Edori et al. (2019) reported 33.20 mg/L. Chemical oxygen demand (COD) measures the total oxygen required to oxidize both organic and inorganic substances in water, providing an important indicator of water suitability for consumption (UNEP, 2006). COD values in the Okpare Olomu River varied across stations, with average concentrations of 40.20, 30.80, 25.20, and 42.40 mg/L at stations 1, 2, 3, and 4, respectively. Except for station 3, all stations exceeded the recommended limit of 30 mg/L for uncontaminated waters (WHO, 2005) and the 10 mg/L guideline for drinking water quality (WHO, 2011). Similar patterns of elevated COD have been reported by Sharma and Walia (2017) and Edori et al. (2019). The observed BOD and COD levels indicate notable oxygen depletion due to organic pollution, emphasising the impact of anthropogenic activities on water quality in the study area.

The average mean concentrations of alkalinity and hardness in water from the Okpare Olomu River were 8.37, 7.42, 6.92, and 11.12 mg/L and 9.16, 7.16, 8.02, and 15.49 mg/L at stations 1, 2, 3, and 4, respectively. The observed trends across stations differed for alkalinity and hardness, with both parameters showing highly significant differences ($p < 0.01$) among stations. Nonetheless, these values were far below the recommended limit of 100 mg/L for drinking water by the WHO (2008), indicating low levels of these parameters relative to water quality standards. Chloride ($Cl^-$) is an inorganic compound formed from the combination of chlorine with metals such as sodium and magnesium, and it is essential for the health of aquatic invertebrates. In this study, the highest chloride concentration was recorded at station 4 (9.35 mg/L), followed by station 1 (6.92 mg/L), with a highly significant difference ($p < 0.01$) among the sampled stations. Major sources of chloride in water include re-suspension of chloride-contaminated sediments, sewage, and industrial discharges. Elevated chloride levels can enhance water conductivity and promote corrosion of metals in contact with the water, while reacting with metals to form soluble salts that increase metal concentrations in water (Edori, Nna, 2018). In comparison, Nnoli et al. (2021) reported much higher chloride values of 114.42 mg/L in Goi Creek, Ogoni land.

The concentrations of potassium (K), sodium (Na), calcium (Ca), and magnesium (Mg) were relatively consistent across all stations, although station 4 generally recorded higher concentrations for most cations. Potassium and sodium levels were lower than those reported by Nnoli et al. (2021), who recorded 14.77 mg/L and 12.96 mg/L in Goi Creek. Calcium concentrations at station 4 (3.76 mg/L) were higher than at other stations, followed by station 1 (1.87 mg/L), while magnesium levels were highest at station 2 (1.06 mg/L). The trends suggest that anthropogenic activities were more pronounced at stations 2 and 3. Differences in concentrations of K, Na, Ca, and Mg across stations were highly significant ($p < 0.01$), reflecting the impact of localised human activities on water quality.

Sulphate ($SO_4^{2-}$), phosphate ($PO_4^{3-}$), nitrate ($NO_3^-$), and total nitrogen (N) showed relatively similar variability across stations. Average concentrations of $SO_4^{2-}$ were 3.05, 3.55, 2.64, and 2.43 mg/L, phosphate 0.66, 0.22, 0.39, and 0.40 mg/L, nitrate 1.94, 1.91, 2.46, and 2.87 mg/L, and nitrogen 0.58, 0.33, 1.28, and 0.55 mg/L at stations 1, 2, 3, and 4, respectively. These values were substantially lower than those reported by Edori and Nna (2018) for $SO_4^{2-}$ (74.16–346.72 mg/L) in effluents discharged into the New Calabar River and fell below the NESREA (2015) requirement of 100 mg/L for drinking water. They also met the WHO (2008, 2011) and USEPA (2008) standards for domestic water use. Excessive sulphate concentrations can cause physiological disorders, including dehydration and gastrointestinal irritation (Jidauna et al., 2014). Sulphates are often associated with metal cations (e.g., Pb, Fe) and anions ($PO_4^{3-}$), indicating that their presence can signal potential contamination by these elements (WHO, 2011; Edori et al., 2019).

Phosphate concentrations were below the maximum permissible limit of 10 mg/L set by the WHO (2011). Station 1 had the highest phosphate levels, likely due to terrestrial runoff and household effluent discharges, reflecting higher washing activities and water clarity in that area. The phosphate concentrations observed were slightly lower than those reported by Edori and Nna (2018) for New Calabar River, but higher than levels recorded in Camligoze Dam Lake, Sivas, Turkey (Dirican, 2015). Nitrate levels in Okpare Olomu River were comparable to those observed in Morna Reservoir Lake, India (Agah et al., 2013) and below NESREA (50 mg/L), USEPA (10 mg/L), and WHO (50 mg/L) guidelines, indicating low risk of nitrate pollution.

