

## Evaluation of the Bacteriological and Physicochemical Characteristics of Sand Mining Site in Ox-Bow Lake in Bayelsa State

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### ABSTRACT

Contamination of surface waters by human activities remains a major public health concern, particularly in developing Countries. This study evaluated the bacteriological and physicochemical quality of water samples from a sand mining site in Ox-Bow Lake in Yenagoa, Bayelsa State, Nigeria. Water samples were collected at monthly intervals for a period of ten calendar months (August 2023 to May, 2024), covering both the dry and wet seasons and analyzed using standard techniques. Results revealed, Total heterotrophic bacteria counts ranged from  $6.1 \times 10^5$ – $11.8 \times 10^5$  CFU/ml; total coliforms from  $2.0 \times 10^4$ – $20.2 \times 10^4$  CFU/ml, total fecal coliform from  $2.8 \times 10^4$ – $14.2 \times 10^4$  CFU/ml; *Salmonella-Shigella* from  $1.4 \times 10^4$ – $3.7 \times 10^4$  CFU/ml.; and Vibriods ranged from  $0.5 \times 10^4$ – $2.9 \times 10^4$  CFU/ml while Pseudomonads were absent. Seasonal variations showed microbial peaks in both dry and wet periods, driven by runoff and dredging activities. Potential pathogens identified included *Vibrio cholerae*, *Salmonella typhi*, *Klebsiella pneumoniae*, and *Chromobacterium violaceum*. Analysis revealed acidic pH range (5.37–5.47), low conductivity (32.74–37.94  $\mu$ S/cm), and poor mineralization. Dissolved oxygen was relatively high (8.57–9.57 mg/L), but elevated biological oxygen demand (4.56–5.56 mg/L), chemical oxygen demand (74.81–78.81 mg/L), and phosphate concentrations (1.43–1.53 mg/L) indicated significant organic and chemical pollution. The range of heavy metal concentration were; lead (2.101–2.234 mg/L), iron (28.931–29.931 mg/L), cadmium (2.672–3.772 mg/L), and chromium (1.881–2.681 mg/L). Total petroleum hydrocarbons ranged from 35.2811 to 39.19146  $\mu$ g/mL. Generally, the ranges of heavy metals and TPH in the control were far lower. These results show that the water samples were contaminated with potential pathogens known to cause disease. Additionally, the physicochemical characteristics of the water samples indicate substantial organic pollution. Heavy metals, including Pb, Fe, Cd, and Cr, were found at concentrations above safe limits, and the detection of total petroleum hydrocarbons showed the level of contamination, all raising health concerns. These findings highlight an urgent need for the monitoring of sand mining activities to safeguard the ecological health of Ox-Bow Lake.

**Keywords:** Ox-Bow Lake, Pathogenic Bacteria, Water quality, Physicochemical Constituents, Pollution.

### Introduction

Sand mining is a coastal activity referring to the actual removal or excavation of sand from the ocean and coastal water floor (Ashraf *et al.*, 2010). Sand mining in Nigeria is achieved using various kind of sand mining/gravel extraction operation like dry-pit mining, wet-pit mining, bar skimming or scalp (use of machine) mining and manual methods. The manual method is mostly subsistence as a source of income to most unemployed youths (Barade and Obire, 2017). Sand mining can generate environmental abnormalities depending on method of extraction, intensity, duration and geological feature of the point of extraction.

Environmental problems arise when the rate of extraction of sand and other materials exceed the rate of natural generation of them in such environment (Ashraf *et al.*, 2010). All these contribute to varying concentration of chemical content especially heavy metals in the water column.

Environmental pollution with heavy metals is very prominent in point source areas such as mining, foundries and smelters, and other metal-based industrial operations (He, *et al.*, 2005). In recent years, there has been an increasing ecological and global public health concern associated with environmental contamination by these metals (He *et al.*, 2005).

It is well known that some of these metals possess potential toxicity to microbes and other life forms within the ecosystem. More so trace metals are important for growth metabolism in living cell at low concentration and microorganism possess mechanism of varying specificity for inter-cellular metal accumulation from external environment; for example, Copper (Cu), Zinc (Zn), Iron (Fe), Nickel (Ni), and Cobalt (Co) (Pradipta, 2008).

Common practices such as the indiscriminate disposal of untreated domestic waste particularly human and animal fecal matter directly into waterways are widespread in many communities (Obire & Aguda, 2012). In addition, untreated industrial effluents are frequently discharged into rivers and lakes, introducing a complex mixture of chemical and biological contaminants that alter the ecological balance and degrade surface water quality (Odonkor & Ampofo, 2013). The environmental consequences of these practices are extensive.

Organic and inorganic pollutants contribute to nutrient enrichment (eutrophication), which can trigger algal blooms, deplete dissolved oxygen, and disrupt aquatic food webs (Ntiba et al., 2017). Physical habitat alterations, including sand mining activities (dredging), sedimentation and shoreline degradation, can destroy spawning grounds for fish and other aquatic organisms. Furthermore, chemical contamination and elevated microbial loads compromise the suitability of these water bodies for domestic and recreational purposes, often leading to large-scale fish kills, biodiversity loss, and the reduction of clean drinking water sources (UNEP, 2016).

The Ox-Bow Lake in Bayelsa State, Nigeria, exemplifies these challenges. The rapid expansion of Yenagoa metropolis along the banks of water bodies has intensified anthropogenic pressures on these water bodies. The direct discharge of raw sewage, solid waste, and surface runoff containing animal waste into the river and lake increases the risk of microbial contamination. Microbiological contamination of surface waters is a pressing public health concern, particularly where untreated water is used for drinking and other household activities. The presence of coliform and enteric pathogens such as *Escherichia coli*, *Salmonella* spp., and *Vibrio* spp. is frequently reported in polluted aquatic environments, serving as indicators of fecal contamination and potential reservoirs of waterborne disease transmission (WHO, 2017).

Alongside microbial contamination, physicochemical parameters such as temperature, pH, turbidity, dissolved oxygen, conductivity, and nutrient concentrations are critical indicators of water quality, influencing bacterial survival, growth, and pathogenicity (APHA, 2017). Chemical pollutants such as heavy metals such as lead, cadmium, chromium, zinc, and copper; and petroleum hydrocarbons are of concern in Niger Delta surface waters. Heavy metals are non-biodegradable, and can accumulate in sediments and aquatic organisms, and may biomagnify along the food chain, posing risks of kidney damage, neurological disorders, and cancer in humans (Duruibe et al., 2007). Total petroleum hydrocarbons (TPH), which represent a broad family of hundreds of hydrocarbon compounds derived from crude oil, are frequently reported in aquatic systems exposed to oil pollution. High levels of TPH disrupt aquatic ecosystems, reduce dissolved oxygen, and exert toxic effects on fish and benthic organisms (Varjani, 2017; Chikere et al., 2011). Changes in these parameters often reflect the combined effects of natural processes and human-induced pollution.

