PHYSIOCHEMICAL AND MICROBIAL PARAMETERS OF SEDIMENTS OF ORHIONMWON RIVER

BY

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DEPARTMENT OF ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY

FACULTY OF LIFE SCIENCES

UNIVERSITY OF BENIN

BENIN CITY

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BEING A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN CITY IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF SCIENCE DEGREE (B.Sc.) IN EN ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY.

NOVEMBER, 2025

DECLARATION

I **MILLAR OSAHENKHOE SUCCESS (MISS)** declare that **"PHYSICOCHEMICAL AND MICROBIAL OF PARAMETERS OF SEDIMENTS IN ORHIONWOM RIVER IN BENIN CITY, NIGERIA"** is my work and that all sources that I have used or quoted have been acknowledged using complete references and that this work has not been submitted before for any other degree at any other University.

MILLAR OSAHENKHOE SUCCESS	DATE

CERTIFICATION

This is to certify that this research titled **"PHYSIOCHEMICAL AND MICROBIAL PARAMETERS OF SEDIMENTS OF ORHIONMWON RIVER IN BENIN CITY, NIGERIA"** was carried out by **MILLAR OSAHENKHOE SUCCESS (MISS)** and presented to the Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City; in partial fulfilment of the requirements for the award of Bachelor of Science (B.Sc) in Environmental Management and Toxicology. It was conducted under suitable conditions, was carefully supervised and subsequently approved as having met the requirements for the award of a Bachelor of Science degree in Environmental Management and Toxicology.

______________________	______________________
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PROJECT SUPERVISOR	

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PROF. (MRS.) E.T. AISEN	DATE
HEAD OF DEPARTMENT	

DEDICATION

This report is dedicated to God Almighty, for his guidance and protection during this project. I also want to dedicate this report to my beloved parent **MRS. EUNICE ISERE** for their unwavering support, prayers, love and financial assistance throughout my academic journey.

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First and foremost, I give all glory to Almighty God, whose grace, strength, and unfailing love guided me through every stage of this work. Without His blessings, this achievement would not have been possible.

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A special thanks to Mummy Favour, who was a school mother to me throughout my days in school your kindness and guidance will never be forgotten.

And lastly, I want to thank myself for a job well done for the resilience, dedication, and strength that brought this dream to reality.

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ABSTRACT

This study assessed the physicochemical and microbial characteristics of sediments from the Orhionmwon River, Edo State. The result of the average mean concentration of the physicochemical and microbial parameter are 5.03 ± 0.20(PH), 43.67 ± 10.44 µS/cm, 1212.61 ± 165.52 mg/kg (calcium), 287.33 ± 93.92 mg/kg (Magnesium), 297.91 ± 81.39 mg/kg, (Potassium) 161.62 ± 32.71 mg/kg (sodium), 0.05 ± 0.01 (Nitrogen), 0.51- 0.16 (TOC), 92.18 ± 2.39(sand), 5.94- 2.38(clay), 1.88 - 0.03(slit), 27.24 ± 10.41(THC), 4.00 ± 1.01 (THC), 1.52 ±0.31(THF), 73.11 ± 11.39(E.coil), and 187.78 - 36.46 (coliform) respectively . Sand and slit showed no significant difference ($p>0.05$), why pH, EC, calcium, magnesium, potassium, sodium, nitrogen, TOC, clay, THC, THB, THF, *E.coli* and coliform respectively exhibit a significant difference ($p <0.05$) across the three sampling stations . The study concluded that the microbial parameters in the sediments were very high.The findings highlight both natural geological influence and serious human impact, posing a clear public health risk. It recommends regular sediment monitoring and urgent improvements in waste management to protect both the environment and community health.

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Freshwater ecosystems, particularly rivers, are vital for sustaining human livelihoods and supporting aquatic biodiversity. Rivers provide essential services such as drinking water, irrigation, and industrial water supply, while serving as habitats for diverse flora and fauna (Dudgeon, 2019). In developing countries like Nigeria, however, these ecosystems face increasing threats from pollution driven by rapid urbanization, poor waste management, and intensive agricultural practices (Ipeaiyeda and Onianwa, 2019). These activities introduce a range of pollutants, including organic matter, heavy metals, and pathogens, into river systems, with sediments acting as long-term repositories for these contaminants (Akoto *et al.,* 2020).

River sediments are critical in environmental studies due to their ability to accumulate pollutants over time, unlike surface water, which is subject to rapid compositional changes (Förstner and Salomons, 2016). Sediments serve as both sinks and sources of contaminants, reflecting the historical and ongoing pollution status of aquatic systems. Key physicochemical parameters such as pH, temperature, electrical conductivity (EC), organic matter content, and heavy metal concentrations like lead, cadmium, and chromium provide valuable insights into the contamination levels and potential ecological risks of sediments (Islam *et al.,* 2015). For instance, elevated physicochemical concentrations in sediments can disrupt aquatic ecosystems and pose toxicity risks to both aquatic organisms and humans reliant on these water bodies (Ali *et al.,* 2019).

In addition to chemical contaminates, river sediments harbour diverse microbial communities that play essential roles in nutrient cycling, organic matter decomposition, and ecosystem stability (Gibbons and Gilbert, 2015). However, the presence of pathogenic microorganisms, such as *Escherichia coli*, *Salmonella* spp., and faecal coliforms, often indicates contamination from sewage or agricultural runoff (Akinbile *et al.,* 2021). These pathogens pose significant health risks to communities that depend on rivers for domestic and agricultural purposes. For example, studies in Nigeria have reported high microbial loads in river sediments, linked to untreated wastewater and agricultural practices (Reuben *et al.,* 2018).

The Orhionmwon River in Edo State, Nigeria, is a critical resource for local communities, supporting fishing, irrigation, and domestic water use. However, its proximity to agricultural lands and human settlements increases its vulnerability to contamination from runoff, domestic waste, and industrial effluents (Oladeji *et al.,* 2022). Despite its ecological and socio-economic importance, there is a significant lack of comprehensive data on the physicochemical and microbiological characteristics of the Orhionmwon River's sediments. This knowledge gap hinders effective environmental monitoring and management, necessitating detailed studies to assess the river's sediment quality and its implications for public health and ecosystem health. Such efforts align with global priorities, including the United Nations Sustainable Development Goals (SDGs), particularly Goals 3 (Good Health and Well-Being), 6 (Clean Water and Sanitation), and 14 (Life Below Water) (UNEP, 2023).

1.2 Statement of the Problem

Sediment quality in freshwater ecosystems is increasingly threatened by human activities, especially in developing countries like Nigeria. Rivers that flow through rural and peri-urban areas often receive untreated waste from agricultural lands, households, and small industries, which alters the physicochemical and microbiological composition of the sediment (Akinbile *et* *al.,* 2021). These alterations can reduce biodiversity, compromise ecological balance, and pose risks to public health through exposure to pathogens and toxic substances.

Most existing environmental monitoring programs in Nigeria tend to focus on surface water quality, neglecting sediment studies, which are critical because sediments can accumulate and retain pollutants over prolonged periods (Akoto *et al*., 2020). Without adequate data on the sediment's physicochemical and microbiological characteristics, it becomes difficult to assess pollution levels accurately or implement effective water management strategies.

These activities may introduce heavy metals, organic pollutants, and pathogenic microorganisms into the river's sediments, compromising its ecological integrity and safety for human use. Despite these concerns, there is a notable lack of sediment-focused studies on the Orhionmwon River, with most environmental monitoring programs in Nigeria prioritizing surface water quality (Akoto *et al.,* 2020).

1.3 Justification of the Study

In an era where sustainable development and environmental protection are global priorities, localized studies like this one are essential. They contribute to broader efforts aimed at achieving clean water, good health, and ecosystem conservation, in line with the United Nations Sustainable Development Goals (UN SDGs), especially Goals 3, 6, and 14 (UNEP, 2023).

The Orhionmwon River is a lifeline for communities in Edo State, supporting diverse socio-economic activities such as fishing, irrigation, and domestic water use. However, the lack of proper waste management systems and the proximity of agricultural and residential activities increase the risk of contamination by organic pollutants, and pathogenic microorganisms (Akinbile *et al.,* 2021). These contaminants can accumulate in sediments, posing long-term threats to aquatic biodiversity and human health. For example, studies have shown that heavy metals in sediments can bioaccumulate in fish, entering the food chain and posing risks to consumers (Ali *et al.,* 2019).