During the reconnaissance survey, visible oil films were observed on the river surface. The sources of oil contamination include pipeline leaks, wellhead spills, sabotage, illegal refining, and tidal movement spreading pollutants. Human Rights Watch (2005) and Idemudia (2009) highlight that crude oil spills in the Niger Delta largely result from pipeline corrosion, poor infrastructure maintenance, and theft-related spills. This study demonstrates that oil pollution, coupled with watershed runoff and other anthropogenic activities, is a major factor driving variability in water quality parameters in Okpare Olomu River.

## Heavy metals in surface water samples

Contamination of aquatic environments by heavy metals (HMs) is a critical concern due to their potential toxicity, persistence, and tendency to bioaccumulate in aquatic habitats (Vincent-Akpu et al., 2015). HMs are widespread in aquatic systems, and understanding their distribution is essential for informing environmental protection and policy measures. Elevated HM levels in water bodies necessitate regular monitoring to safeguard aquatic biodiversity and human health (Ayenimo et al., 2005). In water samples from Okpare Olomu River, the metals were present in the following order of abundance: Fe > Pb > Zn > Cr > Cu > Cd > Mn. This order is comparable to findings in other Niger Delta rivers, such as Ayobahan et al. (2014) in Benin River (Fe > Zn > Mn > Cr > Ni > Cu > Pb), Dibofori-Orji et al. (2019) in Woji Creek (Pb > Ni > Fe > Cd > Cu), and Nnoli et al. (2021) in Goi Creek (Fe > Zn > Mn > Cu > Ni > Cr > Pb > As > Cd > Hg).

The predominance of Fe in aquatic ecosystems has been previously reported by Puyate et al. (2007), Oribhabor and Ogbeibu (2009), Wogu and Okaka (2011), and in Bodo, a tributary of Goi Creek (Vincent-Akpu et al., 2015). In this study, average mean Fe concentrations were 1.56, 2.35, 0.86, and 1.83 mg/L at stations 1, 2, 3, and 4, respectively. These values are similar to those reported by Ayobahan et al. (2014) in the Benin River (2.51 mg/L) and by

Nnoli et al. (2021) in Goi Creek (2.93 mg/L). The Fe concentrations can be attributed to both natural lithogenic and pedogenic processes, as well as oil spill pollution in the Okpare Olomu Kingdom. Statistical analysis showed no significant difference ($p > 0.05$) across stations. Notably, Fe concentrations exceeded the maximum permissible limit of 0.3 mg/L set by NESREA (2015), USEPA (2008), and the WHO (2011), indicating potential health risks. Chromium (Cr) concentrations were 0.06, 0.07, 0.12, and 0.09 mg/L at stations 1, 2, 3, and 4, respectively (Table 6). Oribhabor and Ogbeibu (2009) reported a higher Cr value of 0.153 mg/L in Niger Delta mangrove creeks, while Wogu and Okaka (2011) recorded 0.06 mg/L in Warri River, and Ayobahan et al. (2014) obtained 0.09 mg/L in Benin River. Nnoli et al. (2021) observed higher Cr levels of 1.43 mg/L in Goi Creek.

The Cr concentrations in Okpare Olomu River were below the USEPA (0.1 mg/L) limit but above the WHO (0.05 mg/L) guideline. Cadmium (Cd) concentrations were 0.05, 0.07, 0.05, and 0.02 mg/L at stations 1, 2, 3, and 4, respectively. These values are similar to those reported by Wogu and Okaka (2011) in Warri River, but lower than those reported by Dibofori-Orji et al. (2019) in Woji Creek (0.102 mg/L) and Nnoli et al. (2021) in Goi Creek (0.85 mg/L). Cd contamination in Okpare Olomu River is likely associated with oil spill pollution. Long-term exposure to Cd can result in renal dysfunction, anaemia, bone marrow disorders, cancer, bronchitis, and liver and brain dysfunction (Dara, 2000; Koji et al., 2004). Cd concentrations in this study exceeded permissible limits of 0.003 mg/L (NESREA, 2015), 0.005 mg/L (USEPA, 2008), and 0.003 mg/L (WHO, 2004), posing a significant health risk.

Copper (Cu) concentrations were 0.07, 0.06, 0.06, and 0.09 mg/L at stations 1, 2, 3, and 4, respectively. Excessive intake of soluble copper compounds can accumulate in the liver, potentially altering hepatic function and impairing copper metabolism (Obasi and Akudinobi, 2013). Major sources of Cu in the study area include industrial waste, abattoir effluents, domestic wastewater, and mining activities. While Cu is an essential trace element, it becomes toxic to plants and algae at moderate

