



# Microbiological Contamination and Hydrocarbon Pollution of Surface Water and Sediments in the Okulu River, Rivers State, Nigeria

Chukwudozie Colman Ifiora<sup>1</sup>, G. N. Woke<sup>2</sup>, Felicity Uju Onwudinjo<sup>\*3</sup>, Chimezie Ekeke<sup>4</sup>, T. M. Iringe-Koko<sup>5</sup>, Paul Aforji Osaro<sup>6</sup>

<sup>1,2,4,5,6</sup>University of Port Harcourt, Rivers State, Nigeria, <sup>3</sup>Department of Chemistry, Nwafor Orizu College of Education Nsugbe, Anambra State, Nigeria

| Article Info   | ABSTRACT   |
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| <p><b>Corresponding Author:</b><br/>Felicity Uju Onwudinjo<br/>E-mail:<br/>onwudinjo.felicity@nocen.edu.ng</p> | <p>Surface water bodies in industrialized regions are increasingly threatened by microbiological contamination and hydrocarbon pollution, raising serious concerns for environmental sustainability and public health. The study employed a field-based analytical design to evaluate microbiological and physicochemical contamination of surface water and sediments in the Okulu River. Five sampling stations were established, comprising four industrially impacted sites and one control site. Surface water and sediment samples were systematically collected, preserved, and analyzed for total coliforms, <i>Escherichia coli</i>, petroleum aromatic hydrocarbons, and potassium using standard laboratory techniques. Results were statistically analyzed and compared with World Health Organization standards to assess contamination levels, spatial variation, and associated environmental and public health risks. Results revealed marked spatial variation and widespread contamination of the Okulu River. Total coliforms in surface water exceeded WHO limits at all stations, peaking at SW4 (712 cfu/100 ml) compared to the control (0.01 cfu/100 ml). Sediments showed even higher coliform loads, with SD4 recording 7,765 cfu/100 ml. <i>E. coli</i> counts followed similar trends in surface water (SW4: 84.2 cfu/100 ml) and sediments (SD4: 903.5 cfu/100 ml), indicating fecal pollution. PAH concentrations were extremely elevated in surface water (SW4: 1,723 ppm) and sediments (SD4: 2,606 ppm), far above WHO limits. Potassium exceeded guidelines in impacted sites for water (up to 17.02 mg/L) and sediments (up to 84.08 mg/L). In conclusion, the Okulu River is severely degraded by combined microbiological and hydrocarbon pollution, posing significant ecological and public health risks and necessitating urgent regulatory enforcement, continuous monitoring, and remediation interventions.</p> <p><b>Keywords:</b> Okulu River; microbiological contamination; petroleum aromatic hydrocarbons; surface water; sediments</p> |

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## INTRODUCTION

Surface water bodies and their sediments play a crucial role in maintaining ecological balance which serves as habitat to aquatic life and source of drinking and irrigation water.

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Nonetheless, recent studies show that such systems are becoming more compromised by microbiological pollution and oil pollution, much of which is caused by human activities like industrial effluents, oil exploitation, and ineffective wastewater management. These widespread pollutants are a menace to aquatic life and health of human beings worldwide. Microbiological contamination is where harmful microorganisms like bacteria, viruses and protozoa can be found in water and sediments. These microorganisms are usually of untreated sewage, stormwater, runoff and waste products of urban centres. The inputs of wastewater cause the introduction of pathogenic bacteria into the waters, which may remain in the water column and sediment and continue to contaminate the water (Mendoza-Espinosa & Mojiri, 2024). Microbial pathogens are stored in the sediments and can reappear when there is an increase in flow or disturbance, posing more exposure risks (Mendoza-Espinosa & Mojiri, 2024).

New research also demonstrates the mediation of microbial contamination by new contaminants, including microplastics. Even though it is not directly targeted to traditional microbial pathogens, microplastics are sources of microbial colonization, which has the potential to carry pathogenic bacteria in water systems (Mohammed & Swalaha, 2025). Microplastic can absorb microbes and organic pollutants, forming a transport system to carry contaminants in aquatic environments (Mohammed & Swalaha, 2025). This is important since the contact of the biological contaminants with the physical vectors such as the microplastics can enhance the persistence and distribution of the pathogens in the surface water and sediments.

The main sources of hydrocarbon contamination are petroleum and fossil fuel sources, such as oil spills, industries, outflows of petroleum infrastructure, and maritime transportation. Hydrocarbons contain complex organic compounds including total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAHs), a large number of which are toxic and persistent in the environment. These are hydrophobic pollutants that bind to the sediments and persist in the environment and bioaccumulate over time in the benthic organisms (Henderson et al., 2025). A recent study in the Bonny Estuary, Rivers State, Nigeria, revealed that there were large seasonal differences in the levels of hydrocarbons both in the sediments and the biota. The research discovered that the TPH and PAH levels in sediments and fish tissues were often higher than the regulatory limits, which was indicative of continuous contamination by petrogenic sources of pollution, including oil discharges and combustion emissions (Henderson et al., 2025).

