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Integrated Microbial and Physicochemical Indicators of Pollution in Warri River, Niger Delta, Nigeria

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ABSTRACT

The Warri River in the Niger Delta, Nigeria, is a vital freshwater resource supporting domestic, agricultural, and industrial activities, but it is increasingly threatened by pollution. This study assessed the microbial and physicochemical quality of surface water and sediments from five locations along the Pessu–Aladja stretch of the river to determine their suitability for human and environmental use. Key parameters analyzed included pH, electrical conductivity (EC) and many others using standard methods. Microbial assessments covered total bacterial count (TBC), coliforms, Escherichia coli, and fungi in water, as well as bacterial and fungal counts in sediments, with isolates identified using standard methods. Results were compared with standards from the World Health Organization (2017), NESREA (2011), and Standards Organisation of Nigeria (2015). Findings revealed notable spatial variations influenced by natural processes and human activities. While total dissolved solids and EC were generally low, turbidity and other parameters exceeded permissible limits at some sites, indicating organic and inorganic pollution from effluents and runoff. Sediments largely complied with standards, suggesting comparatively lower anthropogenic impact. Freshwater microbial loads were high, with elevated TBC, coliforms, and detectable E. coli at two sites, alongside diverse bacterial and fungal genera associated with organic pollution and possible faecal contamination. Sediments showed higher microbial densities, particularly at location1, with fungi known for biodegradation potential. Overall, the coexistence of environmental and enteric microorganisms indicates mixed contamination sources. The study revealed that portions of the river are polluted and recommends routine monitoring, adequate water treatment before use, strict regulation of effluent discharge and waste disposal, to safeguard the ecological health of the river.

1. INTRODUCTION

Freshwater sources like rivers, lakes, wetlands, and underground water reserves are vital for human survival and the stability of ecosystems. They support daily life, industrial activities, and farming, and also offer important benefits to the environment such as recycling nutrients, controlling floods, protecting wildlife, and helping regulate the climate. These waters also help in fishing, moving goods, recreational activities, and maintaining cultural traditions, which support human health, food supply, and economic growth. Therefore, the condition and amount of

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freshwater resources strongly influence the well-being of society. Scientific research from around the world consistently shows that damaging these water systems weakens their benefits and increases the risk to people who rely on them (US EPA, 2023; WHO, 2022; UNEP, 2021; PMC, 2022).

In the Niger Delta region of Nigeria, water pollution is a big environmental and health issue. This area is one of the most productive and water-rich parts of Africa, with rivers and estuaries that support the local way of life. Among these, the Warri River is a major freshwater-brackish system that flows through Delta State into the Benin River system and coastal areas. It supports fishing, household water needs, small-scale farming, transportation, and manual work. People living along the river depend on it for survival and income, making the health of this river very important for the social and economic well-being of Warri and nearby areas. Studies have shown that the Warri River is a key water source affecting both rural and urban communities in Delta State (Iyorah *et al.*, 2015; United Nations Environment Programme (UNEP),2011).

Despite its importance, the Warri River has been suffering from serious and complex pollution. The region has a long history of oil exploration, along with fast growing cities, new industries, and poor waste management, causing widespread contamination of water and riverbeds. Many studies have pointed out the presence of petroleum compounds, high levels of heavy metals, nutrient buildup, organic pollutants, and harmful bacteria in the rivers of the Niger Delta (UNEP, 2011; Aigberua *et al.*, 2018; Nwabueze *et al.*, 2021). These pollutants lower water quality, decrease oxygen levels, harm aquatic life, and pose health risks to people who use the water for daily needs and fishing. Oil spills, pipeline leaks, illegal refining, and careless disposal of waste continue to add to the pollution, as detailed in scientific studies and local environmental reports (Vidal, 2011; Okonkwo *et al.*, 2020; UNEP, 2011).