Table 6. **Heavy metal content of water samples from the Okpare Olomu River**

| | Station 1 | Station 2 | Station 3 | Station 4 | | | |
|---|---|---|---|---|---|---|---|
| Parameters | $\bar{x}$ ± SD (min-max) | $\bar{x}$ ± SD (min-max) | $\bar{x}$ ± SD (min-max) | $\bar{x}$ ± SD (min-max) | $p$-value | NESREA 2015 | USEPA/WHO 2004 |
| Fe (mg/L) | 1.56 ± 0.37<br>(0.90–1.75) | 2.35 ± 2.28<br>(1.00–6.40) | 0.86 ± 0.61<br>(0.30–1.78) | 1.83 ± 0.59<br>(0.80–2.20) | $p > 0.05$ | 0.3 | 0.3 |
| Cr (mg/L) | 0.06 ± 0.04<br>(0.01–0.11) | 0.07 ± 0.07<br>(0.00–0.17) | 0.12 ± 0.14<br>(0.00–0.34) | 0.09 ± 0.09<br>(0.01–0.23) | $p > 0.05$ | | 0.1<br>0.05 |
| Cd (mg/L) | 0.05 ± 0.04<br>(0.00–0.10) | 0.07 ± 0.04<br>(0.00–0.10) | 0.05 ± 0.04<br>(0.00–0.10) | 0.02 ± 0.01<br>(0.00–0.02) | $p > 0.05$ | 0.003 | 0.005<br>0.003 |
| Cu (mg/L) | 0.07 ± 0.06<br>(0.03–0.16) | 0.06 ± 0.06<br>(0.01–0.14) | 0.06 ± 0.04<br>(0.00–0.10) | 0.09 ± 0.07<br>(0.02–0.17) | $p > 0.05$ | 1.0 | 1.0<br>2.0 |
| Zn (mg/L) | 0.15 ± 0.06<br>(0.06–0.22) | 0.14 ± 0.09<br>(0.03–0.28) | 0.13 ± 0.05<br>(0.05–0.16) | 0.16 ± 0.12<br>(0.06–0.36) | $p > 0.05$ | 3.0 | 3.0<br>3.0–5.0 |
| Mn (mg/L) | 0.01 ± 0.01<br>(0.00–0.20) | 0.02 ± 0.02<br>(0.00–0.03) | 0.01 ± 0.01<br>(0.00–0.01) | 0.02 ± 0.02<br>(0.01–0.04) | $p > 0.05$ | 0.05 | 0.05 |
| Pb (mg/L) | $0.18^{b}$ ± 0.10<br>(0.00–0.20) | $0.23^{a}$ ± 0.06<br>(0.15–0.31) | $0.10^{b}$ ± 0.04<br>(0.00–0.10) | $0.00^{b}$ ± 0.00<br>(0.00–0.00) | $p < 0.01$ | 0.01 | 0.01 |
| THC (mg/L) | 3.61 ± 1.90<br>(2.06–6.67) | 3.34 ± 1.17<br>(2.23–5.29) | 3.62 ± 1.09<br>(2.32–5.29) | 2.85 ± 0.93<br>(1.53–3.97) | $p > 0.05$ | | |

concentrations. Zinc (Zn) concentrations were 0.15, 0.14, 0.13, and 0.16 mg/L at stations 1, 2, 3, and 4, respectively, with the highest concentration recorded at station 4 and the lowest at station 3. Ayobahan et al. (2014) reported higher Zn concentrations of 1.35 mg/L in Benin River, while Nnoli et al. (2021) recorded 2.54 mg/L in Goi Creek. Statistical analysis revealed no significant differences ($p > 0.05$) in Zn concentrations across stations, indicating uniform distribution in the river stretch. The average mean concentrations of manganese (Mn) in water samples from Okpare Olomu River were 0.01, 0.02, 0.01, and 0.02 mg/L at stations 1, 2, 3, and 4, respectively. These values are lower than those reported by Ayobahan et al. (2014) in Benin River (0.47 mg/L) and Nnoli et al. (2021) in Goi Creek (2.17 mg/L). Mn concentrations in the Okpare Olomu River were below the maximum permissible limits of 0.05 mg/L (NESREA, 2015; USEPA, 2008) and 0.04 mg/L (WHO, 2008), indicating no immediate health risk from this metal. The average concentrations of lead (Pb) were 0.18, 0.23, 0.10, and 0.00 mg/L at stations 1, 2, 3, and 4, respectively, with the highest values recorded at station 2 and Pb not detected at station 4. Lower Pb concentrations (0.001 mg/L) were reported by Wogu and Okaka (2011) in the Warri River, while Ayobahan et al. (2014) recorded 0.03 mg/L in the Benin River. The non-detection of Pb at station 4, downstream of the river, may be due to volatilisation and dilution effects. Statistical analysis revealed a highly significant difference ($p < 0.01$) in Pb concentrations across stations, likely reflecting localized anthropogenic inputs, particularly from illegal crude oil processing. Overall, Pb concentrations at stations 1, 2, and 3 exceeded the maximum permissible limit of 0.01 mg/L set by NESREA (2015), USEPA (2008), and the WHO (2008, 2011), highlighting a potential health concern.