Although several studies have examined either the microbial or physicochemical quality of surface waters in Nigeria, integrated investigations that analyze both aspects concurrently in the same aquatic system remain limited, especially in the Niger Delta.

This study aims to determine both the bacteria and the physicochemical characteristics including heavy metals and total petroleum hydrocarbons of water samples from a sand mining site in the Ox-Bow Lake, in Yenagoa, Bayelsa State, Nigeria; as to ascertain the effect of sand mining activities on the ecological health of the Lake, and on public health.

## Materials and Methods

### Description of Study Area

The study is the Ox-Bow Lake, located in Yenagoa, Bayelsa State, Nigeria. The study station was the Sand Mining Site with coordinates - 04°54'16.90"N, 006°16'45.30"E in the Ox-Bow Lake which is impacted by sand mining activities using dredgers. These activities disrupt the aquatic ecosystem by causing sediment displacement, increasing turbidity, and potentially introducing contaminants from the machinery into the Lake. A water body with coordinates - 04°56'26.36"N, 006°16'13.96"E with minimal anthropogenic interference served as the Control. The photo of Ox-Bow Lake showing the sampling station is presented in Plate 1.



**Plate 1: A Sand Mining Dredger at Ox-Bow Lake**

### **Water Sample Collection**

Water samples were collected at the Sand Mining Site in Ox-Bow Lake using five (5) sterile sample bottles with cap at monthly intervals for a period of ten calendar months (August 2023 to May, 2024), covering both the dry and wet seasons. Each bottle was rinsed with lake water thrice before collecting the sample while submerged below the water surface, with mouth of the bottle facing upstream and filled completely. All samples were labeled and kept in an ice packed cooler and were immediately transported to Rivers State University Microbiology Laboratory within 24hrs of collection for microbiological and physicochemical analysis (APHA 2005).

### **Media Preparation**

Normal saline was prepared by dissolving 8.5 g of NaCl in 1 L of distilled water, dispensed in 9 ml tubes, and sterilized at 121 °C for 15 minutes for use as a diluent in reactivating stressed microorganisms. Nutrient agar (28 g/L) was prepared, sterilized, and aseptically poured for total heterotrophic bacterial counts and sub-culturing. MacConkey agar (52 g/L) was prepared and sterilized for selective isolation of Gram-negative bacteria, while TCBS agar (89 g/L) was prepared for the isolation of *Vibrio* species.

Salmonella-Shigella agar (63 g/L) was prepared and sterilized for isolating *Salmonella* and *Shigella*, and Eosin Methylene Blue agar (36 g/L) was used for fecal coliform isolation. Cetrimide agar (47 g/L with 10 ml glycerol) was prepared and sterilized for isolating *Pseudomonas* species. Sugar fermentation media were prepared with 500 ml base medium containing peptone, Bromocresol dye, and individual sugars such as maltose, glucose, fructose, sucrose, galactose, and lactose were dispensed into tubes, and sterilized at 121 °C for 15 minutes.

### **Microbiological Analysis of Water Samples**

For the enumeration of total heterotrophic bacteria, 0.1 ml of a  $10^{-3}$  dilution was spread on nutrient agar, incubated, and colonies were counted and expressed as CFU/ml (Odeyemi et al., 2019). Total coliform bacteria were enumerated by spreading 0.1 ml of a  $10^{-2}$  dilution on MacConkey agar, incubating at 37 °C for 24–48 hours, and expressing results as CFU/ml. Positive isolates were sub-cultured on nutrient agar for identification. The presumptive coliform test involved inoculating water samples into MacConkey broth with Durham tubes at different volumes (10 ml, 1 ml, 0.1 ml), incubating at 37 °C for 24–48 hours.

Positive tubes were identified by color change and gas production; coliform numbers were determined using the MPN Table (Pepper & Gerba, 2015). Confirmed tests were performed by streaking positive tubes onto EMB agar, where *E. coli* showed a green metallic sheen and *Enterobacter aerogenes* appeared pinkish-mucoid. The completed test involved transferring EMB colonies to nutrient agar and MacConkey broth, followed by incubation and Gram staining; gas-forming, Gram-negative rods confirmed coliform presence.

Fecal coliforms were enumerated by spreading 0.1 ml of a  $10^{-2}$  dilution on EMB agar, incubating at 37 °C, and recording CFU/ml. *Shigella* and *Salmonella* species were isolated on Salmonella-Shigella agar, while *Vibrio* species were enumerated on TCBS agar, both using the same spread plate method and expressed as CFU/ml. *Pseudomonas* species were enumerated on Cetrimide agar under similar conditions.

### Identification and Characterization of Isolates

Bacterial isolates were characterized based on colonial, microscopic, and macroscopic features such as color, morphology, elevation, size, and margin. Discrete colonies were purified through sub-culturing onto freshly prepared nutrient agar plates and incubated at 37°C for 24 hours to obtain pure cultures, which were preserved in 10% glycerol at -4°C. Identification was carried out using ABIS descriptions. Pure colonies were revived on nutrient agar plates and subjected to standard biochemical tests, including Gram reaction, sugar fermentation, catalase, starch hydrolysis, motility, and oxidase tests, for proper characterization.

### Determination of Physicochemical Parameters in Water Samples

Temperature was measured using a mercury-in-glass thermometer (APHA, 2017), while pH was determined with a calibrated Jenway pH meter (Onwugbuta-Enyi et al., 2018). Salinity was analyzed using a salinity meter, and turbidity measured with a Shimadzu UV-160A spectrophotometer at 400 nm (Obire & Aguda, 2012). Conductivity was assessed with a Jenway conductivity meter (APHA, 2017), and total dissolved solids (TDS) determined gravimetrically by oven-drying filtered samples (Adesuyi et al., 2015). Total suspended solids (TSS) were obtained by filtering samples through pre-weighed pads, drying, and re-weighing (APHA, 2017).

Biological Oxygen Demand (BOD) was estimated using the Azide Modification method, while Chemical Oxygen Demand (COD) was determined by the dichromate reflux method (APHA, 2017). Phosphate concentration was analyzed after acid digestion using a UV spectrophotometer at 880 nm (Sharpley et al., 2003). Total petroleum hydrocarbons (TPH) were extracted and quantified using Gas Chromatography with Flame Ionization Detection (GC-FID) (Olawuni et al., 2014).