These findings underscore the fact that hydrocarbon pollution is not just spatially complicated, but also temporally, as it varies depending on seasonal shifts in the hydrology and land use. On the same note, studies conducted on the Kerch Strait of the Black Sea reported the persistence of hydrocarbons in the coastal waters and sediments with quantitative levels of aliphatic hydrocarbons and PAHs. Even though certain decreases were found in concentrations during time, the concentrations were still elevated compared to backgrounds, which means that there was still a pressure of pollution, and inadequate housing policy (Nemirovskaya et al, 2024; Ike et al, 2021). The ongoing pressure of pollution underscores why the cleanup of aquatic systems affected by hydrocarbons is challenging because polluted sediments act as the long-term pollutant stores that release hydrocarbons in spite of the decreasing surface contributions. This issue is indicative of more general gaps in environmental governance and sustainability within Nigerian situations, where a lax

enforcement of regulations and fragmented policy execution undercut environmental protection initiatives (Odimegwu et al, 2025; Anyakora et al, 2020).

The synergistic effects of microbiological contamination and hydrocarbon pollution on the environment only make the existing ecological stress situations compounded, posing additional risks to the stability of ecosystems and human well-being. These interactions are the reflection of the innovations in the climate risks and environmental management research that underlines that the cumulative environmental pressures tend to surpass the ability of natural systems to regenerate (Muogbo et al, 2025). Also, there is inefficient communication of the threat of environmental risks to the local communities, which increases their exposure and reduces their adaptive capacity (Oramah et al, 2025). Taken together, these points of view demonstrate the necessity of context-specific and integrated methods of dealing with long-term sediment-bound pollution and related biological risks. The reason is that, hydrocarbon compounds have the potential to shift the composition of the microbial communities in the sediments, frequently lowering the diversity, leasehold mineral rights and promoting those that degrade hydrocarbons (Lian et al, 2025; Anyakora & Odimegwu, 2021; Odumodu & Odimegwu, 2019). Such changes in microbes have the potential of disrupting the natural biogeochemical processes and affect nutrient cycling. As an illustration, in the case of microbial communities in the hydrocarbon-affected sediments, the functioning of the ecosystem can be modified by prioritising hydrocarbon degradation and other ecological activities.

In addition, the bioaccumulation of toxic compounds by sediments contaminated with PAHs and microplastics can be passed on by food webs to other organisms, such as fish (Spector, 2016). Such a dual contamination therefore does not only pose a threat to the aquatic biodiversity but directly to food security and human wellbeing especially to communities who solely rely on the water bodies to sustain them. An investigation of microbiological contamination and hydrocarbon pollution of surface water and sediments in the Okulu River is highly warranted because of noticeable gaps in existing knowledge and environmental issues recorded. Even though a few studies have evaluated the Okulu River on water quality aspects, including physicochemical, and microbial loads, the studies are either old or narrow in focus. As an example, a 2021 study quantified microbiological and physicochemical parameters of the Okulu River and concluded that total and fecal coliform counts were high, indicating poor water quality, although this study did not assess the presence of hydrocarbon pollutants and the current dynamics in the microbial risks in sediments (Onyeugbo et al., 2021).

Recently, studies have been conducted on PAH in fish tissues of the Okulu River, emphasizing exposure to hydrocarbons via the diet, but failed to measure it in water and sediments and to correlate it with pathogenic microorganisms (Aigberua et al, 2023). Moreover, the current research on the effects of pollution in 2025 utilized the macroinvertebrate abundance and simple water quality indices and reported the poor condition of the river, but failed to incorporate the detailed microbiological profiling and extensive hydrocarbon analyses (Ahuchaogu et al., 2025). These piecemeal attempts indicate significant lapses: no recent comprehensive research that simultaneously measures microbial contamination and concentrations of hydrocarbons in the surface water and sediments of the Okulu River. A renewed research would thus offer a more comprehensive insight into the sources, persistence and possible human health impacts of the pollutants, which is inadequately tackled in existing literature.

## METHODOLOGY

The research design adopted was the field-based analytical research in order to evaluate the microbiological and physicochemical contamination of surface water and sediments in the Okulu River, which is an area affected by multinational industrial processes. The design was such that systematic comparison could be done between the industrially affected sites and a specified control site to interpret discrepancies of the standards of the World Health Organization (WHO). Along the Okulu River, there were five sampling stations set. The four stations (SW1-SW4 in surface waters and SD1-SD4 in sediments) were situated in previously industrial discharged and anthropogenically-impacted areas and one station was used as a control area with minimal anthropogenic effects. Certainly, to gather samples of surface water, the samples were taken in the middle of the stream at about 2030 cm below the water surface in sterile, prewashed plastic containers.