Total hydrocarbon content (THC) in the water samples averaged 3.61, 3.34, 3.62, and 2.85 mg/L at stations 1, 2, 3, and 4, respectively. Nnoli et al. (2021) recorded higher THC concentrations (52.66 mg/L) in Goi Creek, while Edori et al. (2019) reported 45.43 mg/L in the Silver River, Bayelsa State, attributed to illegal bunkering. The THC values observed in this study were below the WHO (2011) recommended limit of 20 mg/L. Compared to station 4, the slightly lower THC concentrations at station 3 may be influenced by tidal effects, which alter water flow, and local topography. These values are also comparable to findings by Uzoekwe and Oghosanine (2011) and Wokoma and Upaghi (2012), who reported THC concentrations of 2.85–2.83 mg/L near points of discharge in Elechi Creek, an area relatively removed from oil-related activities. The observed concentrations of heavy metals and THC in the Okpare Olomu River are largely attributable to the impacts of oil spills in the area. Community discussions indicated a significant oil spill event in 2018, described locally as 'A River on Fire,' which caused substantial environmental degradation. Chronic exposure to petroleum hydrocarbons is associated with health effects including reduced immune function, renal dysfunction, central nervous system and respiratory depression, cardiac arrhythmias, and liver damage (Fowzia, Fakhruddin, 2018; Kuppusamy et al., 2020). These findings, in comparison with other studies, suggest that although crude oil contamination is widespread in the Niger Delta, heavy metal and hydrocarbon concentrations vary between communities. Such variations influence water quality and portability, with some areas showing concentrations above permissible limits, thereby elevating potential health risks.

## Water quality index (WQI)

Water is synonymous with life, and access to freshwater is essential for public health and the welfare of society (Haque et al., 2020). The results of this study highlight the key physicochemical parameters used to assess the water quality of the four sampled stations along the Okpare Olomu River. The cumulative water quality index (WQI) recorded at the study stations is presented in Table 7. The overall WQI observed at stations 1, 2, 3, and 4 were 1113.24, 590.64, 251.76, and 136.21, respectively.

Table 7. **Estimation of the Water Quality Index (WQI) of selected surface water**