Wastewater from industries is another big source of pollution in the Warri River and nearby water bodies. Studies on refinery and industrial discharges in Delta State show that untreated or poorly treated wastewater increases the levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD), cloudiness, and toxic metals such as lead, cadmium, and chromium. When effluent treatment is not sufficient, the river's natural ability to clean itself is overwhelmed, causing poor water quality and damage to the ecosystem downstream. These effects have been confirmed by local investigations into industrial wastewater and refinery discharges in river areas near Warri and nearby towns (Aigberua *et al.*, 2018; Igagara, 2023).

Urban runoff and household waste add to the pollution caused by industry and oil. The fast growth of Warri city has not been matched by sufficient sanitation and waste management systems. Open drains, market waste, sewage, and stormwater carry organic material, nutrients, plastics, and harmful bacteria into the river, leading to increased cloudiness, nutrient buildup, algal growth, and more bacteria, especially total coliform and fecal bacteria (Chindah *and* Braide, 2000; Emoyan *et al.*, 2006). These bacteria can include dangerous pathogens like *Escherichia coli*, *Salmonella*, and *Vibrio*, which pose serious health risks to people using untreated river water for daily use (Igbinosa *and* Okoh,2009).

Sediments play an important role in carrying and storing pollutants in aquatic environments.
They can absorb heavy metals and other long-lasting chemicals, sometimes releasing these substances back into the

water through stirring, movement, or biological activity. Since many pollutants stick to sediments, analyzing sediments can offer a more stable and long-term view of water contamination than checking the waterdirectly(Wang,etal**.** 2025;Custodio,et al. 2020). Themicroorganisms in sediments are keys to processes like breaking down organic matter, cycling nutrients, and cleaning up pollution (Okoh *et al.*, 2007). But pollution changes the communities of these microbes, often favoring more resistant or oil-degrading bacteria like Pseudomonas, Bacillus, and Acinetobacter, while reducing sensitive species ().
An integrated check of both the chemical and microbial aspects of the Warri River is needed to understand the current state of the river, identify areas of pollution, and learn how pollution spreads. Chemical pollutants influence the life of microorganisms, while microbial contamination is one of the biggest threats to health from using surface water. Studying both aspects together gives a full picture of water quality and provides useful information for managing the environment, protecting public health, and ensuring sustainable use of natural resources. The main goal of this study was to examine the microbiological and physical-chemical characteristics of surface water and sediments in the Warri River between Pessu and Aladja.

2. METHODOLOGY

StudyArea
The Warri River is located in Delta State, Nigeria, and flows through several developed and urban areas like Pessu, Ugbuwangue, Enerhen, and Aladja before it reaches the Atlantic Ocean. This region has a tropical monsoon climate, which means it has heavy rainfall during certain times of the year, greatly affecting surface runoff and river flow (Nnodu, *et al.* 2020).

Collection of Sample
Water samples were collected using a clean amber bottle that had been sterilized and properly labeled beforehand. Sediment samples were collected using a clean stainless steel grab sampler and wide-mouthed glass jars that had also been pre-cleaned and labelled. Both samples were collected from five different points along the river to ensure spatial representation of samples' characteristics across the study area. Samples were collected in triplicates. Water samples were placed in airtight bottles while sediment samples were placed in airtight, wide-mouthed glass jars and samples were stored in a cooler maintained at approximately 4°C with ice packs. The samples were promptly transported to the laboratory for further analysis to ensure preservation of their chemical and microbial integrity.

Isolation and Identification of Bacteria
Total heterotrophic bacteria (THB) were determined using Pour Plate Method (APHA 9215 B). 1ml of water sample was weighed and diluted with 9ml of sterilized distilled water in sterilized test tubes to make serial dilutions of 1:10 dilution. Also, 1.0g of sediment sample was weighed and diluted with 9ml of sterilized distilled water in sterilized test tubes to make serial dilutions. Bacteria were enumerated using nutrient agar and incubated at 37^{o}C for 24hours, and colonies were counted using colony counter. Also, total coliform count in the water sample was determined using Multiple Fermentation Technique (APHA 9221B). *Escherichia coli* Counts (EC) were enumerated on Eosin methylene blue agar. The colonies were purified on a fresh agar, and subsequently identified (Buchanan and Gibbons 2020). The identification of the isolates was by using Bergey's Manual of Systemic Bacteriology.