Sediment samples were taken at the riverbed depths (015 cm) with a clean stainless-steel scoop and put in sterile polyethylene bags. All samples were marked, geo-referenced, ice-packed and taken to the laboratory to be analyzed within 24 hours. The standard microbiological techniques were used to determine the total coliform and *Escherichia coli* counts in the surface water and sediment samples. Water samples were subjected to the membrane filtration method and sediment samples were initially homogenized and serially diluted and then analyzed. Proper selective media were used and samples incubated at desired temperatures over a given period. Colony forming units (cfu/100 ml) were counted and noted down. The comparison of the results with WHO allowed limits in order to determine the possible fecal contamination and the risk to the health of the population.

To assess petrochemical contamination, the concentration of Petroleum Aromatic Hydrocarbons in water and sediment samples were assessed. Solvents were used to extract samples through normal protocols of solvent extraction. The extracts were also determined in terms of PAH concentration using gas chromatography and the concentration was given in parts per million (ppm). The values obtained were checked against WHO guideline limits to find out the degree of contamination that was due to industrial activities.

Based on the conventional laboratory analytical techniques, potassium levels in surface water and sediment samples were analysed. Appropriate digestion of samples and flame photometry were used. The concentrations were measured in milligrams per liter (mg/L) and compared with the recommended limits in WHO to determine the possible environmental and health effects. Descriptive statistical analysis of all the laboratory results was done. The mean values were calculated and represented in table and graphical representations. Sampling stations and the control site were compared against the WHO standards, the degree of contamination and spatial variation between WHO standards and the study area were determined.

## RESULTS

### **The Total Coliform Count of Surface Water**

The results obtained from this study points out the variations in the Total Coliform of surface water affected by the activities of the multinational industries in the study area. The control site, had a total coliform count of 0.01 cfu/100ml. this value is slightly above the World Health Organization (WHO) acceptable limit of 0 cfc/100ml (Fig 1). The other sites showed total coliform levels that were very high compared to the WHO acceptable limit for

total coliforms. Station SW4 had the highest total coliform count of 712 cfu/100ml, followed by SW3 with 379.5 cfu/100ml while stations SW1 and SW2 had counts of 27.2 cfc/100ml and 92.3 cfc/100ml respectively. The presence of coliform bacteria suggests the possibility of fecal contamination, which pose health risks to the communities that rely on these water sources for drinking water.

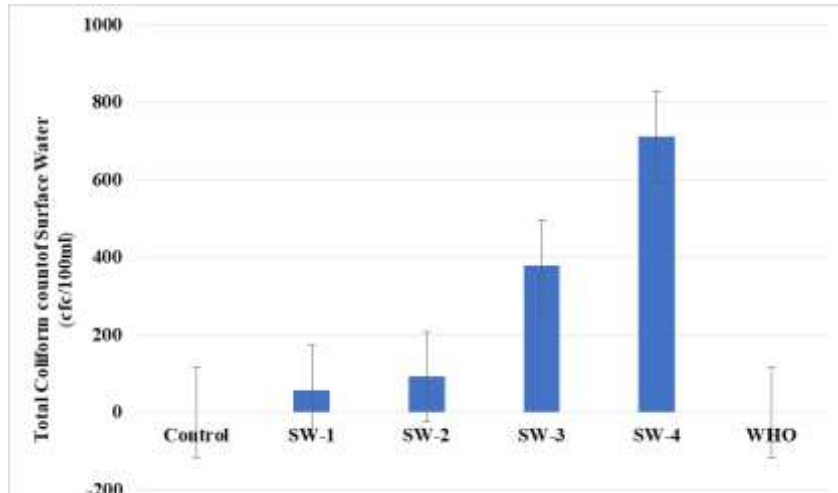


Figure 1: The Total Coliform Count on Surface Water

### The Total Coliform of Sediments

This study shows the variations in the Total Coliform in the sediment samples collected from Okulu River (Fig. 2). The control site had a total coliform count of 0.485 cfu/100ml. This value is above the World Health Organization (WHO) acceptable limit of 0 cfc/100ml. The other sites showed total coliform levels that were very high compared to the WHO acceptable limit for total coliforms. Site SD4 had the highest total coliform count of 7765 cfu/100ml, followed by SD3 with 3675 cfu/100ml. Stations SD1 and SD2 had counts of 212 cfc/100ml and 849 cfc/100ml respectively. The presence of coliform suggests the possibility of fecal contamination of the water bodies associated with industrial and sand mining activities since some the sand miners where seen defecating into the water body.