This study is justified by the urgent need to generate baseline data on the Orhionmwon River's sediment quality. Such data will enable environmental authorities and policymakers to develop targeted pollution control strategies and sustainable river management plans (Akoto *et al.,* 2020).

1.4 Aim and Objectives of the Study

The aim of this study is to assess the physicochemical and microbiological properties of sediments from the Orhionmwon River.

The objective the study is to determine the.

- Physicochemical parameters of sediment samples collected from different locations along the Orhionmwon River.
- Selected microbial parameters in the river sediments.
- Compare with relevant national and international environmental standards.

CHAPTER TWO

LITERATURE REVIEW

2.1 Physicochemical Parameters of Sediments

Otolo *et al.* (2017). Conducted a study to determine Some Physico-Chemical Parameters of Sediments from Ethiope River, Delta State, Nigeria" conducted a baseline study to assess the sediment quality of the Ethiope River by analysing a range of physicochemical parameters across eight different locations. The study aimed to establish a pollution baseline and understand the geochemical processes within the river's sediments. The results of the physicochemical analysis revealed a mean pH of 7.31 ± 0.15 across the sediment samples, indicating a near-neutral to slightly alkaline condition overall. However, significant spatial variation was observed, with pH values ranging from a minimum of 6.07 ± 0.00 in Umutu to a maximum of 8.73 ± 0.00 at the Eku 2 station. The study noted that highly acidic or alkaline conditions can be hazardous to aquatic life. Electrical conductivity, a measure of dissolved ions and mineralization, also varied widely, ranging from 27.90 ± 0.00 µS/cm at the Abraka 2 station to 110.05 ± 0.01 µS/cm at the Eku location point 2, with a mean value of 57.54 ± 0.025 µS/cm. Temperature showed minimal variation along the sample points, ranging from 28.60 ± 0.01 °C to 29.8 ± 0.01 °C, with an average of 29.07 ± 0.02 °C. A key finding was the spatial variation in Total Organic Carbon (TOC). Sediments from the Abraka 2 and Eku 1 stations contained comparatively higher organic matter, with TOC values of 8.80 ± 0.02 and 8.80 ± 0.00 mg/kg respectively. In contrast, the sediment from Abraka 1 had a much lower TOC value of 0.50 ± 0.02 mg/kg, which was attributed to a lower supply of organic matter from vegetation. Nutrient analysis showed that the concentration of phosphate was significantly low across all locations, with a mean value of 0.018 ± 0.01 mg/kg. This was attributed to the low pollution discharge from domestic drainage and the weathering of minerals within the region. Similarly, the mean concentration of nitrogen was also very low, which the study suggested could be due to the near-zero input of nitrogenous effluents. The concentration of calcium ranged from 1.92 ± 0.01 mg/kg at the Sapele 2 location to 12.32 ± 0.01 mg/kg at the Eku 2 sediment location. Magnesium concentration ranged from 5.05 ± 0.01 mg/kg to 7.88 ± 0.01 mg/kg at the Abraka 2 station. The presence of these exchangeable ions was attributed to their solution form in the sediment samples and the weathering of minerals. The study concluded that the results suggest the sediment-dwelling organisms have not yet been severely affected by pollution. However, the authors noted that the present increasing pollution load from rapid industrialization, agricultural fertilizers, and industrial discharge necessitates the urgent implementation of compatible policies and programs. They strongly recommended improved industrial and domestic wastewater treatment methods to discourage the discharge of untreated effluent into the Ethiope River, which is also an important resort and recreational centre.

Agathe *et al.* (2025). Examined the Physicochemical Parameters and Selected Heavy Metals in Water and Sediments in the Mangrove Forest at Akodo-Ise, Lagos State, Nigeria" conducted a comprehensive environmental assessment of a mangrove ecosystem in the Lagos Lagoon. The study aimed to evaluate water quality, sediment characteristics, and heavy metal contamination levels to determine the ecological health and anthropogenic impact on this crucial coastal habitat. The physicochemical analysis of water revealed an average temperature of 28.07°C and a near-neutral mean pH of 7.06, which is favourable for aquatic organisms. However, the electrical conductivity averaged 8080.70 µS/cm, indicating brackish water conditions with a high concentration of dissolved inorganic matter. The average salinity content was 5.34 ‰, with seasonal fluctuations attributed to rainfall and freshwater intake. The oxidation-reduction potential (ORP) had a mean value of 992.3 mV, suggesting a significant quantity of oxygen in the ecosystem, viable for decomposition processes. Sediment analysis showed variation in moisture content across different depths and locations, with the highest average (26.13%) at the seafront (15-30 cm depth). Nutrient analysis revealed that the highest soil phosphorus content (23.27 mg/kg) was observed at the 15-30 cm depth within the inner mangrove. The average potassium content was consistent (0.15 cmol/kg) across several locations, while nitrogen content was highest (0.37%) in the inner mangrove at 15-30 cm depth. The study identified and quantified five heavy metals in the sediments: lead (Pb), iron (Fe), zinc (Zn), copper (Cu), and nickel (Ni). Iron (Fe) concentration was the highest among all metals, with an overall average value of 4061.50 mg/kg, which the authors associated with both natural occurrence and anthropogenic activities. Lead (Pb) had an average concentration of 29.50 mg/kg, which exceeded the USEPA standard acceptable limit. Zinc (Zn) and Nickel (Ni) averaged 91.60 mg/kg and 3.50 mg/kg, respectively. Copper (Cu) concentrations were relatively low (average 29.50 mg/kg) and remained below the WHO acceptable limit of 36 mg/kg. Notably, cadmium (Cd) was not detected in any sampling location. The authors concluded that the relatively high lead concentration and the significant iron levels could be attributed to anthropogenic factors and substantial run-off, highlighting potential environmental concerns. The study emphasizes that while some parameters like copper remain within safe limits, the exceedance of lead standards and the high iron content point to a need for continued monitoring and management of this mangrove ecosystem to mitigate the impacts of human activities.

Adedeji, *et al.* (2023) carried out an Assessment of the impact of anthropogenic influences on the sediment quality of Owalla Reservoir, Southwest, Nigeria" conducted a comprehensive and detailed analysis of the sediment quality in Owalla Reservoir to evaluate the impact of human activities. The study involved an extensive examination of a wide array of physicochemical parameters across different stations (upstream, mid-basin, downstream, open-water, littoral zone) and seasons (dry and rainy) to build a complete picture of the reservoir's sediment characteristics. The results revealed a specific order of dominance for major exchangeable ions. For cations, the order was $Mg^{2+} > Ca^{2+} > H^{+} > Al^{3+} > K^{+} > Na^{+}$, and for anions, it was $PO_4^{3-} > SO_4^{2-} > NO_3^{-} > Cl^{-}$. The textural composition of the sediments was dominated by sand (overall mean 73.1 ± 1.66%), followed by clay (17.4 ± 1.07%) and silt (9.4 ± 0.77%). The sediment was acidic, with overall mean pH values of 5.27 ± 0.06 in H_2O and 4.80 ± 0.05 in $CaCl_2$. Spatially, the deepest mean depth (8.12 ± 1.17 m) was recorded downstream, while the highest mean values of silt (12.89 ± 2.15%), magnesium (2.37 ± 0.19 cmol/kg), phosphorus (110.43 ± 14.79 μgg^{-1}), and organic matter (3.52 ± 0.40%) were found at the upstream station, suggesting a significant influx of materials from the catchment area. The open-water station recorded the maximum mean values for several parameters, including conductivity (828.30 ± 91.70 μScm^{-1}), nitrate (6067.52 ± 192.87 μgg^{-1}), and phosphate (436.93 ± 49.14 μgg^{-1}), indicating areas of concentrated ionic and nutrient load. Seasonally, the study found a high significant difference ($p < 0.001$) for many parameters between the dry and rainy seasons. The dry season was characterized by higher mean values of sand fraction (77.10 ± 1.80%), pH, base saturation, and organic matter. In contrast, the rainy season showed markedly higher values for silt, clay, conductivity, nitrate (5543.04 ± 211.75 μgg^{-1}), phosphate (375.34 ± 39.55 μgg^{-1}), and total nitrogen, highlighting the role of runoff in transporting fine particles and nutrients into the reservoir. Principal Component Analysis (PCA) showed complex relationships between parameters and stations. A strong positive correlation was found between pH, sand fraction, and depth downstream, while parameters like clay, nitrate, and phosphorus correlated strongly at the upstream station. The trilinear Piper plot analysis indicated that the water type was characterized by alkaline earth metals exceeding alkali metals and strong acids exceeding weak acids, with calcium and chloride appearing as the most dominant ions in the diagrammatic representation, slightly contradicting the numerical dominance of magnesium and sulphate. The study concludes that the spatial and seasonal variations in sediment physicochemical parameters, particularly the elevated nutrients and ionic content linked to the upstream and rainy season, are strong indicators of significant anthropogenic influence on the Owalla Reservoir, necessitating management strategies to mitigate catchment-derived pollution.