Isolation and Identification of Fungi

Fungi enumeration was done using malt extract agar. Plates were incubated at 28^{o}C for 3-5 days. Fungal isolates were identified morphologically based on colony characteristics and microscopic observation following standard methods (Barnett *and* Hunter, 1998; Samson *et al.*, 2014).

Physicochemical Analyses

Water and sediment samples were taken and analyzed. Parameters analyzed in fresh water were pH and Temperature using Electrometric method (APHA 460). For the reading Hanna Temperature Meter was used. Electrical Conductivity and Total Dissolved Solid were determined using electrometric method (APHA 2510b). Determination of Total Alkalinity was by using titration method (APHA 2320 B) Other parameters measured were, turbidity using electrometric method (APHA 2130 B), total suspended solids using filtration technique (APHA 208D), Biochemical Oxygen Demand (BOD) using Winkler method (APHA 507), Chemical Oxygen Demand (COD) using open reflux method (ASTM D 1252). For sediment, parameters measured were pH using Electrometric Method (ASTM D1293B), Electrical Conductivity (EC) using Electrometric Method (APHA 145), Total Organic Carbon using Walkey Black Method (ASTM 5310B), Nitrate using Brucine Method **(**APHA4500 NO_3^-), Sulphate using Turbidimetric Method (APHA4500 SO_4^{2-} E), Phosphate using Ascorbic Acid (Colorimetric) Method (APHA4500 SO_4^{2-} P E).

Statistical analysis

Descriptive statistics were used to present the data.

3. RESULTS AND DISCUSSION

Microbial counts in water samples from different locations are presented in tables 1, 2 and 3. The microbial assessment of the sampled water revealed varying degrees of bacterial and fungal contamination across the five sampling locations (L1–L5). Total bacterial counts (TBC) ranged from 5.24 × 10^6 to 9.10 × 10^6cfu/ml, with the highest level recorded at L1 and the lowest at L2. Total coliform counts (TCC) varied between 90 and 270 MPN/100 ml, while E. coli was detected only in L3 and L5 at 1.0 × 10^2 and 1.2 × 10^2 cfu/ml, respectively. The predominant genera included *Bacillus, Staphylococcus, Micrococcus, Enterobacter, Klebsiella, Escherichia, Pseudomonas, and Proteus*. Fungal counts ranged from 2.6 × 10^3 to 4.9 × 10^3 cfu/ml, with L1 exhibiting the highest load. The predominant fungal genera identified included *Aspergillus, Penicillium, Candida, Cladosporium, Fusarium, and Rhodotorula.*

Also microbial counts in sediment samples from different locations are displayed in tables 4 and 5. The bacterial counts in sediment samples exposed mean values ranging from 7.93 × 10^6 cfu/g to 14.48 × 10^6 cfu/g, indicating a considerable microbial presence across the different sampling points. The highest bacterial load was observed in SP1 (14.48 × 10^6 cfu/g), while SP2 (7.93 × 10^6 cfu/g) exhibited the lowest. The bacterial isolates identified from the five sampling locations showed considerable taxonomic diversity, encompassing both Gram-positive and Gram-negative organisms. The predominant genera included *Bacillus, Corynebacterium Staphylococcus, Micrococcus, Enterobacter, Klebsiella, Escherichia, Pseudomonas, and Proteus.* Table 4 showed fungal counts and identified isolates in the sediment samples. Fungal counts ranged from 3.45 × 10^3 to 7.35 × 10^3 cfu/g with L1 exhibiting the highest load. The predominant fungal genera identified included *Aspergillus, Penicillium, Rhizopus, Cladosporium, Fusarium, and Mucor*