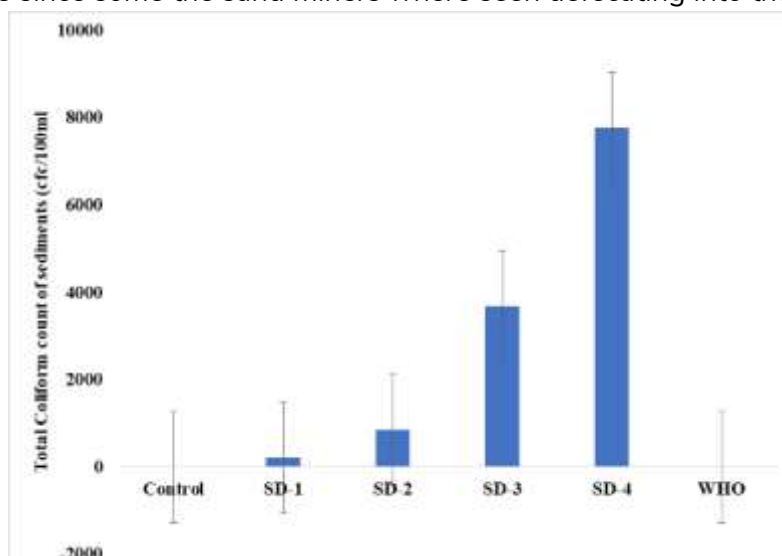


Figure 2: Total Coliform count of Sediments

### The Escherichia Coli (*E. coli*) Count of Surface Water

The results gotten from this experiment shows the variations in the *E. coli* of surface water in the study area (Fig 3). The control site, had *E. coli* count of 0.004 cfu/100ml. this value is small but it is slightly above the World Health Organization (WHO) acceptable limit of 0 cfc/100ml. The other sites had *E. coli* levels that were high when compared to the WHO acceptable limit for *E. coli* count. SW4 had the highest *E. coli* count of 84.2 cfu/100ml, followed by SW3 with 14.9 cfu/100ml. SW1 and SW2 had counts of 2.525 cfc/100ml and 6.83 cfc/100ml. The presence of *E. coli* suggests the possibility of fecal contamination, which pose health risks to the communities that rely on these water sources for drinking water.

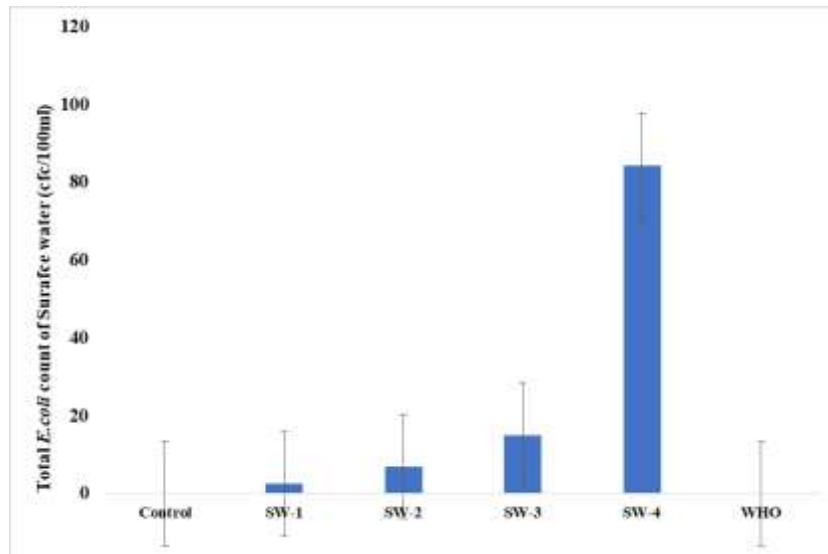


Figure 3: The Escherichia Coli (*E. coli*) Count of Surface Water

### The Total Escherichia Coli (*E. coli*) Count of Sediments

This experiment revealed the variations in the Total *E. coli* count of sediments in the study area. The control site, had a total *E. coli* count of 0.207 cfu/100ml. This value is above the World Health Organization (WHO) acceptable limit of 0 cfc/100ml (Fig 4). The other sites exhibited total *E. coli* levels that were very high compared to the WHO acceptable limit for total *E. coli*. SW4 had the highest total *E. coli* count of 903.5 cfu/100ml, followed by SW3 with 629.5 cfu/100ml. SW1 and SW2 had counts of 39.65 cfc/100ml and 75.2 cfc/100ml. The presence of coliform bacteria such as *E. coli* suggests the possibility of fecal contamination of the water bodies from which these sediment samples were obtained.