Adesuyi *et al*. (2016). Carried out an Assessment on the Physicochemical Characteristics of Sediment from Nwaja Creek, Niger Delta, Nigeria" conducted a study to evaluate the spatial and temporal variations in the physicochemical properties of sediments in Nwaja Creek. The research analysed particle size distribution, pH, conductivity, total organic carbon (TOC), phosphate, and nitrate levels across multiple stations over three months (May, June, July) to understand the environmental dynamics of the creek. The results of the particle size distribution revealed that the sediments were predominantly clay, followed by silt and then sand. The mean monthly composition ranged from 64.28% ± 22.04% to 72.36% ±14.00% for clay, 18.71% ± 12.03% to 27.32% ± 22.17% for silt, and 8.40% ± 6.28% to 9.76% ± 4.59% for sand. The highest percentage of clay (90.55%) was recorded at station 3 in May, while the least (35.89%) was at station 7 in the same month. There were no significant differences ($p < 0.05$) in particle size between stations and months. The pH analysis showed acidic conditions with mean monthly values of 5.39 ± 1.16 in May, 6.54 ± 0.95 in June, and 4.65 ± 0.65 in July. The highest pH (8.50) was recorded at station 2 in May, and the lowest (3.90) at station 2 in July. Significant spatial and monthly differences ($p < 0.05$) were observed in pH levels. High variation was observed in conductivity, with mean monthly values ranging from 44.98 ± 20.79 µS/cm in July to 266.21 ±

151.62 µS/cm in May. Across stations, conductivity ranged from 79.50 ± 64.97 µS/cm at station 6 to 280.83 ± 253.19 µS/cm. The highest value (567.0 µS/cm) was recorded at station 1 in May, and the lowest (23.0 µS/cm) at station 6. Significant differences ($p < 0.05$) were found in conductivity across both stations and months. Total Organic Carbon (TOC) values were generally above 1% at all stations, with the highest mean monthly value in May (3.78% ± 0.98%) and the lowest in June (2.11% ± 0.70%). Spatially, the highest mean TOC was at station 6 (3.65% ± 1.79%), and the lowest at station 3 (1.99% ± 0.5%). Significant differences were observed between stations and months. Nutrient analysis showed that phosphate levels were higher than nitrate concentrations. Mean monthly phosphate ranged from 7.77 ± 1.42 mg/kg in July to 12.82 ± 3.15 mg/kg in May. Across stations, it varied between 6.76 ± 1.20 mg/kg at station 5 and 12.29 ± 4.20 mg/kg at station 7. Nitrate levels were also high and variable, with mean monthly concentrations from 2.33 ± 1.21 mg/kg in June to 6.82 ± 3.13 mg/kg in May. Across stations, nitrate ranged from 2.49 ± 1.76 mg/kg at station 3 to 6.67 ± 4.76 mg/kg at station 6. Significant differences ($p < 0.05$) were observed for both phosphate and nitrate between stations and months. Correlation analysis revealed positive but statistically insignificant relationships between pH and conductivity, organic carbon and conductivity, phosphate and pH, nitrate and organic carbon, and nitrate and phosphate.

Rzetala, and Babicheva (2019). Evaluated the Composition and physio-chemical properties of bottom sediments in the southern part of the Bratsk Reservoir (Russia)" conducted a comprehensive geochemical and sedimentological study to assess the quality and characteristics of bottom sediments in the southern part of the Bratsk Reservoir, one of the world's largest reservoirs. The research aimed to identify relationships between the physical and chemical properties of the sediments and the accumulation of trace elements, many of which are toxic heavy metals. The granulometric analysis revealed that the bottom sediments were predominantly of the terrigenous genetic type, formed from detrital material originating from the banks. The study identified a clear predominance of fine silt and silty-clayed muds. A key methodological finding was that the ratio of particle contents changed significantly towards a higher number of micro-fine particles when using a dispersed sample preparation compared to a semi-dispersed one. In fine silt muds, the 0.05–0.01 mm fraction constituted up to 50–70%, while the total content of silt particles <0.01 mm did not exceed 40%. The content of the sand fraction (>0.25 mm) was minimal, not exceeding 1% in almost all samples. A core component of the study was the trace element analysis. Due to the absence of Russian regulatory standards for sediments, the authors compared concentrations to the geochemical background of bedrock in the Baikal region. The results showed an exceedance of this background for several trace elements: Cobalt (Co), Chromium (Cr), Copper (Cu), Manganese (Mn), Nickel (Ni), Lead (Pb), Thorium (Th), Vanadium (V), and Zinc (Zn). The anomaly ratio (AR), calculated as the content in the sediment divided by the geochemical background, was highest for Co, Ni, and Zn (AR = 2.0–2.18). The analysis of structure-forming components revealed several critical features. The sediments showed varying degrees of "saline contamination," with water-soluble salt content averaging 1.042% and ranging up to 2.080%, which the authors attributed to the proximity of industrial areas. The salinity type was predominantly carbonate-sulphate. The total carbonate content was also high, averaging 24.36% (range: 15.08 to 31.32%), with $CaCO_3$ and $MgCO_3$ prevailing. The humus (organic carbon) content averaged 5.60%, with a high degree of humification suggesting an allochthonous (external) origin for the organic matter. The content of mobile (free) forms of aluminium oxide (Al_2O_3), which acts as a cementing agent, averaged 1.43%. Finally, the study employed Pearson's correlation analysis to evaluate the impact of various sediment characteristics (clay fraction content, organic carbon, carbonates, water-soluble salts) on the accumulation of the identified trace elements. This was an attempt to disentangle the complex physical and chemical mechanisms—such as ion exchange, adsorption, and complex formation with humic acids that govern the absorption and distribution of metals in the sediment matrix.

Adubor et al. (2025). Investigated the Physicochemical Properties of Surface Water, Heavy Metals Levels in Sediments and Macrobenthic Invertebrates Community of Ikpoba River, Benin City, Edo State, Nigeria." This research provided a holistic assessment of the ecological health of the Ikpoba River by integrating analyses of water quality, sediment contamination, and biological indicators across multiple sampling stations. The physicochemical analysis of surface water revealed a critically acidic environment, with a wide pH range of 4.30 to 8.90 and a mean of 5.23. This prevalent acidity was identified as a major concern due to its capacity to increase the solubility and bioavailability of toxic heavy metals, thereby potentiating their negative impacts on aquatic organisms. The study also reported elevated levels of Electrical Conductivity (EC) and Total Dissolved Solids (TDS), which were attributed to significant ionic pollution from urban runoff, domestic waste, and industrial effluents discharging into the river. A core finding of the research was the severe heavy metal contamination within the river's sediments. The concentrations of several toxic metals surpassed recommended limits for freshwater ecosystems, Iron (Fe) ranged from 22.30 to 45.30 mg/L, suggesting inputs from both natural geochemical weathering and anthropogenic sources. Zinc (Zn) was found at levels between 8.46 and 27.10 mg/L, primarily linked to industrial discharge. Copper (Cu) was detected at 1.80 to 12.40 mg/L, a concentration known to be toxic to aquatic invertebrates and likely originating from plumbing materials and pesticides. Lead (Pb) was present at 0.01 to 4.75 mg/L, exceeding World Health

