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Physico-chemistry and Public Health Risk Assessment of Surface Waters around Waterfront Communities in Port Harcourt Metropolis

Akintobi, G.A[1*]., Ogbonna, D.N[2] and Ogba, A[1].
[1]Department of Public Health Sciences, Faculty of Basic Medical Sciences, Rivers State University, Port Harcourt.
[2]Department of Microbiology, Rivers State University, Nkpolu-Oroworukwo, PMB 5080, Port Harcourt, Nigeria.
***Corresponding Author:** *gracephilip496@gmail.com*

ABSTRACT

Anthropogenic activities have contributed to contamination of rivers and creeks within Port Harcourt metropolis, increasing environmental and public health risks. This study assessed the public health risks associated with surface water in communities surrounding Port Harcourt. Surface water samples were collected from five waterfront communities located at Choba, Iwofe, Creek Road, Eagle Island, and Marine Base. Standard analytical methods were employed to determine the physicochemical and microbiological characteristics, and data were analyzed using ANOVA at $p<0.05$. Physicochemical results showed pH (6.8–7.8) and temperature (28.2–30.8°C) were generally within acceptable limits, while dissolved oxygen ranged from 3.8–5.6 mg/L. Elevated pollution indicators were recorded for Biological oxygen demand (3.8–9.5 mg/L), chemical oxygen demand (28–130 mg/L), Total suspended solid (28–120 mg/L), Electric conductivity (650–22,000 µS/cm), total dissolved solid (320–11,000 mg/L), salinity (0.3–70 ppt) and turbidity (18–110 NTU), with Marine Base and Creek Road showing highest contamination. Heavy metal concentrations were elevated, ranging as follows: Iron (0.45–2.40 mg/L), lead (0.015–0.120 mg/L), Cadmium (0.004–0.030 mg/L), Chromium (0.032–0.190 mg/L), Ni (0.058–0.310 mg/L), Cu (0.38–2.60 mg/L) and Zn (0.92–6.20 mg/L), while Iron (≤ 0.3) Lead (≤ 0.01) Cadmium (≤ 0.003) Chromium (≤ 0.05) Nickel (≤ 0.07) were above WHO/SON limits. Although individual Target Hazard Quotients were below 1, the cumulative Hazard Index (2.228) indicated potential health risk. Microbial loads in water were high: total heterotrophic bacterial counts (1.38×10^8–1.64×10^8 CFU/ml), total coliform counts (1.15×10^6–1.23×10^6 CFU/ml), fecal coliform counts (1.2×10^4–2.0×10^4 CFU/ml), and bacteria counts exceeded WHO standards of 1×10^2 CFU/ml for THB and 0 CFU/ml for total and fecal coliforms. Predominant bacterial isolated included; *Escherichia coli*, *Pseudomonas*, *Proteus*, *Shigella* and *Salmonella*. The study concludes that surface waters from the studied communities are significantly impacted by physicochemical, microbial and heavy metal pollution, posing serious ecological and public health risks. The study highlights the urgent need for effective pollution control.

Keywords: Surface water, Waterfront, Anthropogenic activities, Heavy metals, Microorganisms, Public health risk.

Introduction

Surface waters are important because they house aquatic animals; act as an extra source to groundwater and support human economy in the areas of fishing, hunting, recreation, transportation, manufacturing and agriculture (Nwankwoala & Angaya, 2021). Achieving standard surface water quality in Nigeria has been a challenge. Observable poor sanitation practices, especially related to disposal of untreated wastewater, sewage dumping sites, abattoir activities, waste from industries and households and other human activities, directly into the rivers, streams, seas and oceans has impacted on surface water quality (Arimieari *et al.,* 2014). About 95% of households in the riverine or coastal areas in Nigeria particularly those with Waterfront communities have little or no wastewater sanitation facility, especially in the area of domestic waste disposal (Ogbonna *et al.,* 2021). This poor sanitation and unsafe disposal of waste, including human excreta and other bodily fluids, directly into surface waters defaces the water body, elicits offensive odors and has the potency to negatively affect human health, as the populace may be exposed to infectious diseases; and the aquatic life suffers. Storm water and other overland flow also contribute to polluting the surface water bodies due to the presence of solid waste on the ground surface (Kpormon *et al.,* 2023).