| Parameters | NSDWQ (SON, 2007) (Si) | Weightage (Wi) | STATION 1 | | | STATION 2 | | | STATION 3 | | | STATION 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Test result ($V_i$) | Quality rating ($Q_i$) | [($W_i$) ($Q_i$)] | Test result ($V_i$) | Quality rating ($Q_i$) | [($W_i$) ($Q_i$)] | Test result ($V_i$) | Quality rating ($Q_i$) | [($W_i$) ($Q_i$)] | Test result ($V_i$) | Quality rating ($Q_i$) | [($W_i$) ($Q_i$)] |
| pH | 6.5 | 0.000458 | 5.71 | 258 | 0.118243 | 5.71 | 258 | 5.41919E-05 | 5.86 | 228 | 2.48365E-08 | 5.85 | 230 | 1.13828E-11 |
| E. Conduct uS/cm) | 1000 | 2.98E-06 | 22.54 | 2.254 | 6.71E-06 | 17.23 | 1.723 | 2.0003E-11 | 17.28 | 1.728 | 5.95889E-17 | 24.23 | 2.423 | 1.77515E-22 |
| Alkalinity (mg/L) | 100 | 2.98E-05 | 8.37 | 8.37 | 0.000249 | 7.42 | 7.42 | 7.42791E-09 | 6.92 | 6.92 | 2.21277E-13 | 11.12 | 11.12 | 6.59185E-18 |
| Hardness (mg/L) | 100 | 2.98E-05 | 9.16 | 9.16 | 0.000273 | 7.16 | 7.16 | 8.12899E-09 | 8.02 | 8.02 | 2.42163E-13 | 15.49 | 15.49 | 7.21402E-18 |
| TDS (mg/L) | 500 | 5.96E-06 | 8 | 1.6 | 9.53E-06 | 6.46 | 1.292 | 5.67964E-11 | 6.18 | 1.236 | 3.38393E-16 | 13.46 | 2.692 | 2.01615E-21 |
| TSS (mg/L) | 500 | 5.96E-06 | 74 | 14.8 | 8.82E-05 | 71.2 | 14.24 | 5.25367E-10 | 72.6 | 14.52 | 3.13014E-15 | 75.2 | 15.04 | 1.86494E-20 |
| DO (mg/L) | 6 | 0.000497 | 5.54 | 127.6056 | 0.063356 | 5.12 | 133.5211 | 3.14564E-05 | 5.46 | 128.7324 | 1.56181E-08 | 6.24 | 117.7465 | 7.75438E-12 |
| Calcium (mg/L) | 180 | 1.66E-05 | 1.87 | 1.038889 | 1.72E-05 | 1.27 | 0.705556 | 2.84554E-10 | 1.75 | 0.972222 | 4.70937E-15 | 3.76 | 2.088889 | 7.79401E-20 |
| Magnesium (mg/L) | 40 | 7.45E-05 | 0.46 | 1.15 | 8.56E-05 | 1.06 | 2.65 | 6.3785E-09 | 0.55 | 1.375 | 4.75039E-13 | 1.19 | 2.975 | 3.53785E-17 |
| Chloride (mg/L) | 300 | 9.93E-06 | 6.92 | 2.306667 | 2.29E-05 | 4.77 | 1.59 | 2.27449E-10 | 3.54 | 1.18 | 2.25856E-15 | 9.35 | 3.116667 | 2.24276E-20 |
| Sulphate (mg/L) | 100 | 2.98E-05 | 3.05 | 3.05 | 9.09E-05 | 3.55 | 3.55 | 2.7067E-09 | 2.64 | 2.64 | 8.06327E-14 | 2.43 | 2.43 | 2.40205E-18 |
| Nitrate (mg/L) | 50 | 5.96E-05 | 1.94 | 3.88 | 0.000231 | 1.91 | 3.82 | 1.37731E-08 | 2.46 | 4.92 | 8.20603E-13 | 2.87 | 5.74 | 4.88915E-17 |
| Phosphate (mg/L) | 3.5 | 0.000851 | 0.66 | 18.85714 | 0.01605 | 0.22 | 6.285714 | 1.36609E-05 | 0.39 | 11.14286 | 1.16274E-08 | 0.4 | 11.42857 | 9.89659E-12 |
| Potassium (mg/L) | 50 | 5.96E-05 | 1.61 | 3.22 | 0.000192 | 1.35 | 2.7 | 1.14303E-08 | 1.32 | 2.64 | 6.81016E-13 | 2.49 | 4.98 | 4.05749E-17 |
| Sodium (mg/L) | 120 | 2.48E-05 | 1.2 | 1 | 2.48E-05 | 0.83 | 0.691667 | 6.16281E-10 | 1.03 | 0.858333 | 1.52992E-14 | 1.29 | 1.075 | 3.79802E-19 |
| Iron (mg/L) | 0.3 | 0.00993 | 1.56 | 520 | 5.1636 | 2.35 | 783.3333 | 0.051274548 | 0.86 | 286.6667 | 0.000509156 | 1.83 | 610 | 5.05592E-06 |
| Copper (mg/L) | 1 | 0.002979 | 0.07 | 7 | 0.020853 | 0.06 | 6 | 6.21211E-05 | 0.06 | 6 | 1.85059E-07 | 0.09 | 9 | 5.5129E-10 |
| Zinc(mg/L) | 3 | 0.000993 | 0.15 | 5 | 0.004965 | 0.14 | 4.666667 | 4.93025E-06 | 0.13 | 4.333333 | 4.89573E-09 | 0.16 | 5.333333 | 4.86146E-12 |
| Manganese (mg/L) | 0.05 | 0.05958 | 0.01 | 20 | 1.1916 | 0.02 | 40 | 0.070995528 | 0.01 | 20 | 0.004229914 | 0.02 | 40 | 0.000252018 |
| Chromium (mg/L) | 0.05 | 0.05958 | 0.06 | 120 | 7.1496 | 0.07 | 140 | 0.425973168 | 0.12 | 240 | 0.025379481 | 0.09 | 180 | 0.001512109 |
| Cd (mg/L) | 0.005 | 0.5958 | 0.05 | 1000 | 595.8 | 0.07 | 1400 | 354.97764 | 0.05 | 1000 | 211.4956779 | 0.02 | 400 | 126.0091249 |
| Pb (mg/L) | 0.01 | 0.2979 | 0.18 | 1800 | 536.22 | 0.23 | 2300 | 159.739938 | 0.1 | 1000 | 47.58652753 | 0 | 0 | 14.17602655 |
| THC(mg/L) | 10 | 0.000298 | 3.61 | 36.1 | 0.010754 | 3.34 | 33.4 | 3.20367E-06 | 3.62 | 36.2 | 9.54374E-10 | 2.85 | 28.5 | 2.84308E-13 |
| | **$\Sigma W_i = 0.103$** | | **$\Sigma[(W_i)(Q_i)] = 1145.76$**<br>**WQI = 1113.24** | | | **$\Sigma[(W_i)(Q_i)] = 515.27$**<br>**WQI = 500.64** | | | **$\Sigma[(W_i)(Q_i)] = 259.11$**<br>**WQI = 251.76** | | | **$\Sigma[(W_i)(Q_i)] = 140.19$**<br>**WQI = 136.21** | | |

The WQI was highest at station 1 and lowest at station 4. All four analysed stations in this study are classified as Grade E, indicating that the water is unsuitable for drinking purposes.

The WQI values in this study were both higher and lower than those reported by Ayobahan et al., (2014), who recorded WQI values of 234.45, 315.26, 295.09, 1710.49, and 1421.06 at five sampling stations along the Benin River. Across the sampled stations in the present study, heavy metals such as Fe, Cr, Cu, Cd, Mn, Pb, and total hydrocarbon content (THC) were major contributors to the computed WQI values. It is also important to note that dissolved oxygen (DO) contributed to the poor water quality of the Okpare Olomu River, as DO is a critical parameter in determining the WQI of a water body.