Organization (WHO) limits and posing significant neurotoxic risks. Cadmium (Cd), a highly toxic metal even in trace amounts, was found at concentrations up to 1.15 mg/L, associated with battery and electronic waste. The biological assessment, a key component of the study, recorded 482 individual macroinvertebrates. The community was dominated by the orders *Ephemeroptera* (23.03%), *Diptera* (22.61%), *Hemiptera* (18.26%), and *Odonata* (17.01%). The EPT index (*Ephemeroptera, Plecoptera, Trichoptera)*, a key metric for water quality, was calculated at 31.67%, indicating a state of moderate pollution. Spatial analysis revealed a clear gradient of impact; Station 1 exhibited the highest species richness and diversity, while Station 3 recorded the lowest, correlating with proximity to urban runoff and waste discharge points. The study conclusively determined that the Ikpoba River is moderately polluted. The synergistic combination of acidic pH elevated heavy metal concentrations in sediments, and a reduced macroinvertebrate diversity points to substantial anthropogenic pressures, primarily from urbanization, industrial activities, and inadequate waste management practices. The authors underscored the urgent need for intervention strategies, including improved waste management, stringent pollution control measures, and the establishment of a continuous biological monitoring program to restore and preserve the river's ecological integrity.

Akankali and Davies (2021). Heavy Metals and Physicochemical Parameters Evaluation in the Upper Reaches of Bonny River, Niger Delta, Nigeria" conducted a comprehensive environmental assessment to evaluate seasonal variations in water quality and heavy metal contamination across different media (water, sediment, and biota) in the Bonny River ecosystem. The study analysed physicochemical parameters and heavy metal concentrations (Iron - Fe, Zinc - Zn, Copper - Cu) during dry and wet seasons from January to June 2020 and calculated the Bioaccumulation Factor (BAF) to understand metal transfer in the food web. The physicochemical analysis revealed significant seasonal variations ($p<0.05$). Salinity was significantly higher in the dry season, with maximum and minimum values of 138.6 ± 0.05 ppt and 62.3 ± 0.05 ppt, compared to the wet season (134.2 ± 0.05 ppt and 62.4 ± 0.05 ppt). Total Suspended Solids (TSS) were also highest in the dry season, recording a maximum of 272 ± 0.03 mg/L, attributed to turbulent effects and effluent discharge. Water temperature was higher in the dry season (ranging from 27.0°C to 29.3°C) than in the wet season (28.2°C to 27.6°C), which aligns with values reported for other creeks in the Niger Delta. The pH range (6.4-7.2) was within FEPA/WHO (2003) acceptable limits, with slight fluctuations attributed to rainwater runoff. Dissolved Oxygen (DO) levels were higher in the dry season (max 4.35 ± 0.01 mg/L) than in the wet season, which affects aquatic life survival. Heavy metal analysis showed that Iron (Fe) was consistently the most prevalent contaminant across all media. In the swimming crab (Callinectes Amnicola), Fe reached a maximum of 10.67 ± 0.47 µg/g in the dry season. Zinc (Zn) recorded its maximum in crabs at 9.88 ± 0.24 mg/L in the wet season, while Copper (Cu) was lowest across all media, with a maximum of 0.23 ± 0.01 mg/L in crabs during the dry season. The sediment acted as a significant sink for metals, accumulating higher concentrations than the water column. The Bioaccumulation Factor (BAF) was calculated to quantify metal uptake in biota. Both Fe and Zn were accumulators (BAF > 1) in both seasons. Zn showed higher bioaccumulation in the dry season (BAF = 1.59) than in the wet season (BAF = 0.82). Fe had a BAF of 1.11 (dry) and 1.02 (wet). In contrast, Cu was an excluder (BAF < 1) across both seasons, with values of 0.91 (dry) and 0.70 (wet), indicating effective regulatory mechanisms in the crabs or low bioavailability. The study concluded that the seasonal variations and elevated metal concentrations were driven by anthropogenic activities, including industrial effluents, municipal sewage, ship traffic, agricultural runoff, and oil/gas production. The dry season showed higher contamination due to reduced dilution capacity. The high BAF values for Fe and Zn in C. Amnicola, a species constantly found on sediments during low tide, indicate a significant risk of contaminant transfer to higher trophic levels, including humans, and highlight the Bonny River as a seriously polluted ecosystem requiring urgent management intervention.

2.2 Occurrence and Distribution of Microorganisms in Sediments

Udofia *et al.* (2022). Examined the Microbial Abundance, Diversity and Physiochemistry of Sediments of Iko River Estuary, Akwa Ibom State" conducted a comprehensive analysis to determine the microbial load, diversity, and physicochemical properties of the benthic environment in the Iko River Estuary. The study involved the collection of sediment samples from upstream, midstream, and downstream locations for detailed microbiological and geochemical examination. The results of the microbial density analysis revealed a high heterotrophic bacterial load in the sediments, with counts ranging from 2.1×10^6 CFU/g to 4.1×10^6 CFU/g. The sulphate-reducing bacterial count ranged from 2.1×10^1 CFU/g to 3.6×10^1 CFU/g, while the upstream site had a mean fungal count of 1.1×10^2 CFU/g. A significant finding was the complete absence of nitrogen-fixing bacteria across all sampled sites. Culturable microbial isolation and characterization identified a diverse array of bacterial species, including *Bacillu*s, *Streptococcus, Pseudomonas*, *Staphylococcus, Enterobacter, Chromatium, Klebsiella, Proteus, Escherichia, Vibrio, and Shigella*. Fungal species comprised *Aspergillus sp., Geotrichum sp., Penicillium sp., Epicoccum sp., Rhizopus sp., Mucor sp., Trichoderma sp., Cladiosporium sp., Trichophyton sp., and Microsporium sp*. Distribution analysis showed that the downstream sediment sample from Okoroette harboured the highest number of bacterial species (13 out of 17 total, or 76.5%), with *Bacillus subtilis, Klebsiella sp., P. aeruginosa, and P. fluorescens* being the most abundant. Phylum classification via molecular analysis revealed that

Proteobacteria was overwhelmingly dominant, with read counts of 990.0 (67.39%), followed distantly by Bacteroidetes at 168.0 (11.44%). Other phyla included *Planctomycetes* (4.29%), *Chloroflexi* (3.47%), *Firmicutes* (3.40%), and *Acidobacteria (*1.57%). The physicochemical characteristics of the sediments were also determined. Temperature was consistent at 28°C for the upstream and midstream sediments but slightly higher (29°C) downstream. The pH was slightly acidic, measuring 6.20 (upstream), 6.40 (midstream), and 6.50 (downstream). Particle size analysis showed the sediments were dominated by sand (78.42%), followed by clay (20.14%) and silt (1.44%). Electrical conductivity was highest for the downstream sediment (308.6 µS/cm) and least for the midstream sediment (124 µS/cm). The chloride content was consistent across all three stations (309.3 mg/l upstream, 308.6 mg/l midstream and downstream). Nitrate content was 8.03 mg/l, 8.11 mg/l and 8.13 mg/l for the upstream, midstream, and downstream sediments, respectively. Phosphate concentrations were consistently low at 7 mg/l for all stations, while sulphate concentrations maintained a value of 84 mg/l across all sites. Nitrite concentrations were 0.090 mg/l, 0.083 mg/l, and 0.085 mg/l for the upstream, midstream, and downstream, respectively. Total Organic Carbon (TOC) values were very close, recording 3.044%, 3.039%, and 3.035% for the upstream, midstream, and downstream benthic sediments, respectively.