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In recent times, only about 5% of the households have some form of well-developed and acceptable sanitary system. However, 95% of these systems channel their untreated waste through pipes and gutters directly into the surface waters. Other solid wastes like papers, plastic bags, empty cans, toilet papers, sanitary pads, etc, are also disposed indiscriminately into the surrounding water bodies, and these contribute to the overall pollution of the water; destruction of its aesthetics, and devaluation of the economic activities of the people (Ogbonna & Udotong, 2021). Where raw sewage and other bodily fluids are expelled daily (Chindah & Braide, 2020). Wooden supports are constructed where people squat to defecate. Recent improvements have introduced concrete platforms that are usually sat on, especially by the elderly, although at great risk of a very high possibility of contacting various forms of infections. Faecal matter affects the economic and ecological health of any water body (Akani *et al.,* 2022). Communities like waterfronts in Port Harcourt that do not have adequate sanitation facilities are exposed to high risk of excreta-related infections. Most people susceptible to these diseases are children under 3 years. These infectious diseases reportedly include cholera, diarrhea and typhoid fever (GESAMP 2018), noted that contamination of the marine environment by sewage leads to diseases linked to bathing and swimming in marine waters and to the consumption of seafood. Waterborne pathogens are accidentally ingested when water is swallowed or food borne pathogens found in the tissues of fish and shellfish are consumed as seafood (Ogbonna & Origbe, 2021). Another disease caused by this type of poor sanitation practice is dysentery, contracted through intestinal infestation of parasitic worms (Egbai, 2022). Other diseases are salmonellosis, shigellosis, gastric ulcers, giardiasis and amoebiasis. This is supported by the World Health Organization (WHO 2024) that reported that bathing in polluted seas causes some 250 million cases of gastroenteritis and upper respiratory disease every year

Eutrophication is a negative outcome of the disposal of untreated wastewater into surface waters. Nutrients contained in human excreta produce phosphorus and nitrogen in the river. This increase in nutrients results in algal blooms, loss of oxygen, fish kills, loss of biodiversity, amongst other problems (Ogbonna *et al.,* 2021). Additionally, this algal bloom causes some species of algae to produce biotoxins (natural poisons) that can be transferred through the food web, potentially harming higher-order consumers such as marine mammals and humans (Ogbonna & Origbe, 2021). To properly estimate the extent of pollution caused on surface water, proper assessment of its quality has to be carried out based on accepted water quality standards. In Waterfront communities around Port Harcourt metropolis, there is no evidence of established surface water quality and its correlation with standard requirements as well as the public health risks associated with water around such communities (MacPepple *et al.,* 2027).

Hence, the aim of this study is to assess the Physico-chemistry and public health risk assessment of surface waters around waterfront communities in Port Harcourt metropolis.

Materials and Methods

Study Area

The study was conducted around Waterfront Communities in Port Harcourt Metropolis, Rivers State, Nigeria, namely Choba, Iwofe, Creek Road, Eagle Island, and Marine Base. These communities are located along major surface water bodies, creeks, and estuarine systems that drain into the Bonny River and are characterized by intense anthropogenic and economic activities capable of influencing water quality and public health (Kpormon *et al.,* 2023). (state specifically the major activities around these waterfront communities)

Study Design

The study adopted a descriptive study design involving environmental sampling and laboratory-based analyses. The design incorporated physicochemical, microbiological, and heavy metal assessment of surface water samples collected from selected riverine communities within Port Harcourt Metropolis. The study combined field sampling, laboratory analyses, and questionnaire-based assessment of residents' awareness, perception, and exposure patterns regarding surface water pollution.

Sample Collection

Surface water samples were collected following standard procedures for water quality assessment to ensure representativeness, accuracy, and minimal contamination. Sampling was conducted at predetermined locations along the selected study areas. At each station, samples were collected from approximately 15–30 cm below the water surface to avoid surface films and bottom sediments. The samples were collected using sterile bottles properly labeled according to standard microbiological procedures (Ogbonna *et al.,* 2019), and then transported to the Laboratory for analyses within 2 hours of collection in a thermos box containing an ice pack.

Bacteriological Analyses of the Water Samples

The bacterial population of the water samples from the five waterfront communities were enumerated using standard microbiological methods as described by Prescott *et al.,* (2011) and adopted by Kpormon and Douglas (2018), as follows:

Serial dilution

Serial dilutions were carried out using standard method as adopted by Kpormon and Douglas (2018). One millilitre each of the water samples were separately added to 9 ml of normal saline (diluents). After thorough shaking, further 10-fold (v/v) serial dilutions were made by transferring 1 ml of the original solution to freshly prepared normal saline diluents (Prescott *et al.,* 2011).