### Determination of Heavy Metals

Heavy metals (Lead, iron, Cadmium, Chromium) analysis of water samples were carried out using a flame atomic absorption spectrophotometer (Wright and Stuczynski, 1996). The calibration curves were prepared separately for all the metals by running different concentrations of standard solutions. The instrument was set to zero by running the respective reagent blanks. Average values of three replicates were taken for each determination.

### Statistical Analysis

Data on microbiological counts, physicochemical parameters, and heavy metal concentrations were analyzed using GraphPad Prism 8. ANOVA was used to test for significant differences among groups, followed by Duncan's Multiple Range Test (DMRT) for mean separation. Pearson's correlation was applied to assess relationships between bacterial counts and physicochemical parameters, with correlation coefficients (*r*) and p-values used to determine strength and significance.

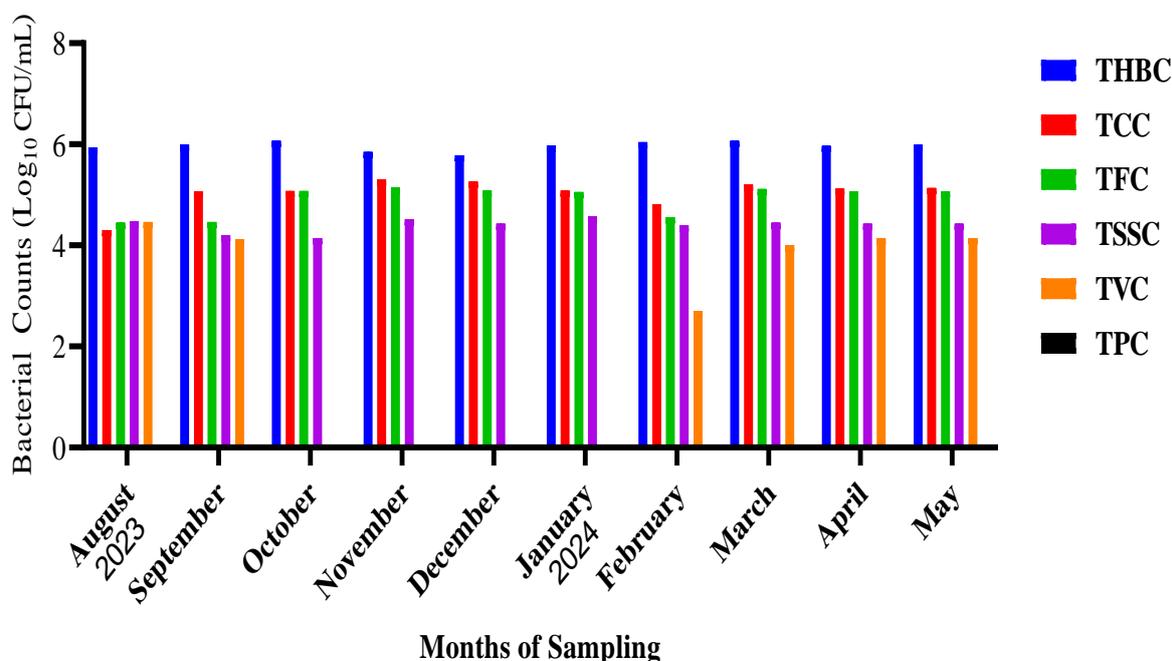
## Results

### Bacteriological Counts

The microbial counts at the dredging site in Ox-Bow Lake (Fig. 1) show a variety of results across the months. In August, the total heterotrophic bacterial count (THBC) was recorded at  $8.7 \times 10^5$  CFU/m, with the total coliform count (TCC) at  $2.0 \times 10^4$  CFU/ml. The total fecal count (TFC) was noted at  $2.8 \times 10^4$  CFU/ml, while the total *Salmonella Shigella* count (TSSC) was at  $3.0 \times 10^4$  CFU/ml. The TVC was recorded at  $2.9 \times 10^4$  CFU/ml, with no TPC detected. In September, THBC increased to  $10.0 \times 10^5$  CFU/ml, and the TCC increased significantly to  $11.5 \times 10^4$  CFU/ml. The TFC remained relatively stable at  $2.9 \times 10^4$  CFU/ml, while the TSSC reduced to  $1.6 \times 10^4$  CFU/ml, and the TVC decreased to  $1.3 \times 10^4$  CFU/ml.

Again, no TPC was detected. October showed an increase in THBC to  $11.7 \times 10^5$  CFU/ml, with TCC slightly higher at  $11.9 \times 10^4$  CFU/ml. The TFC recorded  $11.9 \times 10^4$  CFU/ml, while TSSC decreased to  $1.4 \times 10^4$  CFU/ml. The TVC recorded no values, and TPC remained undetected. In November, THBC decreased to  $7.1 \times 10^5$  CFU/ml, and TCC increased to  $20.2 \times 10^4$  CFU/ml. The TFC also increased to  $14.2 \times 10^4$  CFU/ml, with TSSC at  $3.3 \times 10^4$  CFU/ml. The TVC was not recorded, and no TPC was detected. December experienced a further decline in THBC to  $6.1 \times 10^5$  CFU/ml, with TCC at  $18.2 \times 10^4$  CFU/ml and TFC at  $12.2 \times 10^4$  CFU/ml. The TSSC recorded a count of  $2.7 \times 10^4$  CFU/ml, and no TVC or TPC were detected. In January, THBC showed an increase to  $9.5 \times 10^5$  CFU/ml, with TCC at  $12.1 \times 10^4$  CFU/ml and TFC at  $11.4 \times 10^4$  CFU/ml. The TSSC increased to  $3.7 \times 10^4$  CFU/ml, while no TVC or TPC were detected.

February showed a THBC of  $11.1 \times 10^5$  CFU/ml, with TCC reduced to  $6.6 \times 10^4$  CFU/ml and TFC at  $3.6 \times 10^4$  CFU/ml. The TSSC was at  $2.5 \times 10^4$  CFU/ml, and the TVC recorded a low of  $0.5 \times 10^4$  CFU/ml, with no TPC detected. In March, the THBC increased to  $11.8 \times 10^5$  CFU/ml, while the TCC was recorded at  $16.0 \times 10^4$  CFU/ml. The TFC increased to  $13.0 \times 10^4$  CFU/ml, and the TSSC was at  $2.8 \times 10^4$  CFU/ml. The TVC was noted at  $1.0 \times 10^4$  CFU/mL, with no TPC detected. In April, THBC decreased to  $9.3 \times 10^5$  CFU/mL, with TCC at  $13.2 \times 10^4$  CFU/ml and TFC at  $11.5 \times 10^4$  CFU/ml. The TSSC recorded a count of  $2.7 \times 10^4$  CFU/ml, while TVC was  $1.4 \times 10^4$  CFU/ml, with no TPC detected. In the month of May, THBC was  $9.8 \times 10^5$  CFU/ml, with TCC at  $13.7 \times 10^4$  CFU/ml and TFC at  $11.7 \times 10^4$  CFU/ml. The TSSC was at  $2.7 \times 10^4$  CFU/ml, and TVC was recorded at  $1.4 \times 10^4$  CFU/ml, with no TPC detected.