Table 1: Bacterial Counts in Water Samples from Different Locations

Sample ID	Total Bacterial Count ($\times 10^6$ cfu/ml)	T otal Coliform Count (MPN/100 ml)	*E. coli* Count ($\times 10^2$ cfu/ml)
L1	9.10 ± 0.26	270.00 ± 7.79	ND
L2	5.24 ± 0.15	90.00 ± 2.60	ND
L3	8.37 ± 0.24	210.00 ± 6.06	1.00 ± 0.03
L4	5.94 ± 0.17	140.00 ± 4.04	ND
L5	8.03 ± 0.23	170.00 ± 4.91	1.20 ± 0.03

NOTE: All values are expressed as mean± standard error. ND = Not detected

Table 2: Fungal Counts and Identified Isolates in Water Samples

Sample ID	Total Fungal Count ($\times 10^3$ cfu/ml)	Fungal Isolates Identified
L1	4.90 ± 0.14	*Penicillium* spp.; *Aspergillus* spp.
L2	2.60 ± 0.07	*Aspergillus* spp.
L3	3.80 ± 0.11	*Aspergillus* spp.; *Rhodotorula* spp.
L4	3.20 ± 0.09	*Cladosporium* spp.; *Aspergillus* spp.
L5	4.10 ± 0.12	*Candida* spp.; *Fusarium* spp.

NOTE: All values are expressed as mean± standard error.

Table 3: Bacterial Isolates Identified in Water Samples

Sample ID	Bacterial Isolates Identified
L1	*Bacillus spp. Staphylococcus aureus; Enterobacter spp.; Micrococcus spp*
L2	*Staphylococcus aureus; Bacillus spp.*
L3	*Micrococcus spp;. Klebsiella pneumonia; Escherichia coli.*
L4	*Bacillus spp. Klebsiella pneumonia; Pseudomonas aeruginosa*
L5	*Escherichia coli; Proteus mirabilis; Bacillus spp.*

Table 4: Bacterial Counts in Sediment Samples

Sample ID	Total Bacterial Count ($\times 10^6$ cfu/g)	Bacterial Isolates Identified
SP1	14.48±0.17	*Pseudomonas aeruginosa; Corynebacterium spp; Staphylococcus aureus; Bacillus spp.; Escherichia coli.*
SP2	7.93±0.23	*Micrococcus spp. Bacillus spp. Staphylococcus aureus*
SP3	11.87±0.34	*Staphylococcus aureus; Enterobacter spp.; Bacillus spp. Micrococcus spp.*
SP4	8.32±0.14	*Proteus mirabilis; Pseudomonas aeruginosa; Enterobacter spp.*
SP5	12.13±0.14	*Bacillus spp. Proteus mirabilis; Staphylococcus aureus; Klebsiella pneumonia.*

Table 5: Fungal Counts in Sediment Samples

Sample ID	Total Fungal Count ($\times 10^3$ cfu/g)	Fungal Isolates Identified
SP1	7.35±0.37	*Penicillium* spp; *Fusarium spp; Aspergillus* spp.
SP2	3.45±0.04	*Fusarium spp.*
SP3	5.49±0.31	*Cladosporium spp; Penicillium spp*
SP4	4.62±0.17	*Cladosporium spp; Rhizopus spp*.
SP5	6.80±0.22	*Aspergillus spp; Mucor spp;*

Table 6 displayed the result of the physicochemical characteristics of the water samples. It unveiled pH values of 6.18 to 6.28, Total Dissolved Solids (TDS) ranged between 19 and 31 mg/L, and Electrical Conductivity (EC) varied from 36 to 60 µS/cm while turbidity values ranged between 21–41 NTU.