Cultivation and Enumeration of Bacteria

Total Heterotrophic Bacteria (THB)

An aliquot (0.1ml) from 10^{-3} dilution of water samples were inoculated on the nutrient agar plate in triplicate for isolation and enumeration of total heterotrophic bacteria using standard spread plate methods as described by Prescott *et al.,* (2011)., and incubated for 24hours at 37.2°C. Bacterial colonies that grew cultured plates after incubation were counted and the mean expressed as cfu/ml using the formula below;

$$\text{CFU/ml} = \frac{\text{number of colonies}}{\text{Dilution x volume plated}} \qquad \text{Equation} \quad 1$$

Feacal Coliform Counts (TCC)

Feacal coliform count was enumerated using the Most Probable Number method as described by Prescott *et al,* (2011). The technique includes three successive steps, namely, a presumptive test, a confirmed test, and a completed test. In the presumptive test, MacConkey broth tubes are inoculated with a series of decimal dilutions (0.1, 1ml and 10ml), to give an estimate of the MPN.

The MPN confirmation procedure was carried out by transferring positive presumptive tubes (gas production within 24–48 h) to 2% brilliant green bile lactose broth to test for gas production within 48 h at 44.5 °C for feacal coliforms. Positive tubes were used to calculate the MPN/ml. The presence of faecal coliform bacteria in the samples were established in completed tests using spread plate method on Eosin methylene blue agar plates and incubated for 24 hours at 44.5°C (Ogbonna *et al.,* 2019).

Total Coliform Counts

An aliquot (0.1ml) from 10^{-2} dilution of water samples were inoculated on the MacConkey agar plates in triplicate for isolation and enumeration of Total coliform using standard spread plate methods as described by Prescott *et al* (2011). The inocula were spread evenly on the surface of the MacConkey agar media using a sterile spreader and incubated at 37.2°C for 24 hours, after which the colonies that developed were counted and the mean was expressed into colony forming unit per milliliter (Amadi *et al.*, 2014).

Total *Salmonella-Shigella* Counts (SSC)

An aliquot (0.1ml) from 10^{-2} dilution of water samples were inoculated on the *Salmonella-Shigella* agar in triplicate for isolation and enumeration of *Salmonella* and *Shigella* species using standard microbiological methods as described by Prescott *et al* (2011).

The inocula were spread evenly on the surface of the media using a sterile bent glass rod and incubated at 37°C for 24 hours, after which the colonies that developed were counted and the mean was expressed into colony forming unit per milliliter (Amadi *et al.*, 2014).

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Purification and maintenance of pure culture

After incubation, discrete colonies on the respective culture media used were described and sub-cultured onto freshly on the nutrient agar plate in order to isolate pure of the isolates. The cultures pure isolates were obtained by picking (with sterile inoculating loop) distinct culturally and morphologically different colonies from the various plates (Obire *et al.,* 2003).

Identification of Bacterial Isolates

Pure bacterial isolates were identified by the method described by Pekate (2022). Pure bacterial isolates were subjected to Biochemical tests which include oxidase test, Catalase test, Indole test, oxidase, coagulase, methyl red test, Voges Proskauer test, Starch hydrolysis test, Citrate test, Sugar fermentation test and Triple sugar iron agar test. The identities of the bacterial isolates were confirmed by making reference to the Bergey's Manual of Determinative Bacteriology (Holt *et al.,* 1994).

Determination of Physicochemical Parameters

Physicochemical parameters of the surface water samples were determined using standard analytical procedures recommended by APHA (2005). Temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), and turbidity were measured in situ using a calibrated Horiba LA-920 multiparameter meter. Before each measurement, the probe was rinsed with distilled water and immersed in the sample until stable readings were obtained.

Temperature was measured to assess the thermal condition of the water, as it influences chemical reactions, dissolved oxygen concentration, and microbial activities.

Total Dissolved Solids (TDS), representing the concentration of dissolved inorganic and organic substances in water, were determined using a calibrated HANNA H199300 meter after rinsing the probe with the sample. Measurements were recorded in mg/L once readings stabilized. Total Suspended Solids (TSS) was determined using a HACH DR 2800 meter based on the gravimetric principle. A homogenized water sample was analyzed against a distilled water blank, and TSS values were recorded in mg/L according to APHA procedures.

Chemical Oxygen Demand (COD), an indicator of the oxygen required to chemically oxidize organic and inorganic pollutants, was determined by potassium permanganate oxidation in an acidic medium. The water sample was treated with sodium hydroxide, potassium permanganate, sulfuric acid, and oxalic acid, followed by titration with standardized potassium permanganate solution. COD values were calculated using the appropriate formula.

Biochemical Oxygen Demand over five days (BOD_5) was determined following the APHA 5210B method. Water samples were collected in airtight amber bottles, incubated at 20°C for five days, and dissolved oxygen was measured before and after incubation. BOD_5 was calculated as the difference between initial and final dissolved oxygen concentrations, reflecting the amount of biodegradable organic matter present.