**Fig. 1: Microbial count for Dredging Site in Ox-Bow Lake in the Various Months**

**Key:** THBC: total heterotrophic bacteria count, TCC: total coliform count, TFC: total fecal coliform, TSSC: total *Shigella Salmonella* count, TVC: total *Vibrio* count, TPC: total *Pseudomonas* count.

The distribution of bacteria at the dredging site in Ox-Bow Lake during the dry and wet seasons is presented in Figure 2 and Figure 3 respectively. In the dry season, significant differences were observed between the total heterotrophic bacterial count and both the *Vibrio* and *Salmonella-Shigella* counts, as well as between the fecal and *Salmonella-Shigella* counts.

The *Salmonella-Shigella* count was also significantly higher than the *Vibrio* count. In the wet season, significant differences were found between the total heterotrophic bacterial count and both the *Vibrio* and coliform counts. Significant differences were also noted between the coliform and *Salmonella-Shigella* counts, as well as between the *Salmonella-Shigella* and *Vibrio* counts.

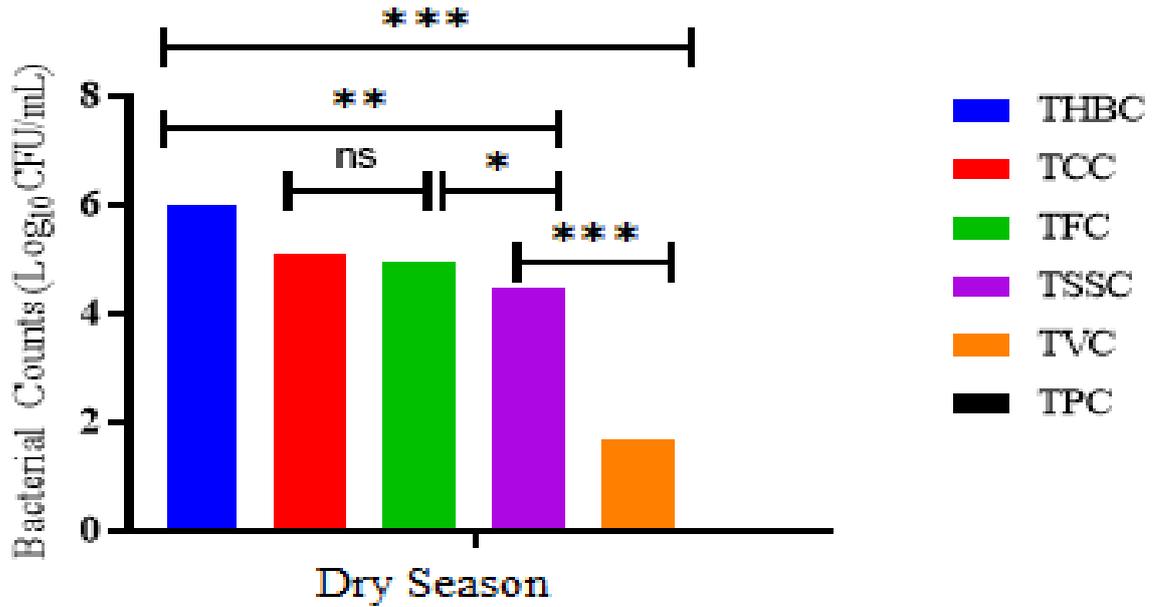


Fig 2: Distribution of Bacteria at the Dredging Site in Ox-Bow Lake during the Dry Season

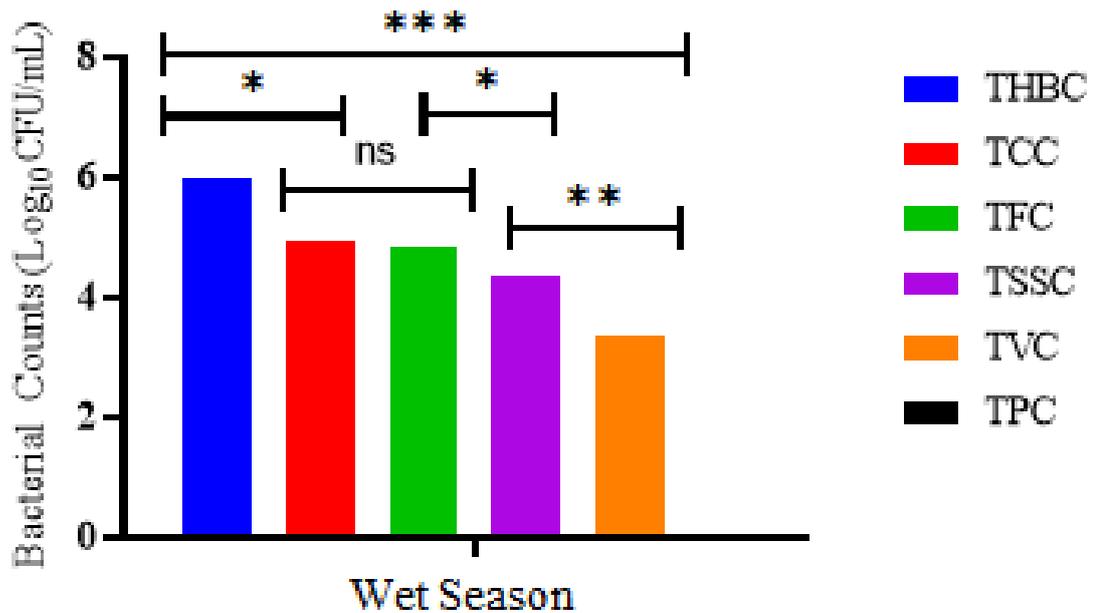


Fig. 3: Distribution of Bacteria at the Dredging Site in Ox-Bow Lake during the Wet Season

**Key:** ns (not significant), \*(Significant), \*\*(highly significant), \*\*\* (very highly significant) at  $p \leq 0.05$ . THBC: total heterotrophic bacteria count, TCC: total coliform count, TFC: total fecal coliform, TSSC: total *Shigella Salmonella* count, TVC: total *Vibrio* count, TPC: total *Pseudomonas* count

The morphological and physiological characteristics and probable identity of bacteria isolated from the dredging site in Ox-Bow Lake are presented in Table 1. The bacteria that were isolated and identified *Klebsiella pneumoniae*, *Klebsiella oxytoca*, *Vibrio*

*cholerae*, *Kluyvera ascorbata*, *Salmonella typhi*, *Chromobacterium violaceum*, *Bacillus cereus*, *Staphylococcus aureus*, *Staphylococcus cohnii*, *Bacillus tequilensis*, *Klebsiella aerogenes*, *Bacillus myoides*, *Citrobacter koseri*, and *yersinia intermedia*.