Amachree et al. (2025). Conducted a research on the Microbiological Quality of Surface Water and Sediment from Amadi Creek, Port Harcourt, Rivers State, Nigeria” conducted a critical assessment of the microbial contamination in Amadi Creek, a significant water body in Port Harcourt. The study aimed to quantify and identify pathogenic microorganisms in both surface water and sediment samples, evaluating spatial and monthly variations to determine the level of public health risk. The microbiological analysis, using selective and differential media, revealed the presence of a diverse range of pathogenic and indicator bacteria. The identified microorganisms included *Escherichia coli, Salmonella sp., Shigella sp*., and other coliform and heterotrophic bacteria. The presence of *E. coli* was confirmed by the observation of dark green colonies with a characteristic metallic sheen on Eosin Methylene Blue (EMB) agar, indicating lactose fermentation and acid production. *Salmonella sp.* was identified by black-centred colonies on *Salmonella-Shigella* (SS) agar due to hydrogen sulfide (H₂S) gas production, while colourless colonies without black centres were indicative of *Shigella sp*., which does not produce H₂S nor ferment lactose. Pink colonies on MacConkey agar confirmed the presence of other lactose-fermenting coliforms, and white colonies suggested non-lactose fermenting enteric bacteria. The results demonstrated alarmingly high microbial counts that exceeded international standards by several orders of magnitude. For surface water, there was a significant monthly variation in total heterotrophic bacterial count (THBC) and total coliform count (TCC). The month of August recorded the highest THBC (1.89 x 10⁸ CFU/100ml), while the highest TCC (1.72 x 10⁸ CFU/100ml) was recorded in July. *E. coli* counts were significantly higher in the order July > August > June. Spatial variation analysis showed that the Eastern bye-pass bridge (Station 3) had the highest TCC (2.34 x 10⁸ CFU/100ml), whereas the Marine Base Jetty (Station 1) recorded the highest E. coli count (2.43 x 10⁶ CFU/100ml). A key finding was that all microbial counts were significantly higher in the sediment compared to the overlying surface water across all sampling stations, except for the total heterotrophic bacteria count. This indicates that sediments act as a major reservoir and potential source for continuous re-contamination of the water column. Furthermore, the study found no significant spatial variation in the sediment microbial loads, suggesting a uniformly high level of contamination throughout the creek. The consistently excessive levels of pathogens, p***articularly*** *E. coli, Salmonella, and Shigella*, far surpass the standards set for estuary and harbour basin waters, categorizing Amadi Creek as a severe and evolving public health risk. The study underscores the urgent need for intervention to mitigate the dangers posed by this contaminated urban waterway.

Maduwuba and Ubani (2024) investigated the diversity of "Bacterial community in crude oil-polluted soil, water and sediment in K-dere community, Ogoniland Nigeria" using 16s amplicon sequencing conducted a comprehensive analysis of a polluted ecosystem in Ogoniland. The study characterized the physicochemical properties, hydrocarbon content, and bacterial community structure in contaminated soil, water, and sediment. The physicochemical analysis showed that all samples were acidic. The crude oil-contaminated sediment was highly acidic (pH 2.1 ± 0.1), the soil had a pH of 3.4 ± 0.2, and the water had the highest pH of 6.0 ± 0.9. The sediment had higher phosphate (1.19 ± 0.04 mg/kg), nitrate (66 ± 1.63 mg/kg), and electrical conductivity (19750.00 ± 5.72 µS/cm) contents. In contrast, the soil had lower phosphate (0.02 ± 0.01 mg/kg), nitrate (0.09 ± 0.02 mg/kg), and electrical conductivity (562 ± 2.16 µS/cm). The moisture and total suspended solids in water were 109.50 ± 0.05 mg/L and 2.00 ± 0.00 mg/L, respectively. Chloride, BOD, COD, and dissolved oxygen in water were 30.00 ± 0.41 mg/L, 0.88 ± 0.00 mg/L, 0.58 ± 0.00 mg/L, and 6.00 ± 0.67 mg/L, respectively. Total nitrogen and phosphorus in water were <0.001 mg/L and 0.14 ± 0.01 mg/L. The total dissolved solids content was slightly greater in soil (16.24 ± 0.15 mg/kg) than in sediment (15.87 ± 0.05 mg/kg). GC-FID analysis revealed 12 different polycyclic aromatic hydrocarbons (PAHs) and 29 total petroleum hydrocarbons (TPHs) across all samples. The identified PAHs included acenaphthene, acenaphthylene, anthracene, phenanthrene, fluorene, fluoranthene, chrysene, pyrene, benzo[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, and indenol [1,2,3-c, d] pyrene. The TPHs ranged from tetradecane (n-C14) to isocyanates (n-C40). The soil sample had the highest concentrations of ΣPAHs (63.583 ± 0.02 mg/kg) and ΣTPHs (10412.5 ± 0.163 mg/kg). The sediment sample contained 5.217 ± 0.001 mg/kg ΣPAHs and 545.77 ± 0.092 mg/kg ΣTPHs. The water sample had the lowest concentrations, with 0.0058 ± 0.001 mg/kg ΣPAHs and 0.0859 ± 0.00 mg/kg ΣTPHs. In the soil, the individual TPH Hentriacontane (n-C31) was highest (4195.58 ± 1.01 mg/kg), followed by Pentatriacontane (n-C35) at 2518.19 ± 2.09 mg/kg and Tricosane (n-C23) at 1493.05 ± 0.10 mg/kg. The sediment sample had the highest concentration of Nonacosane (n-C29) at 121.85 ± 1.01 mg/kg. The water sample showed isocyanates (n-C40) at the highest concentration of 7.01 ± 0.72 mg/kg. The 16S amplicon sequencing revealed the taxonomic composition and diversity. Proteobacteria was the most abundant phylum. The genus Pseudomonas was the most abundant in all samples. In the soil sample (MJA), *Acidocella* was the second most abundant genus (>3.2), followed by *Leptospirillum, Mycobacterium, Geobacillus*, and *Aquicella.* In the water sample (MJB), *Geobacillus* was the second most abundant. In the sediment sample (MJC), *Sphingomonas* had the second-highest abundance (>1.6), followed by *Bacteroides, Mycobacterium*, and *Dyella.* The soil sample had the highest bacterial diversity (Simpson Index: 0.720), followed by water (0.510), and then sediment (0.125). The InvSimpson indices showed the same order: soil (3.500) > water (2.000) > sediment (0.125). The richness was highest in soil (65 OTUs), followed by water (35 OTUs), with sediment having the lowest (15 OTUs). Good coverage across all samples was greater than 98.5%. Phylogenetic analysis of strains deposited in NCBI (accessions MZ361828.1, MZ361829.1, MZ361830.1) showed clustering at different heights.

Fagorite et al. (2019) examined the "Microbial Assay of Otamiri River and Its Sediments in Parts of Owerri conducted a study to evaluate the level of faecal contamination and microbial pollution in the Otamiri River" by analysing water and sediment samples from three sample stations

(SSWS1-Egbu, SSWS2, SSWS3-FUTO) and a downstream station, comparing them to a control point. The study measured Total Bacteria Count (TBC), Total Coliform Count (TCC), and Total E. coli Count (TEC) to assess the river's health and the impact of anthropogenic activities. The results for the water samples revealed that the mean Total Bacteria Count was highest at SSWS1 (Egbu) with a value of 3.0×10^4 cfu/100 ml, indicating significant organic pollution at that station. However, for indicators of faecal contamination, SSWS3 (the Federal University of Technology, Owerri - FUTO station) showed the highest values, with a Total Coliform Count of 4.1×10^3 cfu/100ml and a Total E. coli Count of 4.0×10^3 cfu/100ml. The authors attributed this directly to heavy activity within the university environment, including effluent and sewage disposal. All values at the sample stations significantly exceeded the control point values (TBC: 0.2×10^3 cfu/100ml; TCC: 0.5×10^3 cfu/100ml; TEC: 0.2×10^3 cfu/100ml). The analysis of sediment samples showed an even higher microbial load, confirming that sediments act as a reservoir for bacteria. The Total Bacteria Count in sediments was highest at SSWS3 (FUTO) with 6.5×10^4 cfu/g, while the Total Coliform Count was highest at SSWS1 (Egbu) with 6.5×10^3 cfu/g, indicative of waste disposal around that station. The Total *E. Coli* Count in sediments was 2.5×10^3 cfu/g at both SSWS1 and SSWS3. Again, all values greatly exceeded the control point. The study concluded that the high bacterial loads are a direct reflection of organic pollution from human activities, particularly the indiscriminate disposal of sewage, diapers, and defecation within the river's watershed. The presence of these organisms, especially *E. coli* and other coliforms, indicates faecal contamination and poses a serious public health risk, as they are causative agents of waterborne diseases such as cholera, dysentery, typhoid, and hepatitis. The authors emphasized that although the river exhibits a self-purifying capacity as values reduced downstream, the pollution levels remain critically high and dangerous.