Heavy metal concentrations

Heavy metal concentrations, including lead (Pb), nickel (Ni), zinc (Zn), iron (Fe), copper (Cu), chromium (Cr), and cadmium (Cd), were determined using a UNICAM 929 Atomic Absorption Spectrophotometer (AAS). Water samples were acid-digested with nitric and hydrochloric acids, concentrated by heating, filtered, and diluted before analysis. The AAS was calibrated using appropriate hollow cathode lamps for each metal, and concentrations were measured based on the absorption of light by free atoms in the flame, which is directly proportional to the concentration of the respective metal in the sample (Inengite, 2015).

Statistical Analyses

Data generated from physicochemical analysis, heavy metal determination, bacterial and enumeration were subjected to statistical analysis using the Statistical Package for Social Sciences (SPSS) version 25.0.

Results

The results of the physicochemical characteristics of the surface water samples from the different locations are presented in Table 1. Table 2 presents the concentrations of heavy metals in surface water samples.

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Table 1: Physicochemical Characteristics of Surface Water Samples from Different Locations in Port Harcourt

S/N	Parameter	Location of Surface water Samples					
		Choba	**Iwofe**	**Creek Road**	**Eagle Island**	**Marine Base**	**P. value**
1	pH	6.8 ±0.2[a]	7.0 ±0.3[a]	7.6 ±0.2[a]	7.2 ±0.3[a]	7.8 ±0.2[a]	0.426
2	DO (mg/L)	5.6 ±0.4[ab]	5.1 ±0.5[ab]	4.0 ±0.3[a]	4.5 ±0.4[a]	3.8 ±0.3[a]	0.031
3	BOD (mg/L)	3.8 ±0.5[a]	4.5 ±0.6 [a]	8.2 ±1.0[c]	6.1 ±0.8[ab]	9.5 ±1.2[c]	0.025
4	TSS (mg/L)	28 ±5[a]	35 ±6[ab]	95 ±15[d]	55 ±10[c]	120 ±20[e]	0.001
5	EC (µS/cm)	650 ±80[a]	850 ±100[cd]	12,500 ±2,00[c]	4,500 ±700 [ab]	22,000 ±3,00[d]	0.006
6	TDS (mg/L)	320 ±40[a]	410 ±50 [ab]	6,200 ±90[cd]	2,300 ±40[c]	11,000 ±1.5 [d]	0.002
7	Sanility (ppt)	0.3 ±0.1a	0.6 ±0.2ab	18.0 ±3.0c	6.5 ±1.5c	70.0 ±4.0c	0.004
8	Temperature(°C)	28.2 ±0.8[a]	28.5 ±0.7[a]	30.5 ±0.9[a]	29.8 ±0.6[a]	30.8 ±1.0[a]	0.320
9	COD (mg/L)	28 ±6[a]	35 ±7[ab]	95 ±18[d]	60 ±12[c]	130 ±25[e]	0.008
10	Turbidity (NTU)	18 ±4[a]	25 ±6[a]	85 ±15[c]	45 ±10[ab]	110 ±20[d]	0.028

*Means with similar superscript across the group showed no significant difference (P>0.05)

Table 2: Heavy Metal Concentrations (mg/L) of Surface Water Samples

S/N	Heavy Metal	Location of Surface water Sample and Heavy Metal Concentrations (mg/L)				
		Choba	**Iwofe**	**Creek Road**	**Eagle Island**	**Marine Base**
1	Iron (Fe)	0.45 ±0.8[a]	0.62 ±0.10[a]	1.85 ±0.30[ab]	1.10 ±0.20[ab]	2.40 ±0.40[c]
2	Lead (Pb)	0.015 ±0.04[a]	0.022 ±0.06[a]	0.085 ±0.015[b]	0.048 ±0.010ab	0.120 ±0.020[c]
3	Cadmium (Cd)	0.004 ±0.01[a]	0.006 ±0.02[a]	0.021 ±0.005[ab]	0.012 ±0.003[ab]	0.030 ±0.006[b]
4	Chromium (Cr)	0.032 ±0.07[a]	0.045 ±0.08[a]	0.140 ±0.030[b]	0.085 ±0.020[a]	0.190 ±0.040[b]
5	Nickel (Ni)	0.058 ±0.10[a]	0.072 ±0.12[b]	0.220 ±0.040[a]	0.130 ±0.030[ab]	0.310 ±0.050[ab]
6	Copper (Cu)	0.38 ±0.06[a]	0.55 ±0.09[a]	1.85 ±0.30[ab]	1.10 ±0.20[ab]	2.60 ±0.40b
7	Zinc (Zn)	0.92 ±0.15[a]	1.25 ±0.20[ab]	4.80 ±0.80[c]	3.40 ±0.60[b]	6.20 ±1.00[d]

*Means of Triplicate samples with similar superscript across the group showed no significant difference (P>0.05)