**Table 1: Morphological and Physiological Characteristics and Probable Identity of Bacteria Isolated from the Sand Mining Site in Ox-Bow Lake**

Isolate Code	Colony Shape	Colour	Colony Size	Texture	Elevation	Gram Reaction	Catalase	Oxidase	Citrate	Motility	Starch Hydrolysis	Methyl Red	Voges Proskuaer	Indole	Glucose	Lactose	Maltose	Mannitol	Fructose	Sucrose	Xylose	Sorbitol	Probable Organism
MA1	irregular	Blue	3mm	Moist	Raised	-ve rods	+	-	-	-	+	-	+	-	+	-	+	+	+	+	+	+	<i>Klebsiella pneumoniae</i>
EMB1	circular	Light pink	3mm	Moist	flat	-ve rods	+	-	+	-	-	+	-	-	+	-	+	+	+	+	-	+	<i>Klebsiella oxytoca</i>
NA1	circular	Cream	2mm	moist	flat	-ve rods	+	-	+	+	+	+	-	+	-	-	+	-	+	+	+	-	<i>Vibrio cholerae</i>
EMB2	circular	Pale pink with purple dot	2mm	Moist	Raised	-ve rods	+	+	+	+	-	-	+	-	+	-	+	-	+	+	+	-	<i>Kluyvera ascorbata</i>
SSA1	circular	Pale pink with black dot	2mm	Moist	flat	-ve rods	+	+	+	-	+	+	-	+	-	+	+	+	+	+	+	+	<i>Salmonella typhi</i>
NA2	circular	Purple	2mm	Moist	flat	-ve rods	+	+	-	+	+	+	+	-	+	-	+	-	+	-	-	-	<i>Chromobacterium violaceum</i>
NA3	circular	Cream	3mm	Dry	Raised	+ve rods	+	-	+	+	-	+	+	+	+	-	+	+	+	+	+	+	<i>Bacillus cereus</i>
NA4	circular	Golden yellow	3mm	Moist	flat	+ve cocci	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	+	<i>Staphylococcus aureus</i>
MA2	circular	yellow	2mm	Moist	raised	+ve cocci	+	+	-	-	+	+	-	+	+	+	+	+	+	-	-	-	<i>Staphylococcus cohnii</i>
NA5	round	White	3mm	Dry	flat	+ve rods	+	-	+	+	+	-	+	+	+	+	+	+	+	+	+	+	<i>Bacillus tequilensis</i>
SSA2	round	Pale pink	3mm	Mucoid	Raised	-ve rods	+	-	+	+	-	-	-	-	+	+	+	+	+	+	+	+	<i>Klebsiella aerogenes</i>
NA6	irregular	Milk colour	3mm	Dry	Raised	+ve rods	+	-	+	+	-	+	-	-	+	-	+	-	+	+	+	-	<i>Bacillus myoides</i>
MA3	circular	Bright pink	2mm	Moist	Raised	-ve rods	+	+	+	-	+	+	+	+	+	+	-	+	+	+	+	+	<i>Yersinia intermedia</i>
MA4	circular	Pale pink	2mm	Dry	Flat	-ve rods	+	+	+	-	-	+	-	+	+	+	+	-	+	+	+	+	<i>Citrobacter koseri</i>

**Keys:** Gram Rxn = Gram Reaction; Cat = Catalase; Oxi = Oxidase; Cit = Citrate; Mot = Motility; SH = Starch Hydrolysis; VP = Voges Proskuaer Ind = Indole; Glu = Glucose; Lac = Lactose; Mal = Maltose; Man = Mannitol; Fru = Fructose; Suc = Sucrose; Xyl = Xylose; Sor = Sorbitol; + = Positive; - = Negative

Results of the physicochemical analysis of water samples from the sand mining (dredging) site in Ox-Bow Lake are presented in Table 2. The physicochemical constituents varied across sampling months and between the sand mining and control sites. The pH values ranged from 5.37 at the dredging site in August 2023 to 5.78 at the control site (October 2023–May 2024) and were consistently below NSDWQ (6.5–8.5) and WHO (6.5–6.8) standards. Temperature varied between 24.5 °C (dredging site, August) and 26.8 °C (control site, October–May), remaining within the WHO guideline range of 15.5–32 °C.

Electrical conductivity values ranged from 30.49  $\mu\text{S}/\text{cm}$  in the control (August) to 37.94  $\mu\text{S}/\text{cm}$  (dredging site, May), while TDS varied between 17.29 mg/L (control, August) and 21.63 mg/L (dredging site, May). Both parameters remained below guideline limits (NSDWQ: 2000  $\mu\text{S}/\text{cm}$ , 500 mg/L; WHO: 1000  $\mu\text{S}/\text{cm}$ , 500 mg/L). Salinity ranged from 1.03 mg/L (control, August) to 3.09 mg/L (dredging site, October–May), remaining below WHO limits (30–60 mg/L). Nitrate values ranged from 0.21 mg/L (dredging site, August) to 0.72 mg/L (control, October–May), all within permissible limits (10mg/L).

Turbidity was higher at the dredging site (7.81–7.91 NTU) than at the control (2.80–3.80 NTU), with dredging site values exceeding NSDWQ and WHO thresholds (5 NTU). TSS ranged from 14.30 mg/L (control, August) to 16.30 mg/L (control, January), exceeding the NSDWQ limit (10 mg/L) but remaining below the WHO limit (30 mg/L).