### Comprehensive pollution index (CPI)

The cumulative comprehensive pollution index (CPI) recorded at the study stations is shown in Table 8. The CPI values at stations 1, 2, 3, and 4 were 1.67, 2.20, 1.24, and 0.66, respectively. The highest CPI was observed at station 2, while the lowest value was recorded at station 4. Based on these values, station 1 (CPI = 1.67) and station 3 (CPI = 1.24) are classified as moderately polluted**,** station 2 (CPI = 2.20) is severely polluted, and station 4 (CPI = 0.66) is slightly polluted (Table 9). These pollution levels are primarily driven by physicochemical parameters and heavy metals such as pH, Fe, Cr, Cd, and Pb.

### Health risk assessment

### Non-carcinogenic risk assessment

According to the USEPA risk assessment guidelines, when the target hazard quotient (THQ) of a contaminant exceeds 1.0, the probability of adverse health effects due to exposure is high. In this study, the THQs for oral exposure (THQ_oral) of heavy metals were below 1.0 for most metals, except for arsenic across the sampled stations. This suggests that consumers of water from these locations may be at a high risk of illnesses associated with elevated arsenic exposure. The hazard index (HI) indicates overall non-carcinogenic risk; populations are considered safe when HI < 1.0, whereas HI > 1.0 implies potential non-cancer health effects (Tripathee et al., 2016; Saha, Paul, 2018). In this study, the HI values exceeded 1.0 (HI > 1), indicating that oral consumption of surface water from the sampled stations poses a non-carcinogenic risk. This demonstrates that drinking this water could expose consumers to heavy metal contamination and increase the likelihood of illnesses associated with prolonged ingestion of elevated metal concentrations.

### Carcinogenic risk interpretation: oral carcinogenic risk of heavy metals in surface water

The estimated carcinogenic risk (CR_oral) through ingestion of lead, chromium, cadmium, and arsenic at stations 1, 2, 3, and 4 did not exceed the USEPA (2012) acceptable range for carcinogenic risk (1 × 10^–6 – 1 × 10^–4). However, the integrated carcinogenic risk (ICR) values classified the surface water as Grade VI (High risk). This implies that continuous consumption of surface water from Okpare Olomu River could predispose the population to cancer-related health risks. Immediate public health interventions are necessary to address this risk. Continuous monitoring and further studies are recommended to safeguard the health of the local population.

### Relationship between WQI, CPI, and health risk

The assessment of the Okpare Olomu River revealed that water quality, pollution levels, and potential health risks are closely interlinked. The water quality index (WQI) provides a composite measure of the overall status of water quality, integrating physicochemical parameters and heavy metal concentrations. In this study, the WQI values were highest at station 1 and lowest at station 4, with all stations classified as Grade E, indicating unsuitability for drinking.

Table 8. **Estimation of the Comprehensive Pollution Index (CPI) of selected surface water**