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Table 1 shows considerable spatial variation in the physicochemical quality of surface water from Choba, Iwofe, Creek Road, Eagle Island, and Marine Base. The physicochemical characteristics of the surface water varied considerably among the sampling locations. pH ranged from 6.8 ± 0.2 at Choba to 7.8 ± 0.2 at Marine Base, with no significant spatial variation ($p = 0.426$). In contrast, dissolved oxygen (DO) differed significantly ($p = 0.031$), decreasing from 5.6 ± 0.4 mg/L at Choba to 3.8 ± 0.3 mg/L at Marine Base. BOD increased from 3.8 ± 0.5 mg/L at Choba to 9.5 ± 1.2 mg/L at Marine Base ($p = 0.025$), while TSS ranged from 28 ± 5 to 120 ± 20 mg/L ($p = 0.001$). EC, TDS, and salinity also showed significant spatial variations, ranging from 650 ± 80 to 22,000 ± 3,000 µS/cm ($p = 0.006$), 320 ± 40 to 11,000 ± 1,500 mg/L ($p = 0.002$), and 0.3 ± 0.1 to 70.0 ± 4.0 ppt ($p = 0.004$), respectively. Temperature ranged from 28.2 ± 0.8 to 30.8 ± 1.0°C but was not significantly different ($p = 0.320$). COD and turbidity increased markedly from Choba to Marine Base, ranging from 28 ± 6 to 130 ± 25 mg/L ($p = 0.008$) and 18 ± 4 to 110 ± 20 NTU ($p = 0.028$), respectively.

The concentrations of heavy metals in surface water samples collected from Choba, Iwofe, Creek Road, Eagle Island, and Marine Base indicate varying degrees of metal contamination across the study locations (Table 2). The heavy metal concentrations in the surface water varied considerably among the sampling locations. Iron (Fe) ranged from 0.45 ± 0.08 mg/L at Choba to 2.40 ± 0.40 mg/L at Marine Base, while lead (Pb) increased from 0.015 ± 0.04 to 0.120 ± 0.020 mg/L. Cadmium (Cd) ranged from 0.004 ± 0.01 to 0.030 ± 0.006 mg/L, and chromium (Cr) from 0.032 ± 0.07 to 0.190 ± 0.040 mg/L. Nickel (Ni) ranged between 0.058 ± 0.10 and 0.310 ± 0.050 mg/L, whereas copper (Cu) increased from 0.38 ± 0.06 to 2.60 ± 0.40 mg/L. Zinc (Zn) recorded the highest concentrations overall, ranging from 0.92 ± 0.15 mg/L at Choba to 6.20 ± 1.00 mg/L at Marine Base. Generally, Choba and Iwofe recorded the lowest heavy metal concentrations, while Creek Road and particularly Marine Base showed elevated concentrations of most metals.

Table 3 presents the bacterial population of water samples collected from the different study locations. The total heterotrophic bacterial (THB) counts ranged from 1.38×10^8 CFU/mL in Iwofe to 1.64×10^8 CFU/mL in Marine Base, while total coliform counts (TCC) ranged from 1.15×10^6 to 1.23×10^6 CFU/mL in Creek Road and Choba, respectively. Faecal coliform counts (FCC) varied from 1.2×10^4 CFU/mL in Iwofe to 2.0×10^4 CFU/mL in Eagle Island. Total Salmonella-Shigella counts (TSHC) ranged from 1.1×10^4 CFU/mL in Iwofe to 1.9×10^4 CFU/mL in Creek Road, whereas total Salmonella counts (TSC) ranged from 1.0×10^4 CFU/mL in Iwofe to 1.4×10^4 CFU/mL in Marine Base.

Figure 1 revealed that *Escherichia coli* was the predominant bacterial isolate (29%), followed by *Klebsiella* spp., *Pseudomonas* spp., *Shigella* spp., and *Proteus* spp. (10% each), *Salmonella* spp. (9%), *Vibrio* spp. (8%), and *Enterobacter* spp. and *Staphylococcus* spp. (7% each).
The predominance of enteric bacteria indicates extensive faecal contamination of the surface waters and poor microbiological quality.