Table 7 disclosed the result of the physicochemical characteristics of the sediment samples. It exposed pH values of 6.38 ± 0.01 to 6.59 ± 0.01, Total Organic Carbon (TOC) ranged between 2.63 ± 0.09 and 6.37 ± 0.18% and Electrical Conductivity (EC) varied from 98.02 ± 1.97 to 184.01 ± 2.28 µS/cm while Sulphate values ranged between 4.14 ± 0.05–7.29 ± 0.42 mg/kg.

Table 6: Physico-chemical Parameters of Water Sample Compared with WHO/NESREA/SON Standards

Parameter (Unit)	Acceptable Limit (WHO/NESREA/SON)	L1	L2	L3	L4	L5
pH (—)	6.5 – 8.5	6.21 ± 0.01	6.20 ± 0.01	6.20 ± 0.01	6.18 ± 0.01	6.28 ± 0.01
TDS (mg/L)	≤ 500	31.00 ± 0.18	27.00 ± 0.17	27.00 ± 0.12	19.00 ± 0.12	26.00 ± 0.15
EC (µS/cm)	≤ 1000	60.00 ± 0.41	52.00 ± 0.21	52.00 ± 0.17	36.00 ± 0.18	50.00 ± 0.20
Turbidity (NTU)	≤ 5	40.86 ± 0.17	22.94 ± 0.09	22.94 ± 0.09	31.79 ± 0.09	32.13 ± 0.09
TSS (mg/L)	≤ 30	78.00± 0.21	43.00± 0.23	43.00 ± 0.23	54.00 ± 0.21	61.00 ± 0.22
BOD (mg/L)	≤ 6	10.32± 0.09	5.38 ± 0.01	5.38 ± 0.03	3.71 ± 0.01	8.94 ± 0.02
COD (mg/L)	≤ 10	23.45 ± 0.12	7.09 ± 0.02	11.70 ± 0.06	8.83 ± 0.02	19.79. ± 0.12

NOTE: All values are expressed as mean± standard error.

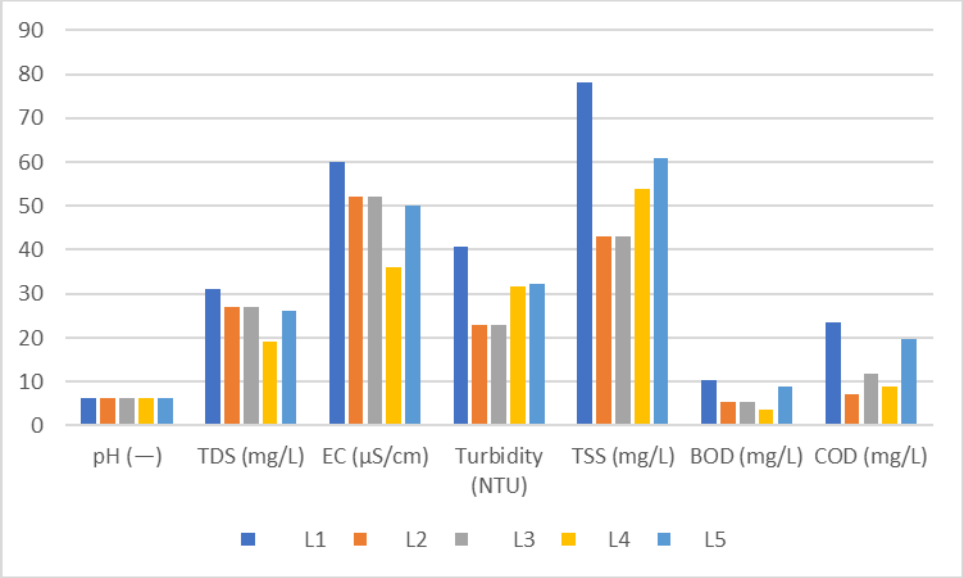


Figure 1: Variation in measured parameters in Water sample at different locations

Table 7: Physico-chemical characteristics of sediment samples compared with WHO / NESREA / SON standards