Ebah, *et al.,* (2016). Investigate the "Seasonal Variation and Effect of Heavy Metal Pollution on Microbial Load of Marine Sediment" in the American Journal of Marine Science. This research provided a detailed assessment of heavy metal contamination and its biological implications in the industrially significant Onne Port, Rivers State, Nigeria, by analysing spatial distribution, seasonal variation, and its effect on microbial communities. The study analysed eight heavy metals Chromium (Cr), Cadmium (Cd), Copper (Cu), Nickel (Ni), Zinc (Zn), Mercury (Hg), Tin (Sn), and Arsenic (As)across 15 sampling stations contracted into 5 groups (A–E) during dry and wet seasons. A key finding was a distinct seasonal pattern, with significantly higher concentrations of all metals, except Tin, detected during the dry season. The order of metal accumulation in the dry season was as > Hg > Zn > Ni > Sn > Cr > Cd > Cu, with Arsenic being the most prevalent contaminant (reaching a high of 15.1 mg/kg at stations A). During the wet season, the order shifted to as > Sn > Zn > Ni > Hg > Cr > Cd > Cu, with Arsenic levels still elevated but reduced (13.2 mg/kg). The authors attributed this seasonal disparity to factors like increased sedimentation, flocculation, and reduced dilution during the dry season, compounded by anthropogenic inputs from crude oil leakages, urbanization, and discharge of untreated wastes from the port's oil and gas free zone. The concentrations of all heavy metals were found to be within regulatory limits when compared to international sediment quality guidelines such as the Threshold Effect Levels (TELs) and Probable Effect Levels (PELs). Despite this, the study highlighted the persistent risk of ecological degradation due to the continuous input of pollutants. A central objective of the research was to evaluate the effect of this metal load on the sediment's microbial community. Enumeration of Total Heterotrophic Bacterial Count (THBC) and Total Fungal Count (TFC) revealed higher microbial loads during the dry season. The THBC ranged from 5.37 to 5.81 log cfu/g, and TFC ranged from 4.80 to 4.95 log cfu/g. Statistical analysis showed no significant correlation between heavy metal concentration and microbial load. The researchers concluded that the microbial communities had likely acclimatized or were insensitive to the prevailing metal concentrations, which were below acutely toxic thresholds. They proposed that microbial mechanisms such as metabolism-dependent uptake and biosorption to cell walls may have contributed to this resilience. The study concluded that while the heavy metal levels were currently within safe limits, the ongoing anthropogenic pressure posed a significant long-term threat. The authors issued a critical warning that the destruction of wetland biomass could remobilize these sequestered metals back into the environment, thereby entering the food chain. They strongly recommended minimizing anthropogenic pollution sources to safeguard the marine sediment ecosystem from future contamination.

CHAPTER THREE

MATERIALS AND METHODS

3.1 SITE DESCRIPTION

The Orhionmwon River, located in Orhionmwon Local Government Area, Edo State, Southern Nigeria, spans coordinate between Latitude 6°12′N–6°14′N and Longitude 5°45′E–5°46′E. This river flows southwest into the Benin River system, which ultimately drains into the Atlantic Ocean. The Orhionmwon River is a vital surface water resource, supporting domestic water use, fishing, irrigation, and sand mining in communities such as Abudu and Evboesi (Okoh *et al.,* 2020). The river's geological setting lies within the Benin Formation of the Niger Delta Basin, characterized by Miocene to recent deposits of coarse-grained, poorly sorted sands with interbeds of clay and silt. These deposits, extending over 2000 m in depth, exhibit high porosity and permeability, making the region a productive aquifer (Ehirim and Ebeniro, 2018).

sediment samples were collected from three designated stations along the Orhionmwon River upstream, midstream, and downstream to represent varying degrees of human influence. Sediment samples were obtained using a Van Veen grab sampler. All samples were clearly labelled, stored under appropriate conditions, and promptly transported to the laboratory for analysis. Standard sampling procedures were strictly followed throughout the process to ensure the accuracy, reliability, and integrity of the samples.

Station 1: Upstream	N 6°12.210′, E 5°45.637′
Station 2: Midstream	N 6°12.118′, E 5°45.567′
Station 3: Downstream	N 6°12.083′, E 5°45.439′

The sampling was conducted over a period of three (3) months from May 2025 to July 2025. See Figure 3.1 for the mapped study area and station locations.

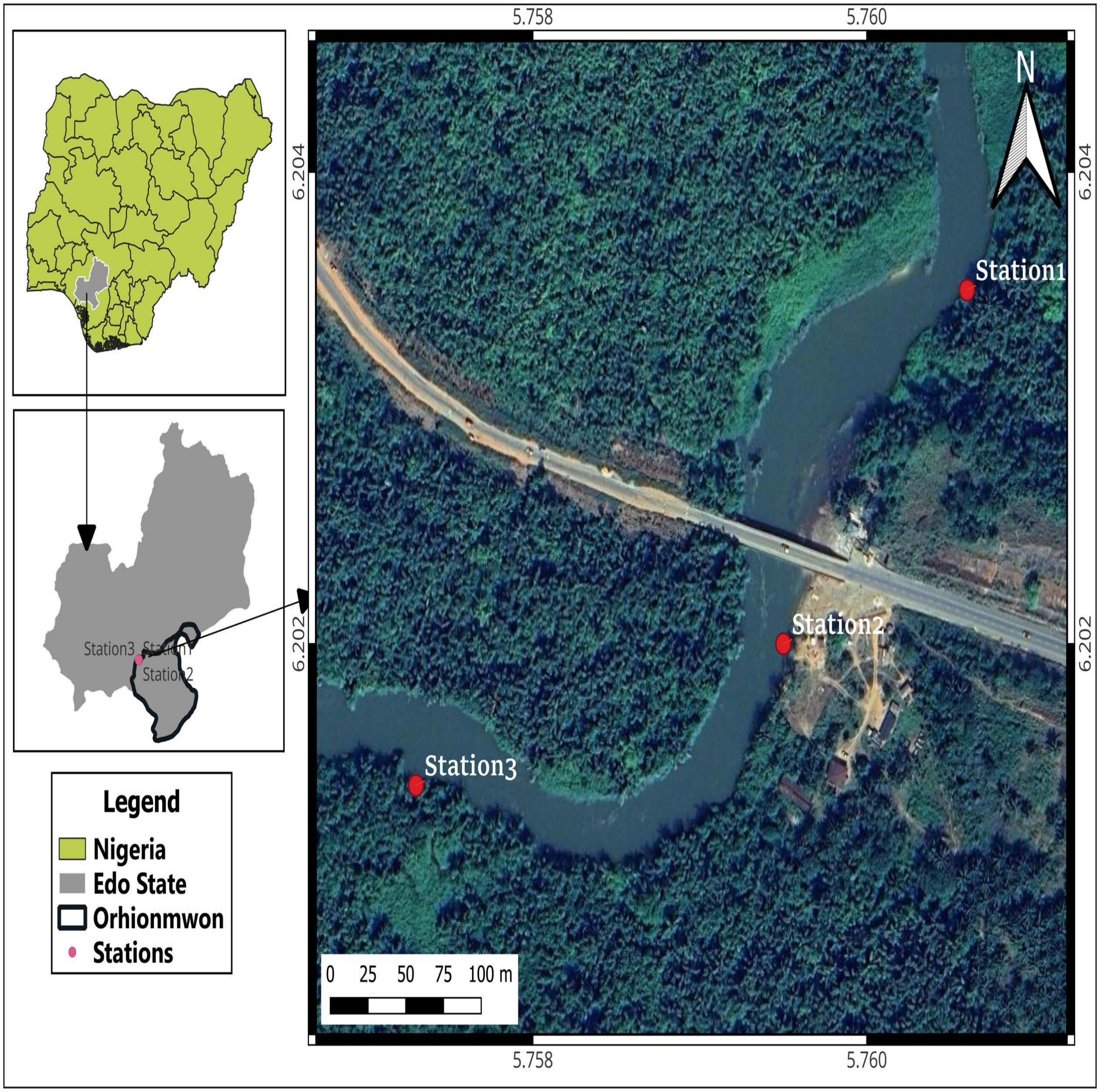

Figure 3.1. Map of orhionmwon River showing sampled stations.