Table 3 Bacterial Population of Surface Water

Location	**Bacterial Population (CFU/ml)**				
	Total Heterotrophic Bacteria ($\times 10^8$)	**Total coliform ($\times 10^6$)**	**Feacal coliform ($\times 10^4$)**	**Total *Shigella* ($\times 10^4$)**	**Total *Salmonella* ($\times 10^4$)**
Choba	1.44 ± 4.1^a	1.23 ± 0.8^a	1.8 ± 0.2^a	1.6 ± 0.1^a	1.3 ± 0.7^a
Iwofe	1.38 ± 1.21^a	1.22 ± 0.2^a	1.2 ± 0.1^a	1.1 ± 0.2^a	1.0 ± 0.6^a
Creek Road	1.43 ± 1.91^a	1.15 ± 0.7^a	1.8 ± 1.4^a	1.9 ± 0.3^a	1.2 ± 0.6^a
Eagle Island	1.58 ± 4.1^a	1.19 ± 0.2^a	2.0 ± 1.8^a	1.5 ± 0.4^a	1.3 ± 0.3^{ab}
Marine base	1.64 ± 5.2^a	1.20 ± 0.3^a	1.9 ± 0.1^a	1.5 ± 0.7^a	1.4 ± 0.2^{4b}
P-value	0.195	0.836	0.136	0.407	0.004
WHO Limit	$1X10^2$	0/100ml	0/100ml	0/100ml	0/100ml

*Means with similar superscripts down the group showed no significant difference (P>0.05)

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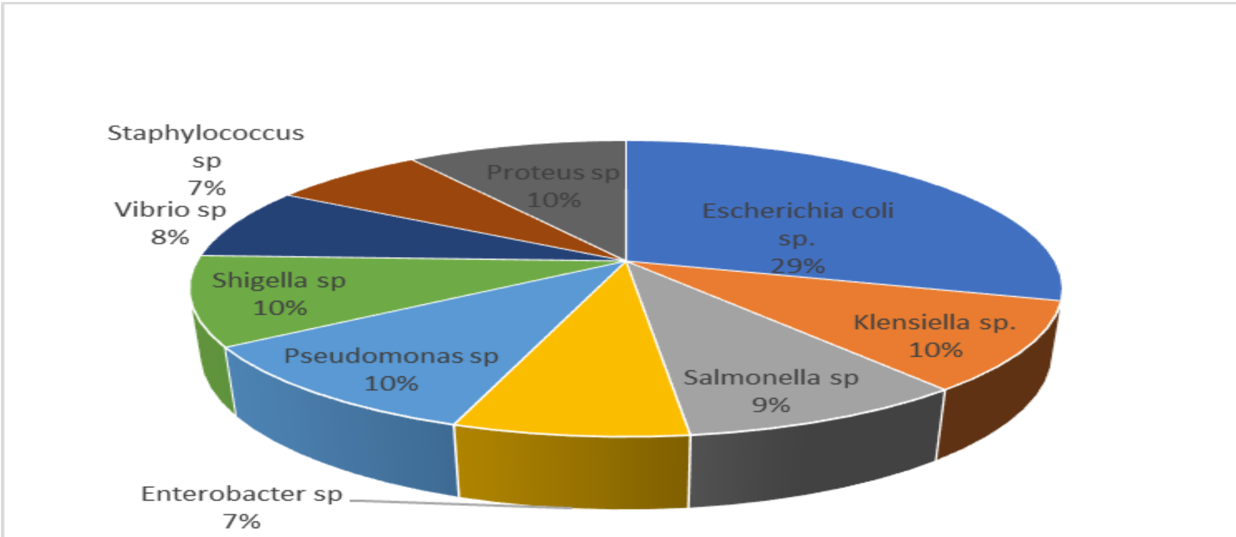

Discussion

The findings of this study revealed that, pH remained within the WHO and Standard Organization of Nigeria (SON) permissible limits (6.5–8.5) and did not differ significantly (P = 0.426), most of the other parameters exceeded permissible limits, indicating varying degrees of pollution. Neutral pH suggests that the waters can support microbial and aquatic life; however, acceptable pH alone does not imply good water quality (WHO, 2022; SON, 2023). The pH of an environment where microbes and other aquatic organisms live affects their metabolic activities because it affects the functioning of enzymes, hormones, and proteins. pH is a major factor in all chemical reactions associated with the formation, alteration, and dissolution of chemical (Yao and Byme, 2001)

Dissolved oxygen in samples from Choba and Iwofe met the recommended minimum value of 5 mg/L. At the same time, Creek Road, Eagle Island, and Marine Base recorded lower concentrations, indicating oxygen depletion caused by microbial degradation of organic wastes. Correspondingly, biochemical oxygen demand (BOD) (3.8–9.5 mg/L) and chemical oxygen demand (COD) (28–130 mg/L) exceeded WHO limits across all locations, reflecting heavy organic and chemical pollution from sewage, industrial effluents, petroleum activities, and urban runoff (UNEP, 2023; Sharma *et al.,* 2023).