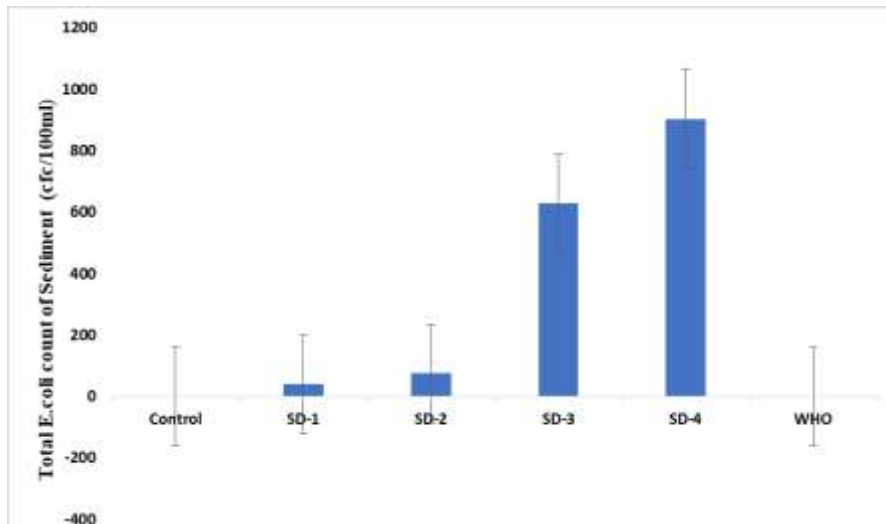


Figure 4: The Total Escherichia Coli (*E. coli*) Count of Sediments

### The Petroleum Aromatic Hydrocarbon (PAH) of Surface Water

This study exhibited varying levels of Petroleum Aromatic Hydrocarbon (PAH) in the different surface water samples collected (Fig. 4,20). PAH is a measure of the total concentration of aromatic hydrocarbons present in water, derived from petroleum sources. High PAH levels can signify significant contamination and potential environmental risks. The control sample had a low TPH value of 0.535 ppm, indicating minimal or low contamination. The low PAH level in the control site can be considered as a reference with the affected sites. SW1 and SW2 had PAH values of 607.5 ppm and 821.7 ppm respectively, pointing out relatively high PAH levels. SW3 and SW4 had even higher PAH values of 1437 ppm and 1723 ppm respectively.

Comparing the PAH values of these samples, to the WHO acceptable value of 0.0007 ppm, it is evident that all the samples collected, including the control has PAH values that exceed acceptable limit. These obtained values suggest the immediate need for remediation and restoration efforts to mitigate the environmental and health hazards associated with the presence and impact of petrochemical industries in these communities.

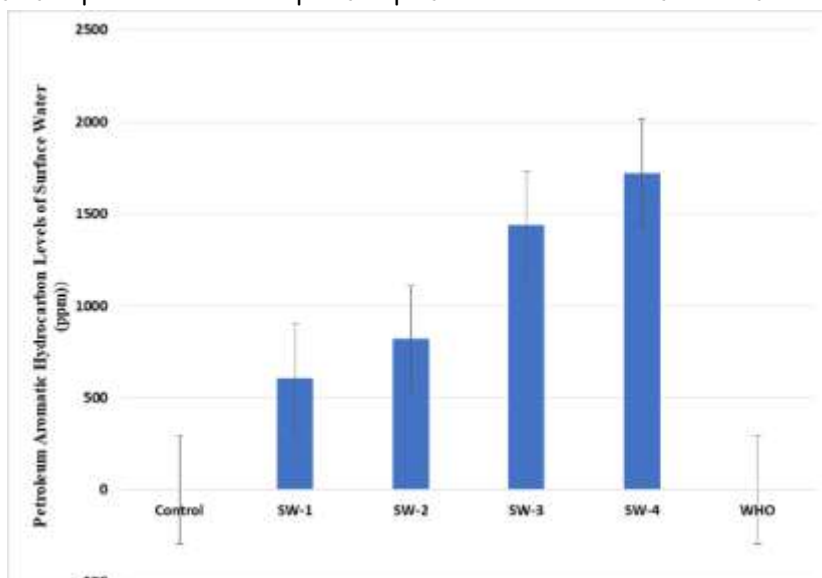


Figure 5: The Petroleum Aromatic Hydrocarbon (PAH) of Surface Water

### The Petroleum Aromatic Hydrocarbon (PAH) of Sediments

The results show different levels of Petroleum Aromatic Hydrocarbon (PAH) in different sediment samples collected from the different communities /locations affected by petrochemical industries. The control site had a PAH value of 3.907 ppm. This suggests minimal concentrations of PAH in the control site. Although, this value is large when compared to the World Health Organization (WHO) PAH limit of 0.0007 ppm, it can be used as a baseline or reference for comparison for the affected sites. The station SD1 exhibited a high PAH of 1409 ppm, while SD2 had a PAH value of 1727 ppm (Fig. 6). The stations SD3 and SD4 had PAH values of 2272 ppm and 2606 ppm respectively, indicating very high PAH contamination. All the sites, including the control site, had PAH values exceeding the WHO recommended limit of 0.0007 ppm.