DO concentrations were highest at the control site (12.06 mg/L, October–May) and lowest at the dredging site (8.57 mg/L, August). All values were above the minimum required threshold (5 mg/L). BOD ranged from 4.56 mg/L (dredging site, August) to 6.61 mg/L (control, October–May); values at the control site slightly exceeded the NSDWQ limit (5 mg/L), though all remained below the WHO standard (15 mg/L). COD was elevated throughout, ranging from 74.81 mg/L (dredging site, August) to 109.71 mg/L (control, November), consistently exceeding NSDWQ (10 mg/L) and WHO (40 mg/L) limits. Phosphate concentrations were between 1.02 mg/L (control, August) and 1.53 mg/L (dredging site, October–May), all exceeding NSDWQ (0.1 mg/L) and WHO (0.05–0.37 mg/L) standards.

Overall, parameters that consistently exceeded permissible limits included turbidity, TSS, COD, BOD (at the control), and phosphate, with higher deviations observed at the dredging site.

The results for the Heavy metal concentrations in water samples from Ox-Bow Lake and of the control station are presented in Figure 4. The Heavy metal concentrations in water samples from Ox-Bow Lake varied across months and stations, with consistently higher levels at the sand mining station compared to the control. Lead (Pb) concentrations ranged from 0.441 mg/L at the control site in August 2023 to 2.234 mg/L at the sand mining station in May 2024. All values exceeded the NSDWQ and WHO permissible limit of 0.01 mg/L, with sand mining station concentrations (2.101–2.234 mg/L) higher than control values (0.441–0.667 mg/L). Iron (Fe) levels varied from 9.732 mg/L (control, August) to 29.931 mg/L (sand mining, October–May). Both stations exceeded the NSDWQ/WHO limit of 0.3 mg/L by more than an order of magnitude. Control site concentrations ranged from 9.732–12.632 mg/L, whereas sand mining levels remained consistently elevated (28.931–29.931 mg/L). Cadmium (Cd) concentrations ranged from 0.78 mg/L (control, August) to 3.772 mg/L (sand mining, January). These values exceeded the maximum permissible limit of 0.003 mg/L (WHO/NSDWQ). Control levels increased progressively from 0.78 mg/L in August to 1.98 mg/L in May, while sand mining site values remained significantly higher (2.672–3.772 mg/L). Chromium (Cr) recorded the lowest concentration (0.131 mg/L) at the control site in August, while the highest (2.681 mg/L) was recorded at the sand mining station in October. Control values increased gradually from 0.131–0.211 mg/L, while sand mining values fluctuated between 1.881–2.681 mg/L. All concentrations exceeded the NSDWQ/WHO guideline value of 0.05 mg/L.

Total petroleum hydrocarbon (TPH) concentrations in Ox-Bow Lake varied across sampling months, with consistently higher levels at the sand mining station compared to the control (Figure 5). The control, TPH concentrations ranged from 10.1119 $\mu\text{g}/\text{mL}$  in August 2023 to 15.1119 $\mu\text{g}/\text{mL}$  in May 2024, showing a gradual increase over time. Sand mining station, values ranged from 35.2811 $\mu\text{g}/\text{mL}$  in August 2023 to 39.1914 $\mu\text{g}/\text{mL}$  in May 2024, also showing a steady rise across the sampling months.

**Table 2: Physicochemical Constituents of the Water Samples from the Sand Mining and Control Stations in Ox-Bow Lake**

Parameter	August 2023		October		November		January 2024		May		Standard	
	Control	Dredging site	Control	Dredging site	Control	Dredging site	Control	Dredging site	Control	Dredging site	NSDWQ (2007)	WHO (2017)
pH	5.56	5.37	5.78	5.47	5.78	5.47	5.78	5.47	5.78	5.47	6.5-8.5	6.5-6.8
Temp (°C)	25.8	24.5	26.8	25.5	26.8	26.5	26.8	26.5	26.8	26.5	-	15.5-32
EC (µs)	30.49	32.74	31.49	33.74	31.49	33.94	31.49	33.94	31.49	37.94	2000	1000
TSS (mg/l)	14.30	15.22	15.30	16.22	15.30	16.22	16.30	16.22	15.30	16.22	10	30
Turb (NTU)	2.80	7.81	3.80	7.91	3.80	7.91	3.80	7.91	3.80	7.91	5	5
DO (mg/l)	11.06	8.57	12.06	9.57	12.06	9.57	12.06	9.57	12.06	9.57	5	5
BOD (mg/l)	5.61	4.56	6.61	5.56	6.61	5.56	6.61	5.56	6.61	5.56	5	15
COD (mg/l)	108.21	74.81	109.21	75.81	109.71	75.81	109.21	75.81	109.21	78.81	10	40
TDS (mg/l)	17.29	19.63	18.29	20.63	18.29	20.63	19.29	20.63	19.29	21.63	500	500
Sal (mg/l)	1.032	3.083	1.052	3.093	1.052	3.093	1.05	3.093	1.052	3.093	-	30-60
PO <sub>4</sub> <sup>3-</sup> (mg/l)	1.024	1.43	1.034	1.53	1.034	1.53	1.034	1.53	1.034	1.53	0.1	0.05-37
NO <sub>3</sub> <sup>-</sup> (mg/l)	0.62	0.21	0.72	0.31	0.72	0.31	0.72	0.34	0.72	0.34	10	10

**Keys:** EC-electrical conductivity, TSS-total suspended solid, Tur-turbidity, DO-dissolved oxygen, BOD-biological oxygen demand, COD-chemical oxygen demand, TDS-total dissolved oxygen, NSDWQ - Nigerian Standard for Drinking Water Quality, WHO- world health organization.