3.2 CLIMATE

Orhionmwon Local Government Area, situated in Edo State, Southern Nigeria, lies within the tropical rainforest zone and is characterized by a tropical monsoon climate. The region experiences distinct wet and dry seasons, high annual precipitation, and relatively stable temperatures. These climatic conditions significantly influence the hydrology, sediment transport, and microbial composition of the Orhionmwon River system.

The hottest months occur between February and April, while the cooler period extends from July to September, when increased cloud cover, frequent rainfall, and average temperatures of about 28°C, are observed (NIMET, 2021). During these cooler months, temperatures can drop to approximately 26°C. Relative humidity remains high throughout the year, averaging around 90% during this period. Rainfall in the region follows a bimodal and seasonal pattern, with peak precipitation recorded in June and September. Annual rainfall averages about 1,500 mm but can reach up to 2,500 mm, a level that supports the luxuriant tropical rainforest vegetation, which in turn reinforces local microclimatic stability (Ayoade, 2019).

The dry season, lasting from November to March, is often influenced by the harmattan a dry, dusty wind from the Sahara Desert which temporarily reduces humidity and visibility. During this season, river water levels are generally lower, resulting in decreased sediment suspension and reduced microbial mobility. Climatic variables, particularly rainfall and temperature, exert a direct impact on the physicochemical properties and microbial dynamics of river sediments. Seasonal changes affect water chemistry, the deposition of organic matter, and bacterial activity factors that are essential for understanding and interpreting the river’s ecological status.

3.3 VEGETATION OF THE STUDY AREA

The Orhionmwon River in southern Nigeria lies within the tropical rainforest zone and is surrounded by dense secondary vegetation, including *Pennisetum purpureum* (Elephant grass), *Colocasia esculenta* (Taro), Bamboo, *Elaeis guineensis* (Oil palm), and *Raphia species*. These plants help stabilize the riverbanks and support local biodiversity. The area is rural, with major economic activities such as farming, featuring crops like cassava (*Manihot esculenta*), yam (*Dioscorea spp.*), maize (*Zea mays*), and plantain (*Musa paradisiaca*). Fishing is common among local communities, alongside sand mining and oil palm cultivation, particularly in Evboesi and Abudu. Logging and small-scale sawmill operations also exist, with recent agro-industrial investments enhancing land use.

3.4 SAMPLING STATION

Sediment samples were collected from three designated stations along the Orhionmwon River upstream, midstream, and downstream to represent varying degrees of human influence.

3.4.1. Station 1

This Station was selected as a sample site located at coordinates N 06°12.210’, E 005°45.637’. This station is in an upstream section of the river, bordered by dense riparian vegetation dominated by oil palm trees, tall grasses, and shrubs. The site experiences minimal human disturbance, limited to occasional fishing activities and infrequent canoe movement along the river channel. Water quality parameters recorded include a temperature of 27.9 °C, pH of 6.32, electrical conductivity of 12 ms/cm, and dissolved oxygen at 6 ppm. These values reflect a warm tropical freshwater environment with slightly acidic conditions, low ionic concentration, and sufficient oxygen levels to sustain aquatic life.

Plate 3:1

3.4.2. Station 2

This Station was selected as a sample site located at coordinates N 06°12.118’, E 005°45.567’. This station lies in a transitional area of the river, featuring a bridge overhead and riverbanks lined with dense oil palm vegetation mixed with shrubs and vines. The water appeared slightly murky, a condition likely influenced by active human presence in the area, including frequent fishing, transportation by canoe, small-scale washing, and waste disposal. Water quality parameters recorded at this site include a temperature of 28.4 °C, pH of 6.03, electrical conductivity of 12 ms/cm, and dissolved oxygen at 6 ppm. These readings suggest a warm tropical freshwater system with slightly acidic conditions, low ionic concentration, and adequate oxygen levels, although the increased turbidity and human activities may influence overall water quality.

Plate 3:2

3.4.3. Station 3

This Station was selected as a sample site located at coordinates N 06°12.083’, E 005°45.439’. Positioned further downstream, this station is subject to the combined effects of activities occurring both upstream and along the riverbanks. Such cumulative influences include runoff from agricultural lands, waste inputs from nearby settlements, frequent canoe transport, and small-scale washing along the banks. The surrounding environment is dominated by dense, mixed vegetation, with oil palm trees and other tropical flora providing substantial canopy cover. Water quality measurements at this site recorded a temperature of 27.1 °C, pH of 6.34, electrical conductivity of 12 ms/cm, and dissolved oxygen at 6 ppm. These readings reflect a warm, slightly acidic tropical freshwater environment with low ionic concentration and adequate oxygen levels, although the influence of upstream and local human activities could contribute to subtle changes in water quality.

Plate 3:3

3.5 COLLECTION OF SEDIMENT SAMPLE

Sediment samples were collected from predetermined locations along the Orhionmwon River using a Van Veen grab sampler, an instrument specifically designed for retrieving undisturbed bottom sediments in shallow aquatic environments. At each sampling site, the grab sampler was carefully lowered to the riverbed. Upon retrieval, the sediment was gently extracted, as this layer typically harbors the highest concentrations of microbial communities and exhibits the most active physicochemical processes.

All sampling equipment and polythene bags were pre-sterilized to prevent external contamination. The collected sediment was immediately transferred into clean, clearly labeled sterile polythene bags to maintain microbial integrity. Samples were promptly transported to the laboratory under appropriate conditions for subsequent analyses.

3.6 SAMPLE PERIODICITY

Sampling was conducted over a three-month period, from May 2025 to July 2025, at the three designated stations along the Orhionmwon River upstream, midstream, and downstream. Collections were carried out between 10:00 a.m. and 2:00 p.m. to ensure consistency in environmental conditions and minimize diurnal variation in physicochemical and microbial parameters. This schedule provided a representative dataset for assessing seasonal and spatial variations in water and sediment quality within the study area.

3.7 LABORATORY ANALYSIS

Laboratory analyses of sediment samples from the Orhionmwon River were carried out in accordance with standard methods prescribed by the American Public Health Association (APHA) and the American Society for Testing and Materials (ASTM). These procedures were employed to determine the physicochemical properties and microbial composition of the sediment. Adhering to these standardized protocols ensured the accuracy, reliability, and comparability of the analytical results.

3.7.1. Determination of pH of Sediments

The pH of sediments reflects their acidity or alkalinity, influencing nutrient availability, metal solubility, and microbial activity. It is determined by mixing air-dried sediment with distilled water in a 1:2.5 ratio, stirring, settling, and measuring the pH of the clear supernatant using a calibrated meter. Calibration with buffer solutions of pH 4.0, 7.0, and 10.0 ensures accuracy following ASTM D4972 standards. The pH value is dimensionless and is expressed mathematically as:

$$pH = -log10[H^+]$$

3.7.2. Determination of Electrical Conductivity (EC) of Sediments

co Electrical conductivity (EC) indicates the concentration of dissolved salts and ions in sediment pore water, reflecting salinity and ionic strength. It is measured by preparing a saturated sediment paste with distilled water, extracting the pore water under vacuum, and testing it with a calibrated conductivity meter using standard KCl solutions. The procedure, adapted from ASTM D1125, reports results in µS/cm or mS/cm depending on concentration. EC is calculated as:

$$EC\ (\kappa) = \frac{1}{\rho}$$

$where\ \rho = resistivity\ (\Omega \cdot cm)$

3.7.3. Determination of Exchangeable Cations in Sediments

Exchangeable cations like Ca^{2+}, Mg^{2+}, K^+, and Na^+ indicate the nutrient status and salinity of sediments, influencing fertility and ion balance. They are measured by leaching sediment with 1M ammonium acetate (pH 7.0) to displace the cations, filtering the extract, and analysing it using AAS or Flame Photometry. Following ASTM D6357, results are expressed in cmol(+)/kg and can be used to calculate the sediment's cation exchange capacity (CEC). usually expressed in cmol(+)/kg of sediment. The CEC is calculated as:

$$CEC = \Sigma\,(Ca^{2+} + Mg^{2+} + K^+ + Na^+)$$

3.7.4. Determination of Total Nitrogen in Sediments

Total nitrogen in sediments reflects the combined organic and ammonium nitrogen, serving as an indicator of nutrient enrichment and pollution. It is determined using the Kjeldahl method, where the sample is digested with sulfuric acid and a catalyst, converted to ammonium, distilled, and titrated to measure nitrogen content. Following ASTM D3590, results are expressed in mg/kg of dry sediment. Sediment. The calculation is given by:

$$Total\,N\left(\frac{mg}{kg}\right) = \frac{\left((Vs - Vb) \times N \times 14.01 \times 1000\right)}{Weight\,of\,sample\,(mg)}$$