Total suspended solids (TSS), electrical conductivity (EC), total dissolved solids (TDS), salinity, and turbidity all showed significant differences (P < 0.05). Choba recorded the lowest values, whereas Marine Base consistently had the highest concentrations. Except for Choba, TSS exceeded the recommended limit, indicating increased sediment loads capable of reducing light penetration and transporting pollutants. Similarly, EC (650–22,000 µS/cm), TDS (320–11,000 mg/L), and salinity (0.3–70.0 ppt) increased markedly towards Marine Base, suggesting strong influences from saline water intrusion, industrial discharges, and petroleum-related activities. Electrical conductivity is the measure of a material's ability to allow the transport of an electric charge. It is measured by the presence of total concentration of ions, and it is influenced by the temperature of the system (Nazir *et al.,* 2015). The conductance of any material or medium is a function of the number of ions present and is used to predict the concentration of ions or minerals present in the medium (Joshi *et al*., 2009; Ikeme *et al*., 2014; Rahmanian *et al*., 2015), but cannot be used to determine the specific ion present. Elevated turbidity (18–110 NTU) at all locations further indicates high suspended particles and microbial contamination risks (WHO, 2022; Edokpayi *et al.,* 2021).

Water temperature was slightly elevated at Creek Road and Marine Base may have contributed to lower dissolved oxygen levels by reducing oxygen solubility. Temperature is one of the important parameters of physiochemical analysis of water.

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It helps to regulate the maximum dissolved oxygen concentration of the water, and influences the rate of chemical and biological reactions. Temperature is an important characteristic that can vary widely; it can be influenced by a number of variables including: geographic location, shading, water body size and depth (Chagas and Suzuki, 2005).

Overall, Marine Base recorded the highest concentrations for all heavy metals, followed by Creek Road and Eagle Island, while Choba had the lowest levels. Most of the measured metals exceeded the permissible limits recommended by the World Health Organization (WHO) and the Standards Organization of Nigeria (SON), suggesting significant anthropogenic pollution.

Iron (Fe) concentrations exceeding the WHO/SON limit of 0.3 mg/L at all locations. Elevated iron concentrations may result from industrial discharges, corrosion of metallic infrastructure, and runoff from surrounding urban areas. Although iron is an essential micronutrient, excessive concentrations impair water quality by affecting taste, colour, and supporting the growth of iron bacteria (WHO, 2022).

Lead (Pb) concentrations at all sampling sites exceeded the recommended limit of 0.01 mg/L. Similarly, cadmium (Cd) concentrations (0.004–0.030 mg/L) were consistently above the permissible limit of 0.003 mg/L. Both metals are highly toxic even at low concentrations and may originate from petroleum activities, industrial effluents, battery wastes, paints, and urban runoff. Chronic exposure to lead and cadmium has been associated with neurological disorders, kidney damage, developmental impairment, and increased cancer risk (WHO, 2022; UNEP, 2023).

Chromium (Cr) concentrations at Choba and Iwofe remained within or close to the WHO limit (0.05 mg/L), Creek Road, Eagle Island, and Marine Base exceeded the standard. Nickel (Ni) concentrations also surpassed the permissible limit (0.07 mg/L) at most locations, particularly Marine Base and Creek Road. Elevated chromium and nickel concentrations are commonly linked to industrial wastewater, metal processing, petroleum exploration, and urban activities, and prolonged exposure may result in skin irritation, respiratory problems, and carcinogenic effects (Sharma *et al.,* 2023).

Copper (Cu) concentrations were higher only at Marine Base, exceeding the WHO limit of 2.0 mg/L, whereas zinc (Zn) concentrations exceeded the permissible limit (3.0 mg/L) at Creek Road, Eagle Island, and Marine Base. Although copper and zinc are essential trace elements, excessive concentrations can become toxic to aquatic organisms and humans, affecting liver, kidney, and gastrointestinal functions (WHO, 2022).

The bacteriological assessment of surface water from Choba, Iwofe, Creek Road, Eagle Island, and Marine Base revealed extensive microbial contamination across all study locations, indicating poor sanitary quality and significant public health risks. The consistently high Total Heterotrophic Bacterial (THB) counts, despite showing no significant variation among locations ($P > 0.05$), suggest that the water bodies receive continuous inputs of biodegradable organic matter from anthropogenic sources. Such contamination is commonly associated with untreated domestic wastewater, sewage discharge, indiscriminate refuse disposal, decaying organic matter, and urban runoff. The uniformly high THB counts therefore indicate widespread environmental pollution rather than localized contamination. Similar findings were reported by Akani *et al.* (2023), Ogbonna and Origbe (2021), and Chinedu *et al.* (2024), who attributed elevated bacterial populations in surface waters of southern Nigeria to rapid urbanization, poor sanitation, and indiscriminate waste disposal.