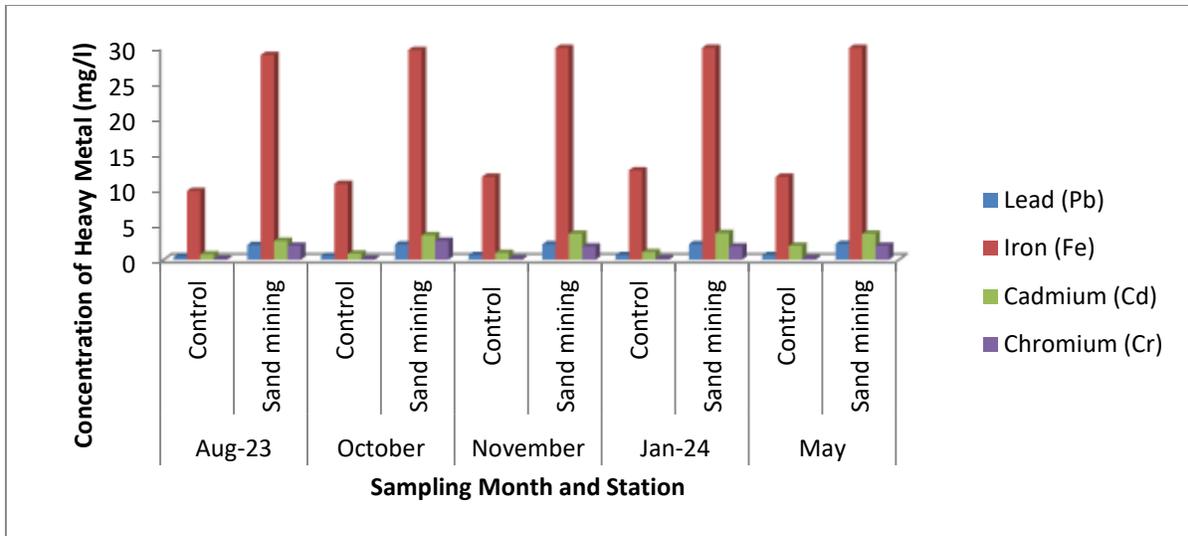


Fig. 4: Concentration of heavy metals in sand mining site in Ox-Bow Lake

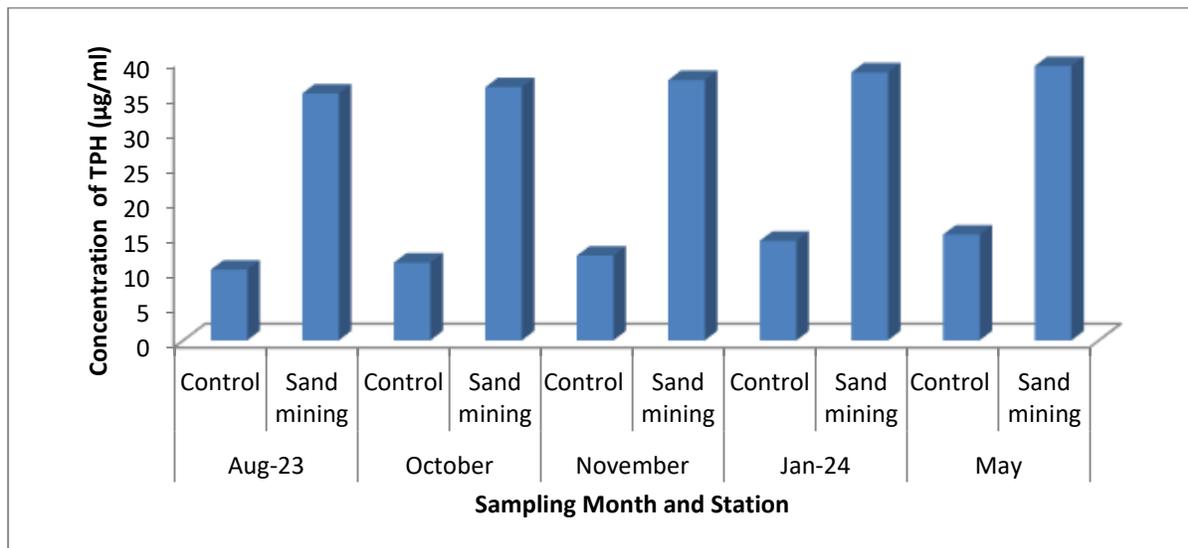


Fig. 5: Concentration of Total petroleum hydrocarbon (TPH) in sand mining site in Ox-Bow Lake

### Discussion

The study of Ox-Bow Lake water showed consistently elevated microbial loads, highlighting severe organic and fecal contamination. The total heterotrophic bacterial count greatly exceeded the acceptable threshold of  $5.0 \times 10^2$  CFU/ml commonly used as a contamination indicator in natural waters (WHO, 2017). Elevated THBC values are often associated with anthropogenic influences such as dredging, sewage inputs, and agricultural runoff (Obire & Aguda, 2021), and reflect conditions favorable for opportunistic pathogens (Odonkor & Ampofo, 2013).

The persistently high coliform counts ( $2.0 \times 10^4$  CFU/ml –  $20.2 \times 10^4$  CFU/ml) across all sampling periods confirm continuous fecal contamination. Coliforms are well-established indicators of fecal pollution and water safety (Edokpayi *et al.*, 2018). The detection of *Salmonella–Shigella* counts further suggests sustained input of enteric pathogens, with direct implications for transmission of waterborne diseases such as typhoid and dysentery (Akinyemi *et al.*, 2019). These results align with reports from similar Nigerian aquatic systems, where fecal indicator bacteria frequently exceed permissible limits due to poor sanitation and direct waste discharge (Ogbonna *et al.*, 2022).

The periodic detection of *Vibrio* spp., including *Vibrio cholerae*, is particularly concerning. *Vibrio* species are autochthonous to aquatic environments, but their proliferation is linked to high organic matter and moderate salinity (Colwell, 2015). Recent studies in Nigeria have documented the presence of toxigenic *V. cholerae* in surface waters, demonstrating their capacity to persist in aquatic reservoirs and fuel outbreaks (Odu & Ugboma, 2023; Akinyemi et al., 2024). Seasonal dynamics in this study showed higher THBC and coliform counts in both dry and wet seasons, with dry-season concentration effects favoring heterotrophic growth, and wet-season runoff amplifying pathogen influx. Similar seasonal trends have been reported in Bayelsa and Lagos states, where cholera incidence peaks following hydrological fluctuations (Adewale et al., 2022). The diversity of bacterial isolates further emphasizes the lake's compromised state. Pathogens such as *Salmonella typhi*, *Vibrio cholerae*, *Klebsiella pneumoniae*, and *Staphylococcus aureus* coexist with opportunistic organisms like *Chromobacterium violaceum* and *Yersinia intermedia*. The detection of *C. violaceum* is notable, as although rare, it has been linked to fatal septicemia in tropical regions (Yang & Li, 2020). Similarly, *Klebsiella* species are frequently implicated in multidrug-resistant infections, highlighting the potential public health burden associated with exposure (Magiorakos et al., 2020). The relatively even distribution of isolates (each ~6.66%) may be attributed to sediment re-suspension from dredging, which enhances microbial diversity by redistributing nutrients and microorganisms across the water column (Dalu & Wasserman, 2018).

The physicochemical characteristics of Ox-Bow Lake indicate significant alterations associated with dredging activities. The persistently acidic pH observed is a notable concern, as low pH conditions can increase the solubility and mobility of heavy metals, thereby enhancing ecological and public health risks. Similar acidic trends have been reported in other sand mining-impacted water bodies, where sediment disturbance reduces buffering capacity and alters water chemistry (Mensah et al., 2019).