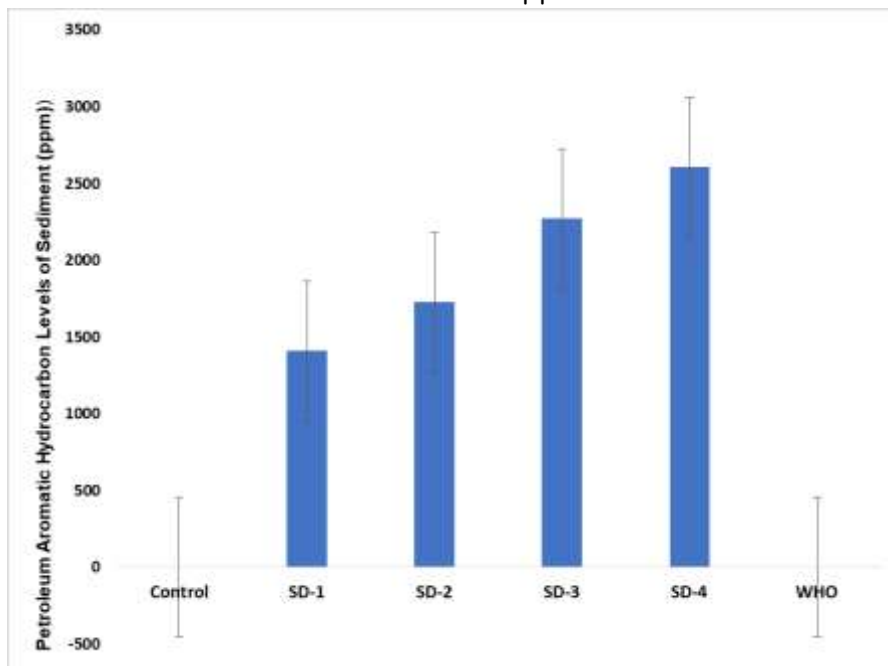


Figure 6: Petroleum Aromatic Hydrocarbon (PAH) of Sediments

### The Potassium Concentration of Surface Water

The results of the experiment showed the concentrations of Potassium (K) in surface water from different sites in the study area affected by multinational industries. Potassium is a metal that can pose serious health and environmental risks when present in quantities or amounts exceeding 10 mg/L as recommended by the World Health Organization (WHO). The control site had a Potassium concentration value of 2.747 mg/L. SW1 had a Potassium concentration of 9.248 mg/L. Although these levels of Potassium in surface water is high, it still conforms to the WHO recommended limit. SW2, SW3 and SW4 had Potassium levels of 12.64 mg/L, 17.02 mg/L and 14.88 mg/L respectively (Fig 7). These values are very high and also exceed the WHO recommended limit of 10 mg/L. This suggests that the concentrations of Potassium in the surface water samples from these sites pose significant risks to human health and the environment.