| Parameters | NSDWQ (SON, 2007) ($S_i$) | STATION 1 | | | STATION 2 | | | STATION 3 | | | STATION 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Test result ($C_i$) | Pollution index ($P_i$) | Pollution grade | Test result ($C_i$) | Pollution index ($P_i$) | Pollution grade | Test result ($C_i$) | Pollution index ($P_i$) | Pollution grade | Test result ($C_i$) | Pollution index ($P_i$) | Pollution grade |
| pH | 6.5 | 5.71 | 0.88 | **Slight Pollutant** | 5.71 | 0.88 | **Slight Pollutant** | 5.86 | 0.90 | **Slight Pollutant** | 5.85 | 0.90 | **Slight Pollutant** |
| E. Conduct (uS/cm) | 1000 | 22.54 | 0.02 | Non pollutant | 17.23 | 0.02 | Non pollutant | 17.28 | 0.02 | Non pollutant | 24.23 | 0.02 | Non pollutant |
| Alkalinity (mg/L) | 100 | 8.37 | 0.08 | Non pollutant | 7.42 | 0.07 | Non pollutant | 6.92 | 0.07 | Non pollutant | 11.12 | 0.11 | Non pollutant |
| Hardness (mg/L) | 100 | 9.16 | 0.09 | Non pollutant | 7.16 | 0.07 | Non pollutant | 8.02 | 0.08 | Non pollutant | 15.49 | 0.16 | Non pollutant |
| TDS (mg/L) | 500 | 8 | 0.02 | Non pollutant | 6.46 | 0.01 | Non pollutant | 6.18 | 0.01 | Non pollutant | 13.46 | 0.03 | Non pollutant |
| TSS (mg/L) | 500 | 74 | 0.15 | Non pollutant | 71.2 | 0.14 | Non pollutant | 72.6 | 0.15 | Non pollutant | 75.2 | 0.15 | Non pollutant |
| Calcium (mg/L) | 180 | 1.87 | 0.01 | Non pollutant | 1.27 | 0.007 | Non pollutant | 1.75 | 0.01 | Non pollutant | 3.76 | 0.02 | pollutant |
| Magnesium (mg/L) | 40 | 0.46 | 0.01 | Non pollutant | 1.06 | 0.03 | Non pollutant | 0.55 | 0.01 | Non pollutant | 1.19 | 0.03 | Non pollutant |
| Chloride (mg/L) | 300 | 6.92 | 0.02 | Non pollutant | 4.77 | 0.02 | Non pollutant | 3.54 | 0.01 | Non pollutant | 9.35 | 0.03 | Non pollutant |
| Sulphate (mg/L) | 100 | 3.05 | 0.03 | Non pollutant | 3.55 | 0.04 | Non pollutant | 2.64 | 0.03 | Non pollutant | 2.43 | 0.02 | Non pollutant |
| Nitrate (mg/L) | 50 | 1.94 | 0.04 | Non pollutant | 1.91 | 0.04 | Non pollutant | 2.46 | 0.05 | Non pollutant | 2.87 | 0.06 | Non pollutant |
| Phosphate (mg/L) | 3.5 | 0.66 | 0.19 | Non pollutant | 0.22 | 0.06 | Non pollutant | 0.39 | 0.11 | Non pollutant | 0.4 | 0.11 | Non pollutant |
| Potassium (mg/L) | 50 | 1.61 | 0.03 | Non pollutant | 1.35 | 0.03 | Non pollutant | 1.32 | 0.03 | Non pollutant | 2.49 | 0.05 | Non pollutant |
| Sodium (mg/L) | 120 | 1.2 | 0.01 | Non pollutant | 0.83 | 0.01 | Non pollutant | 1.03 | 0.09 | Non pollutant | 1.29 | 0.01 | Non pollutant |
| Iron (mg/L) | 0.3 | 1.56 | **5.20** | **Serious pollutant** | 2.35 | **7.83** | **Serious pollutant** | 0.86 | **2.87** | **Heavy pollutant** | 1.83 | **6.10** | **Serious pollutant** |
| Copper (mg/L) | 1 | 0.07 | 0.07 | Non pollutant | 0.06 | 0.06 | Non pollutant | 0.06 | 0.06 | Non pollutant | 0.09 | 0.09 | Non pollutant |
| Zinc(mg/L) | 3 | 0.15 | 0.05 | Non pollutant | 0.14 | 0.05 | Non pollutant | 0.13 | 0.04 | Non pollutant | 0.16 | 0.05 | Non pollutant |
| Manganese (mg/L) | 0.05 | 0.01 | 0.20 | Non pollutant | 0.02 | 0.40 | Non pollutant | 0.01 | 0.2 | Non pollutant | 0.02 | 0.40 | Non pollutant |
| Chromium (mg/L) | 0.05 | 0.06 | **1.20** | **Medium pollutant** | 0.07 | **1.40** | **Medium pollutant** | 0.12 | **2.4** | **Heavy pollutant** | 0.09 | **1.80** | **Medium pollutant** |
| Cd (mg/L) | 0.005 | 0.05 | **10** | **Serious pollutant** | 0.07 | **14** | **Serious pollutant** | 0.05 | **10** | **Serious pollutant** | 0.02 | **4.00** | **Heavy pollutant** |
| Pb (mg/L) | 0.01 | 0.18 | **18** | **Serious pollutant** | 0.23 | **23** | **Serious pollutant** | 0.1 | **10** | **Serious Pollutant** | 0 | 0.00 | Non pollutant |
| THC(mg/L) | 10 | 3.61 | 0.40 | Non pollutant | 3.34 | 0.33 | Non pollutant | 3.62 | 0.40 | Non pollutant | 2.85 | 0.29 | Non pollutant |
| | | CPI | 1.67 | Moderate pollution | CPI | 2.20 | Severe pollution | CPI | 1.25 | Moderate pollution | CPI | 0.66 | Slight pollution |

Table 9. **Summary table of CPI for selected surface water**

| | CPI value | Level | Explanation of water quality grades |
|---|---|---|---|
| Station 1 | 1.67 | IV | Moderate pollution |
| Station 2 | 2.20 | V | Severe pollution |
| Station 3 | 1.24 | IV | Moderate pollution |
| Station 4 | 0.66 | III | Slight pollution |

The WQI trends reflect the cumulative impact of physicochemical deterioration and heavy metal contamination, highlighting areas where the water is most stressed. The comprehensive pollution index (CPI) complements the WQI by quantifying the extent of contamination from both physicochemical parameters and heavy metals. Station 2 recorded the highest CPI (2.20), classifying it as severely polluted, while station 4 had the lowest CPI (0.66), indicating slight pollution. This demonstrates that locations with higher WQI values also tend to have higher CPI, confirming that poor water quality is associated with increased pollutant loads.