Parameter	Unit	WHO/ NESREA/ SON	SP1	SP2	SP3	SP4	SP5
pH	–	6.5–8.5	6.48 ± 0.01	6.45 ± 0.02	6.59± 0.01	6.54 ± 0.01	6.38 ± 0.01
EC	µS/cm	<1000	122.01± 5.09	130.02± 3.99	133.01± 2.00	184.01± 2.28	98.02± 1.97
TOC	%	<10	6.37 ± 0.18	2.63 ± 0.09	3.85± 0.05	3.09± 0.14	5.16 ± 0.34
Nitrate	mg/kg	<10	4.83 ± 0.09	1.92 ± 0.10	2.67± 0.06	2.14 ± 0.15	3.46 ± 0.16
Sulphate	mg/kg	<250	7.29 ± 0.42	4.14 ± 0.05	5.03± 0.31	4.61 ± 0.32	6. 78 ± 0.22
Phosphate	mg/kg	<5	5.11 ± 0.16	2. 67 ± 0.18	3.85± 0.18	3.09 ± 0.08	4.53 ± 0.19

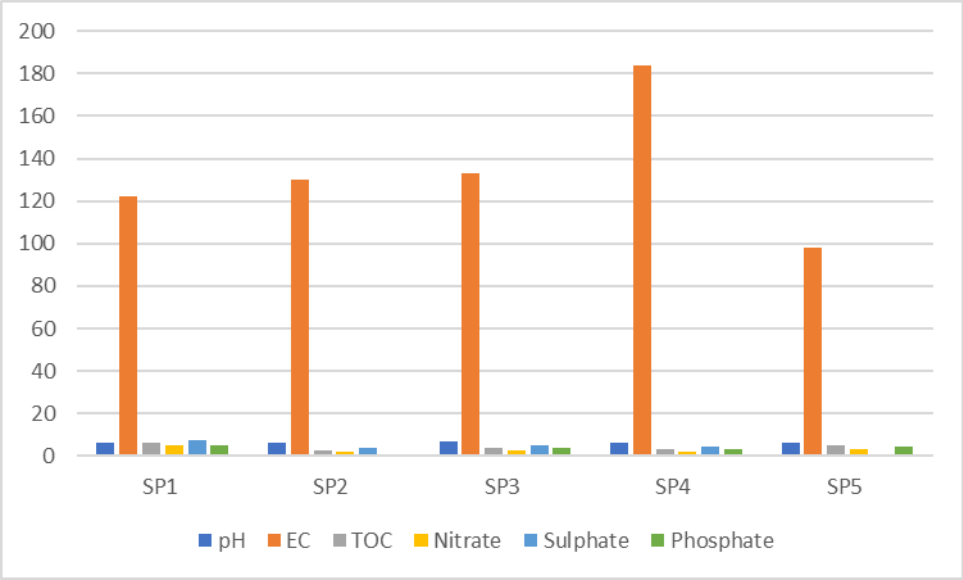


Figure 2: Variation in measured parameters in sediment sample at different locations

Microbial analysis of surface water from five sampling sites showed large differences in microbial levels, which reflect changes in human activity, organic matter levels, and local environmental factors. High counts of total heterotrophic bacteria found at all sites suggest high levels of nutrients and organic material, which support the growth of microbes. These levels went beyond the safe limits for drinking water set by the World Health Organization and the Nigerian Industrial Standards, meaning the surface waters are not safe for direct human use. Similar trends have been seen in other polluted surface waters in the Niger Delta, where domestic, agricultural, and industrial waste contribute to high microbial levels (Edokpayi *et al.*, 2017; Ezeronye *and* Ubalua, 2005).