The Total Coliform Counts (TCC) recorded in all sampling locations greatly exceeded the World Health Organization (WHO) guideline of zero coliform organisms per 100 mL of potable water. Coliform bacteria are widely recognized as indicators of faecal contamination and poor sanitary conditions. Their widespread occurrence suggests continuous discharge of untreated domestic wastewater, leaking septic tanks, open defecation, municipal wastes, and contaminated stormwater into the surrounding rivers. The absence of significant differences among locations indicates that faecal pollution is widespread throughout the waterfront communities of Port Harcourt. These findings are consistent with Wokoma *et al.* (2022) and Eze *et al.* (2023), who similarly reported high coliform densities in urban rivers affected by untreated wastewater and inadequate sanitation infrastructure.

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The presence of faecal coliforms (FCC) in all water samples provides stronger evidence of contamination by human and animal excreta. Although Eagle Island recorded the highest FCC, differences among locations were not statistically significant, indicating widespread faecal contamination across the study area. Since faecal coliforms are indicators of enteric pathogens, their presence suggests a high risk of waterborne diseases such as cholera, typhoid fever, diarrhoea, dysentery, and gastroenteritis. According to WHO (2022) and WHO and UNICEF (2023), faecal coliforms should be absent in water intended for human consumption because their presence significantly increases the risk of disease transmission.

The relatively high Total Hydrocarbon-utilizing Bacterial Counts (TSHC) reflect the petroleum-related activities characteristic of the Niger Delta. The higher counts observed at Creek Road and Marine Base likely resulted from chronic hydrocarbon contamination associated with oil exploration, boat traffic, fuel spills, and industrial activities. Hydrocarbon-utilizing bacteria are recognized indicators of petroleum pollution because they proliferate in environments where hydrocarbons serve as carbon and energy sources. Similar observations have been reported by Chikere *et al.* (2021), who demonstrated abundant hydrocarbon-degrading bacteria in petroleum-contaminated aquatic ecosystems of the Niger Delta.

Unlike the other microbial parameters, Total *Salmonella*-*Shigella* Counts (TSC) differed significantly among the study locations ($P = 0.004$), with Marine Base recording the highest count. This variation may reflect localized differences in sewage disposal, sanitation practices, and population density. The occurrence of *Salmonella* and *Shigella* species in all sampling locations is particularly concerning because these pathogens are responsible for typhoid fever, salmonellosis, bacillary dysentery, and severe gastroenteritis. Their detection confirms recent faecal contamination and demonstrates that the surface waters are unsafe for drinking and other domestic uses without adequate treatment. These findings agree with Akani *et al.* (2023) and Egbai *et al.* (2022), who reported the occurrence of enteric pathogens in polluted surface waters of southern Nigeria. Overall, the elevated bacteriological counts indicate severe anthropogenic pollution and highlight the urgent need for improved sanitation, wastewater treatment, routine water quality monitoring, and effective environmental management to safeguard public health in Port Harcourt metropolis.

The high prevalence of *E. coli*, a recognized indicator of recent faecal pollution, suggests contamination from untreated sewage, leaking septic systems, open defecation, and contaminated stormwater runoff. Its presence signifies an increased risk of waterborne diseases, particularly diarrhoea and gastroenteritis (WHO, 2022). Similarly, the occurrence of *Klebsiella* spp. and *Enterobacter* spp. further confirms faecal contamination and raises concerns over the environmental dissemination of multidrug-resistant bacteria (WHO, 2023). The isolation of *Salmonella* spp. and *Shigella* spp. indicates poor sanitary conditions and the potential transmission of typhoid fever, salmonellosis, and bacillary dysentery through untreated water. The detection of *Vibrio* spp. is equally important because it suggests the possible risk of cholera and other seafood- and water-related infections, particularly in estuarine environments (NCDC, 2024). The occurrence of *Pseudomonas* spp. reflects both environmental contamination and petroleum-related activities characteristic of the Niger Delta, while *Proteus* spp. and *Staphylococcus* spp. indicate contamination from human activities and domestic wastes. Overall, the predominance of enteric and opportunistic pathogens demonstrates that the surface waters are microbiologically unsafe for domestic use without treatment.

Conclusion

The findings of this study revealed that, the surface waters studied had elevated BOD, COD, TDS, TSS, conductivity, salinity, and turbidity, together with reduced dissolved oxygen, indicating substantial anthropogenic impacts from domestic sewage, industrial effluents, petroleum-related activities, and tidal saline intrusion. The fact that several heavy metals exceeded the WHO and SON guideline values highlights potential ecological degradation. The predominance of enteric and opportunistic pathogens demonstrates that the surface waters are unsafe for domestic use without treatment. These findings highlight significant public health risks and emphasizes the need for improved sanitation, wastewater treatment, routine microbiological surveillance, and effective environmental management to reduce the burden of waterborne diseases.

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