Dissolved oxygen (DO) and biological oxygen demand (BOD) patterns suggest increased organic matter decomposition at the dredging site. Elevated BOD, alongside consistently high COD, reflects substantial organic and chemical loading.

A trend commonly observed in disturbed freshwater ecosystems (Boyd & Tucker, 2012; Hazen & Chapman, 1996). This oxygen stress may further influence microbial ecology by selecting facultative and anaerobic taxa, thereby reshaping microbial community structure. High turbidity, total suspended solids (TSS), and phosphate concentrations reinforce the role of dredging in mobilizing sediments and nutrients into the water column. Previous studies have similarly reported that sediment resuspension during mining significantly increases particulate loads and nutrient cycling (Mitsch & Gosselink, 2015; Zhao et al., 2022). Such enrichment may fuel eutrophication, promoting microbial proliferation and diversity shifts. Although electrical conductivity, total dissolved solids (TDS), salinity, and nitrate remained within permissible limits, the consistent exceedance of turbidity, TSS, COD, BOD, and phosphate suggests that dredging imposes long-term ecological pressures. Elevated nutrient and organic matter inputs provide substrates that enhance microbial metabolism and biomass accumulation. Indeed, higher microbial loads and the occurrence of diverse bacterial taxa in dredging-impacted environments have been reported elsewhere (Sun et al., 2005; Olawuni et al., 2014).

The elevated concentrations of Pb, Fe, Cd, and Cr observed in Ox-Bow Lake highlight the significant influence of sand mining activities on aquatic ecosystems. The consistently higher levels at the sand mining station compared to the control site suggest anthropogenic inputs, as mining operations often mobilize metal-rich sediments into the water column (Ogbeibu et al., 2014; Edokpayi et al., 2017). Similar findings have been reported in mining-impacted aquatic systems, where sediment disturbance and leaching of associated minerals elevated Pb and Cd levels above international standards (Li et al., 2019; Aderinola et al., 2009).

From a health perspective, Pb and Cd are of particular concern due to their cumulative toxicity. Chronic exposure to Pb can impair neurological development in children and cause cardiovascular dysfunction in adults (Needleman, 2004; WHO, 2011). Cd exposure has been linked to kidney damage and skeletal demineralization (Jarup & Akesson, 2009). The concentrations detected far exceeded the WHO (2017) and NSDWQ (2007) guidelines, suggesting potential public health risks for communities relying on the lake for domestic or recreational use.

Ecologically, elevated Fe and Cr levels can negatively impact aquatic productivity. Excessive Fe alters water chemistry, reducing oxygen availability and impairing fish gill function (Singh *et al.*, 2010), while Cr, especially in its hexavalent form, is mutagenic to aquatic organisms (Costa & Klein, 2006). The cumulative presence of multiple heavy metals increases the likelihood of synergistic toxicity within the aquatic food web (Tchounwou *et al.*, 2012).

Importantly, heavy metal pollution also influences microbial load and diversity in aquatic ecosystems. Elevated Cd and Pb levels have been shown to inhibit the growth of sensitive microbial populations while selectively enriching resistant strains, often carrying metal resistance genes that co-exist with antibiotic resistance determinants (Gillan *et al.*, 2015; Seiler & Berendonk, 2012). This shift in microbial diversity reduces ecological balance, impairs natural bioremediation processes, and may facilitate the emergence of multi-resistant pathogens (Olowoake *et al.*, 2022). Similar trends of altered microbial community structure in response to heavy metal stress have been documented in mining-impacted rivers and wetlands (Mishra *et al.*, 2018).

The findings therefore show that heavy metal enrichment from sand mining activities not only poses direct human and ecological health risks but also indirectly threatens microbial diversity, which is essential for maintaining aquatic ecosystem function. This aligns with previous studies emphasizing the need for continuous biomonitoring of both chemical contaminants and microbial indicators in freshwater systems (Olawuni *et al.*, 2014; Mensah *et al.*, 2019).

The elevated levels of Total Petroleum Hydrocarbons (TPH) observed in Ox-Bow Lake, particularly at the sand mining station, indicate ongoing hydrocarbon inputs likely associated with anthropogenic disturbances. Sand mining operations can enhance hydrocarbon accumulation by resuspending contaminated sediments and facilitating leaching of petroleum-derived residues from surrounding catchments (Obire & Nwaubeta, 2002; Ite *et al.*, 2013).

The steady rise in TPH concentrations across months further suggests cumulative contamination, consistent with reports from other freshwater systems exposed to continuous industrial or artisanal activities (Oluwafemi *et al.*, 2019).

TPHs are environmentally persistent and pose significant ecological threats due to their toxic, mutagenic, and carcinogenic properties (Das & Chandran, 2011). They can impair photosynthetic activity by forming surface films that reduce light penetration, limit oxygen exchange, and alter aquatic primary productivity (Mishra *et al.*, 2018). Furthermore, hydrocarbons readily bioaccumulate in fish and benthic organisms, thereby entering the food chain and increasing health risks for human populations dependent on these resources for food and livelihood (Kostka *et al.*, 2011; Chikere *et al.*, 2019). Petroleum hydrocarbons significantly influence microbial community structure. Hydrocarbon contamination has been shown to increase the abundance of hydrocarbonoclastic bacteria such as *Pseudomonas*, and *Bacillus*, while reducing sensitive taxa and overall microbial diversity (Yakimov *et al.*, 2007; Chikere & Ekwuabu, 2014). This selective enrichment promotes biodegradation processes but often results in an imbalanced microbial community dominated by specialized degraders (Head *et al.*, 2006). Such shifts may reduce ecosystem resilience, as the decline of functionally diverse microbial populations weakens natural nutrient cycling (Atlas & Hazen, 2011).

The link between hydrocarbon contamination and microbial dynamics is particularly important in aquatic environments like Ox-Bow Lake, where petroleum residues can co-select microbial resistance traits, including those related to antibiotic resistance (Brar *et al.*, 2017). Thus, the elevated TPH concentrations not only pose direct ecological and toxicological threats but also have indirect implications for microbial diversity and public health.

## Conclusion

Sand mining has significantly degraded Ox-Bow Lake, leading to elevated bacterial loads, fecal indicators and epidemic-prone pathogens. Excessive nutrients, and elevated chemical oxygen demand, heavy metals and TPH further support microbial proliferation and ecosystem imbalance while reducing ecosystem resilience. This poses combined ecological and public health risks through pathogen proliferation, and bioaccumulation of toxicants. These findings highlight urgent need for stricter regulations on sand mining activities, to safeguard freshwater resources and community health.

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