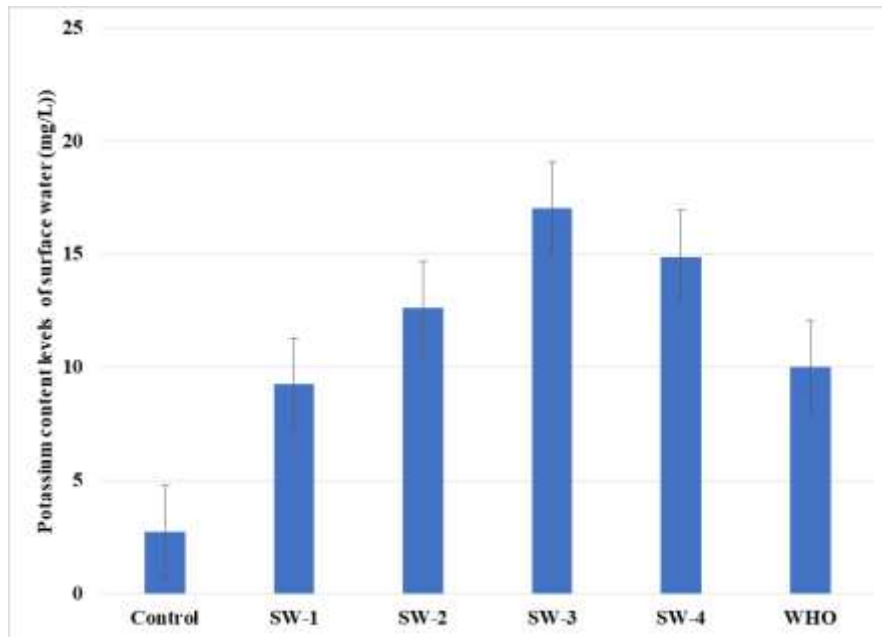


Figure 7: The Potassium Concentration of Surface Water in the study area

### The Potassium Concentration of Sediments

Potassium is a metal that can have detrimental effects on human health and the environment. It is primarily released into the environment through industrial activities. In this experiment, the focus was on assessing the Potassium levels in sediment samples collected from various sites affected by multinationals. The Control Site, exhibited the lowest Potassium concentration of 13.55 mg/L, which is obviously higher than the WHO acceptable value of 10 mg/L. This indicates that the sediment in the Control Site has been contaminated with Potassium. The other sites had Potassium concentrations of 21.8 mg/L, 28.67 mg/L, 34.72 mg/L and 84.08 mg/L for SD1, SD2, SD3 and SD4 respectively. These values are significantly higher than the WHO recommended limit for Potassium (Fig. 8).

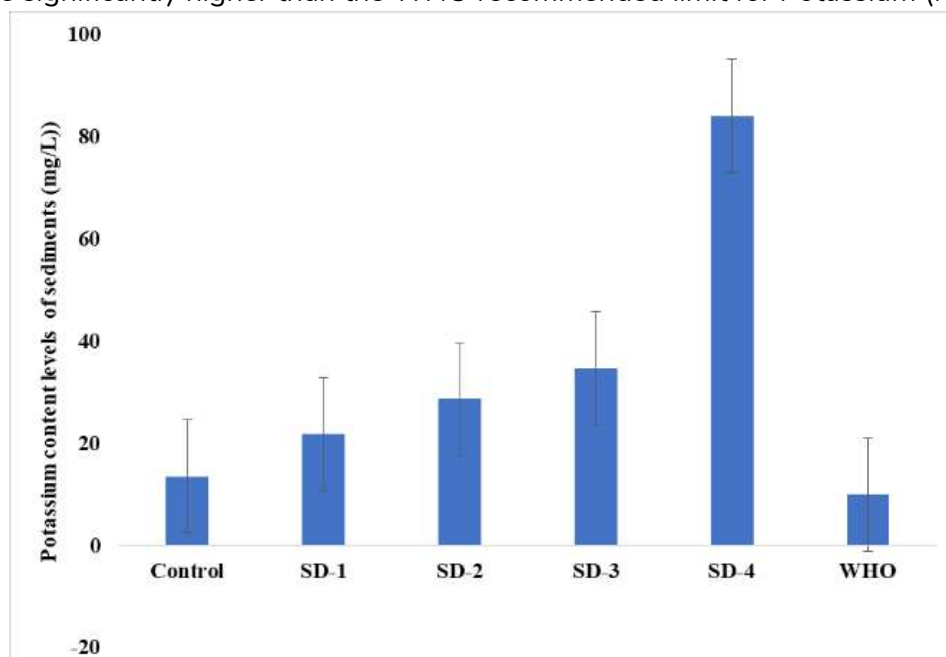


Figure 8: The Potassium Concentration of Sediments in the study area

## Discussion

The overall count of coliform in surface water showed intense spatial distribution with the control site showing 0.01 cfu/100 ml which was slightly above the zero limit recommended by WHO. This observation was in line with the reports by Tzimotoudis et al. (2025), who noted that even in reference sites, there were detectable coliforms as a result of diffuse anthropogenic inputs. Conversely, the coliform level was too high in stations SW3 and SW4 indicating that there was a lot of pollution by microbes. Assegide et al. (2022) reported similar high loads of coliform in industrially affected surface waters, which they related to the untreated industrial discharges and bad sanitation habits.

The total coliform in the sediment were significantly more than the total coliform in the surface water, especially SD3 and SD4. This observation was consistent with that of O'Donovan et al. (2025), who indicated that sediments serve as storage of fecal bacteria, which over a period of time concentrates contaminants. The high sediment coliform levels as compared to surface water show that there has been a long term contamination and resuspension potential particularly where sand mining activities have taken place. The counts of *E. coli* in surface water exhibited a curve like that of total coliforms with the highest count in SW4. This observation concurred with a similar study by Khan et al. (2020), which associated high *E. coli* concentration with fecal pollution and high risk to the health of the population in oil-producing societies. On the contrary, the low yet measurable *E. coli* concentration at the control site indicates background pollution, which may be due to non-point sources.