Total coliform bacteria count also showed widespread faecal contamination, with levels far above the recommended limit of zero MPN per 100 mL. This type of contamination is often linked to sewage leaks, open defecation, agricultural run-off, and untreated waste discharge, which are ongoing problems in many parts of the Niger Delta (Akinde *et al.*, 2011; Chigor *et al.*, 2012). The highest coliform levels at Location1 are likely due to its closeness to human areas and increased runoff, which helps carry faecal matter into the water. The presence of *Escherichia coli* at Locations 3 and 5 shows recent faecal pollution and suggests the possible presence of other harmful germs like *Salmonella*, *Shigella*, and enteric viruses(Payment *and* Locas, 2011).. The absence of E. coli at other sites may point to less human activity, lower faecal input, or conditions that make it hard for bacteria to survive. Higher microbial levels at Locations 1 and 3 suggest direct pollution from domestic and animal waste, whereas lower levels at Locations 2 and 4 may indicate less disturbance and better natural cleaning processes. The bacterial community included both harmful and opportunistic bacteria such as E. coli, Staphylococcus aureus, Klebsiella pneumoniae, Pseudomonas aeruginosa, and Proteus species, showing significant health risks. The presence of these microbes suggests multiple pollution sources, including domestic waste, artisanal activities, and oil-related operations, which align with previous studies in the area.

Fungal analysis showed some levels of contamination. These levels are similar to those found in other surface waters in the Niger Delta and are above the safe levels for untreated domestic use as set by WHO and NIS guidelines. Higher fungal levels at Locations 1 and 5 suggest more organic material input, while lower levels at Location 2 may point to less human impact or better dilution and natural cleaning processes. Genera like *Aspergillus* and *Penicillium* are often linked to organic and hydrocarbon pollution, as they can break down complex substances.

Physicochemical factors showed site-specific differences that support the observed microbial trends. Slightly acidic pH levels were common across all sites, a typical feature of tropical surface waters that may be due to organic decomposition and human waste. While total dissolved solids and electrical conductivity stayed within acceptable ranges, high turbidity and suspended solids at some sites suggest particle pollution from runoff, erosion, and waste discharge. High levels of biochemical and chemical oxygen demand, especially at Locations 1 and 5, show

significant organic and chemical pollution that can lower oxygen levels and cause ecosystem stress.

Sediment microbial analysis also showed differences in bacterial and fungal levels, which reflect nutrient availability, organic matter content, and human influence. Organic pollution from domestic and industrial waste increases microbial growth by providing food and energy (Ogeleka *and* Tesi, 2011). High bacterial levels at SP1 indicate significant organic pollution, while lower levels at SP2 may suggest less nutrient input or the presence of harmful substances like hydrocarbons and heavy metals. Overall, bacterial levels in sediments fall within the typical range found in tropical aquatic environments, suggesting they are similar to other affected areas.

Fungal communities in sediments mainly included *Aspergillus*, *Penicillium*, *Fusarium*, and *Mucor*, which are important for decomposing organic matter and breaking down complex pollutants. While fungal levels were lower than bacterial levels, this is normal in sediment environments, where fungi thrive in specific nutrient-rich niches. The sediment samples generally met the standards set by WHO, NESREA, and SON, indicating little human pollution.

In summary, the combination of microbial and physical records shows specific pollution areas mainly caused by human activities. The variety of microbes found shows both pollution effects and natural cleaning abilities, highlighting their importance as indicators of environmental health.

4. CONCLUSION AND RECOMMENDATIONS

The study concludes that the surface water sources examined are influenced by both natural and human-induced factors. While some of physicochemical parameters fall within acceptable limits, high turbidity, TSS, BOD, and COD values at specific sites indicate organic pollution and deteriorating water quality. The presence of diverse bacteria and fungal species further confirms contamination from organic and faecal sources. The assessment of sediment samples from different locations revealed that the sediments serve as reservoirs of diverse microorganisms with both ecological and public health significance. The bacterial counts and fungal counts indicate active microbial metabolism and nutrient availability across the sites. Although the water remains generally fresh and usable after treatment, its direct consumption without proper purification poses potential health risks. Therefore, the ecosystem's health depends largely on effective management of waste disposal, effluent discharge, and continuous monitoring of both microbial and chemical indicators.

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