Health risk assessment further contextualizes these indices in terms of human exposure. The hazard index (HI) values exceeded 1.0 across the stations, signifying non-carcinogenic risk, while integrated carcinogenic risk (ICR) classified the water as high risk (Grade VI). The correlation between elevated WQI and CPI values and the observed health risks implies that areas with high pollution indices are more likely to pose adverse health effects to the local population. Parameters contributing most to WQI and CPI, such as Fe, Cd, Pb, Cr, and total hydrocarbons (THC), are also the key contributors to health risks, linking environmental contamination directly to potential public health impacts. Overall, the results indicate a strong relationship between water quality degradation, pollution levels, and health risk: higher WQI and CPI values correspond with greater potential for non-carcinogenic and carcinogenic risks. This underscores the need for targeted interventions in stations with the highest indices to protect human health and restore the ecological integrity of Okpare Olomu River.

## CONCLUSIONS

The assessment of surface water from the Okpare Olomu River reveals significant concerns regarding water quality and associated human health risks. The concentrations of heavy metals in the water were relatively moderate compared to other studies in the region; however, Fe, Cd, and Pb levels exceeded the maximum permissible limits set by NESREA (2015), USEPA (2008), and the WHO (2008), indicating a potential for adverse health effects. Health risks associated with long-term exposure to petroleum hydrocarbons in the river include decreased immune function, kidney and liver damage, central nervous system and respiratory complications, and cardiac arrhythmias. The water quality index (WQI) and comprehensive pollution index (CPI) further confirmed that the river is unsuitable for drinking, with high pollution loads particularly at upstream and midstream stations. Non-carcinogenic and carcinogenic health risk assessments corroborated these findings, showing elevated potential for both immediate and long-term health impacts from the consumption of water from the river. These findings highlight the urgent need for targeted interventions, including water treatment, regular monitoring, pollution control measures, and community education, to mitigate contamination and safeguard public health. Effective regulatory enforcement and sustainable management practices are essential to ensure that inhabitants relying on the Okpare Olomu River have access to safe and clean water.

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## PAVIRŠINIO VANDENS KOKYBĖS INDEKSO ANALIZĖ OKPARE OLOMU UPĖJE PIETŲ NIGERIJOJE

*Santrauka*

Šiame tyrime buvo įvertintos Okpare Olomu upės (Ughelli South, Deltos valstija, Nigerija) paviršinio vandens fizikinės ir cheminės savybės, sunkiųjų metalų tarša bei vandens kokybė. Vandens mėginiai iš keturių stočių buvo analizuojami pagal fizinius ir cheminius parametrus, sunkiuosius metalus (Fe, Pb, Cd, Cr, Cu, Zn, Mn) ir bendrą angliavandenilių kiekį (THC). Nuo 5,71 iki 5,86 svyravusios pH reikšmės rodė, kad vanduo šiek tiek rūgštus. Elektrinis laidumas (17,23–24,23 µS/cm), bendras ištirpusių medžiagų kiekis (6,18–13,46 mg/l) ir bendras suspenduotų kietųjų dalelių kiekis (71,20–75,20 mg/l) buvo nedidelis, o ištirpusio deguonies (5,12–6,24 mg/l) ir biocheminio deguonies sunaudojimo (3,34–7,43 mg/l) rodikliai atspindėjo vidutinę vandens kokybę. Sunkiųjų metalų koncentracijos mažėjo tokia tvarka: Fe (0,86–2,35 mg/l) > Pb (0,00–0,23 mg/l) > Cd (0,02–0,07 mg/l) > Cr (0,06–0,12 mg/l) > Cu (0,06–0,09 mg/l) > Zn (0,13–0,16 mg/l) > Mn (0,01–0,02 mg/l). Fe, Pb ir Cd koncentracijos viršijo NESREA, USEPA ir PSO (WHO) leistinas ribas. THC reikšmės svyravo nuo 2,85 iki 3,62 mg/l. Pagal vandens kokybės indeksą (WQI: 136,21–1113,24) visos stotys priskirtos E klasei, t. y. vanduo laikomas netinkamu gerti. Kompleksinis taršos indeksas (CPI: 0,66–2,20) rodo, kad 2-oji stotis yra stipriai užteršta, 1-oji ir 3-ioji – vidutiniškai užterštos, o 4-oji – silpnai užteršta. Sveikatos rizikos vertinimas atskleidė nekancerogeninę arseno poveikio riziką (HI > 1), o integruotas kancerogeninės rizikos vertinimas rodo didelį onkologinių ligų išsivystymo potencialą vandens vartotojams. Tyrimo rezultatai verčia skubiai taikyti taršos mažinimo strategijas, vykdyti nuolatinę stebėseną ir imtis visuomenės sveikatos priemonių, siekiant sumažinti sunkiųjų metalų taršą ir apsaugoti bendruomenes, priklausomas nuo Okpare Olomu upės vandens.

**Reikšminiai žodžiai:** Okpare Olomu upė, vandens kokybės indeksas (WQI), sunkieji metalai, kompleksinis taršos indeksas (CPI), sveikatos rizikos vertinimas