The *E. coli* concentrations in the sediment were significantly larger than surface water especially at SD4. This finding was consistent with that by Yoneda et al. (2024), which showed the favorable environment of sediments to survive and regrow *E. coli*. On the other hand, the surface waters had a lower count as a result of dilution and environmental stressors. The concentrations of petroleum aromatic hydrocarbon (PAH) in surface water were way above the WHO limits in all the sites. This observation was consistent with Ofori et al. (2021), who indicated that there were high levels of PAH around petrochemical facilities. Conversely, the lower value of PAH in the control site albeit still above the standards show relative background contamination.

Equally, the levels of sediment PAH were very high especially at SD3 and SD4. Similar results were reported in a related study by Ikpe et al. (2024), which found an equal sediment accumulation of PAH in industrial river systems, with sediments being long-term sinks of pollution. At SW2-SW4, potassium levels in the surface water were higher than WHO limits. This observation was consistent with that of Oladimeji et al. (2022) who linked high levels of potassium to industrial effluents. Control site, on the contrary, was not out of bounds. The concentration of potassium in sediments was also very high as compared to the surface water. This observation was consistent with that of Olowojuni et al., who reported a metal build-up in sediments because of the low mobility and the constant influx of industries (2023).

### **Consequences to the health, food security and quality of the environment.**

This study has important implications on the health, food security and the quality of the environment of the communities around the Okulu River. The high count of total coliforms and *Escherichia coli* in the surface water and the sediments signify extreme fecal contamination, and pose significant threats of waterborne diseases. These environmental health problems may add a disease burden to the community and overburden the

healthcare systems, especially in susceptible rural environments (Agofure et al., 2019a). The stress condition and exposure to contaminated resources may also increase the levels of stress and decrease the efficiency of health service delivery (Agofure et al., 2019b). Moreover, long-term exposure to contaminated air can also be among the contributors to psychosocial and mental health struggles, particularly when it comes to already susceptible groups (Ume et al., 2026). To eliminate these risks, culturally sensitive and integrated health system solutions are needed as stressed by Egwuaka et al. (2025).

In food security terms, elevated levels of petroleum aromatic hydrocarbons (PAHs) are of great concern with regard to the contamination of aquatic food. Accumulation of toxic hydrocarbons in fish, is a danger to the food safety of the population, a threat to nutritional security. This dilemma is in tension with the current attempts to encourage safe and functional foods as one of the strategies to address micronutrient deficiencies (Chinenye et al., 2025). Also, water pollution during food processing can cause problems with its quality, preservation, and safety, which are the focus of research on food oxidation and preservation (Nwagbo et al., 2020). Environmental contaminants can also have a detrimental impact on the integrity of locally processed foods, such as fermented and plant-based foods (Chude et al., 2021; Aniemena et al., 2024). Besides, polluted water sources may be used in food crop processing and preparation, which may change the nutrient content of the food (Okpalanma et al., 2024; Okpalanma et al., 2025).

The quality of the environment is also at risk since the sediments serve as a long time store of microbial pollutants and hydrocarbons resulting in long term degradation of the ecosystem. This compromises the ecological equilibrium and minimizes the use of safe natural resources by human beings. Despite theoretical perspectives like state responsibility, which reflect the role of governance in the management of environmental resources (Okosa, 2018), the lack of a strong enforcement can also cause such pollution to continue.

## CONCLUSION

This paper presents clear data that microbiological contamination and hydrocarbon pollution are the key factors that affect surface water and sediments in the Okulu River that can be greatly explained by industrial activities and excessive human use along the river. The number of total coliform and *Escherichia coli* in surface water and sediments were always higher than the World Health Organization allowable limits, which confirm the extensive fecal contamination of the river and the significance of the situation in the context of high risks to human health of those populations who use the river as the source of domestic and economic activity. The significantly increased loads of microbes in the sediments are also indicative of their status as long-term sources of contamination which can reintroduce pathogens into the water column.

In the same manner, the very high levels of petroleum aromatic hydrocarbons in the surface water and sediments indicate chronic petroleum chemical pollution of the Okulu River system. The fact that these hydrocarbons remain in sediments even after many years highlights the long-term environmental effects, such as bioaccumulation and possible passage via the aquatic food chain. High potassium levels and especially the industrially affected locations indicate the overall effects of anthropogenic inputs on the geochemical quality of the river. The results depict a very poor water quality which is ecologically and human health threatening. The paper highlights the necessity of tightening control of discharges by industries, enhancing waste management systems, ongoing water and

sediment quality monitoring of the Okulu River, and specific remediation actions to rehabilitate the water and sediment quality of the Okulu River and protect human health.

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