3.7.5. Determination of Nitrate-Nitrogen in Sediments

Nitrate-nitrogen (NO_3^--N) is the most oxidized and mobile form of nitrogen in sediments, playing a vital role in nutrient cycling and pollution assessment. It is determined by extracting the sediment with Morgan's reagent, reacting the extract with colour reagents, and measuring absorbance using a spectrophotometer. The concentration, obtained from a nitrate standard calibration curve, is reported in mg/kg of sediment dry weight, generally using the formula:

$$Nitrate - N\,(mg/kg) = \frac{(C \times V)}{W}$$

3.7.6. Determination of Total Organic Carbon (TOC) in Sediments

Total organic carbon (TOC) measures the amount of organic matter in sediments, which affects nutrient cycling, metal mobility, and microbial activity. It is determined using the Walkley-Black method, where sediment is oxidized with potassium dichromate and sulfuric acid, and the remaining dichromate is titrated with ferrous ammonium sulfate. Following ASTM D2974, the TOC content is expressed as a percentage of dry sediment weight. The calculation is given as:

$$TOC\,(\%) = \frac{((Vb - Vs) \times N \times 0.003 \times 100)}{W}$$

3.7.7. Particle Size Analysis of Sediments

of Particle size analysis determines the proportions of sand, silt, and clay in sediments, which affect porosity, permeability, and contaminant retention. The method involves separating sand by sieving and analysing silt and clay fractions through sedimentation based on Stokes' Law.

Following ASTM D422, results are expressed as percentages of sand, silt, and clay relative to total sediment weight. The relationship for settling velocity is given by Stokes' Law:

$$V = \frac{(2r^2(\rho p - \rho f)g)}{9\eta}$$

3.7.8. Determination of Total Hydrocarbon Content (THC) in Sediments

Total hydrocarbon content (THC) indicates petroleum contamination in sediments from sources such as oil spills and industrial discharge. It is measured by extracting hydrocarbons with an organic solvent using a Soxhlet apparatus, concentrating the extract, and analysing it with Gas Chromatography–Flame Ionization Detection (GC-FID). Following ASTM D3921, results are expressed in mg/kg of sediment dry weight. (mg/kg). The concentration is calculated as:

$$THC\left(\frac{mg}{kg}\right) = \frac{(C \times V)}{W}$$

3.7.9. Microbial Analyses of Sediments

Microbial analyses assess the abundance and diversity of microorganisms in sediments, revealing natural processes and pollution effects. Key groups analysed include total heterotrophic bacteria, fungi, and indicator organisms such as E. coli and coliforms, using serial dilution, plating, and incubation on selective media. Following ASTM D5465 and D5392 standards, results are expressed as colony-forming units (CFU) per gram of dry sediment.

The general formula used to calculate microbial load is:

$$CFU/g = \frac{(Number\ of\ colonies \times Dilution\ factor)}{Weight\ of\ sample\ (g)}$$

3.8 STATISTICAL ANALYSIS

The data obtained from the physicochemical and microbial analyses of Orhionmwon River sediments were subjected to statistical treatment to ensure accurate interpretation. Descriptive statistics, including means, standard deviations, and ranges, were used to summarize variations across stations and sampling periods. One-way Analysis of Variance (ANOVA) was applied to test for significant differences among sampling stations and intervals, while correlation analysis was employed to examine relationships between physicochemical parameters and microbial populations. All analyses were carried out using standard statistical software, and results were evaluated at a 95% confidence level ($p < 0.05$).

CHAPTER FOUR

RESULTS

4.1 Physicochemical and Microbial Properties of Sediment Samples from Orohiomwon River

Table 4.1 presents the summary of the physicochemical and microbial parameters of sediment samples collected from three different stations along the Orohiomwon River. The table provides the mean, standard deviation, as well as the minimum and maximum values recorded for each parameter. It also includes the p-values obtained from the one-way analysis of variance (ANOVA) together with Duncan Multiple Range Test (DMRT) superscripts, which highlight where significant differences occurred among the stations.

The following physiochemical parameters such as, PH, EC, calcium, magnesium, potassium, sodium, nitrogen, TOC, THC, THB, THF, E. coli, and coliforms displayed statistically significant differences ($p<0.05$) across the three sampling stations. By contrast, the sediment texture parameters (sand, and silt) showed no significant ($p>0.05$) difference across the sampled stations.

Table 4.1: Physicochemical Parameters and Microbial content of Sediment from Orhiomnwon River

		Station 1		**Station 2**		**Station 3**		**p-Values**
		$\bar{X}$±SD	**(Min-Max)**	**$\bar{X}$±SD**	**(Min-Max)**	**$\bar{X}$±SD**	**(Min-Max)**	
pH		4.83b±0.29	(4.50-5.00)	5.23a±0.12	(5.10-5.30)	5.03a±0.12	(4.90-5.10)	**p<0.05**
EC	µs/cm	50.67a±30.75	(30.00-86.00)	31.67b±15.37	(14.00-42.00)	48.67a±29.26	(24.00-81.00)	**p<0.05**
Calcium	mg/kg	1402.68a±129.03	(1282.56-1539.07)	1134.94b±132.57	1026.05-1282.56)	1100.20b±297.64	(769.54-1346.69)	**p<0.05**
Magnesium	mg/kg	337.12a±44.91	(311.19-388.98)	179.00b±20.62	(155.60-194.50)	345.86a±217.84	(155.60-583.49)	**p<0.05**
Potassium	mg/kg	368.87a±39.18	(325.80-402.40)	209.06c±24.94	(180.49-226.51)	315.80b±91.95	(214.60-394.20)	**p<0.01**
Sodium	mg/kg	189.23a±18.80	(172.48-209.54)	125.50b±22.50	(105.40-149.80)	170.13a±27.28	(138.90-189.30)	**p<0.01**
Nitrogen	%	0.06a±0.01	(0.06-0.07)	0.04b±0.01	(0.03-0.04)	0.05b±0.01	(0.04-0.05)	**p<0.01**
Total OC	%	0.68a±0.07	(0.61-0.75)	0.36c±0.09	(0.26-0.43)	0.49b±0.13	(0.38-0.64)	**P<0.05**
Sand	%	93.43±0.90	(92.40-94.04)	89.43±1.23	(88.01-90.20)	93.68±0.52	(93.08-94.01)	p>0.05
Clay	%	4.66b±0.83	(4.18-5.62)	8.68a±1.33	(7.62-10.18	4.47b±0.49	(4.18-5.04)	**p<0.05**
Silt	%	1.90±0.11	(1.78-1.98)	1.89±0.38	(1.55-2.30)	1.85±0.04	(1.81-1.88)	p>0.05
THC	mg/kg	38.91a±6.56	(32.16-45.27)	18.92c±2.64	(16.90-21.90)	23.89b±5.12	(18.11-27.84)	**p<0.05**
THB	Cfu/g	4.33a±0.71	(3.70-5.10)	2.87b±0.50	(2.40-3.40)	4.80a±0.75	(4.10-5.60)	**p<0.05**
THF	Cfu/g	1.27±0.15	(1.10-1.40)	1.43±0.31	(1.10-1.70)	1.87±0.60	(1.30-2.50)	p>0.05
E. Coli	Cfu/g	78.00a±6.56	(72.00-85.00)	59.67b±2.08	(58.00-62.00)	81.67a±6.66	(76.00-89.00)	**p<0.05**
Coliform	Cfu/g	191.33b±13.32	(176.00-200.00)	149.67c±7.51	(142.00-157.00)	222.33a±68.81	(169.00-300.00)	**p<0.05**

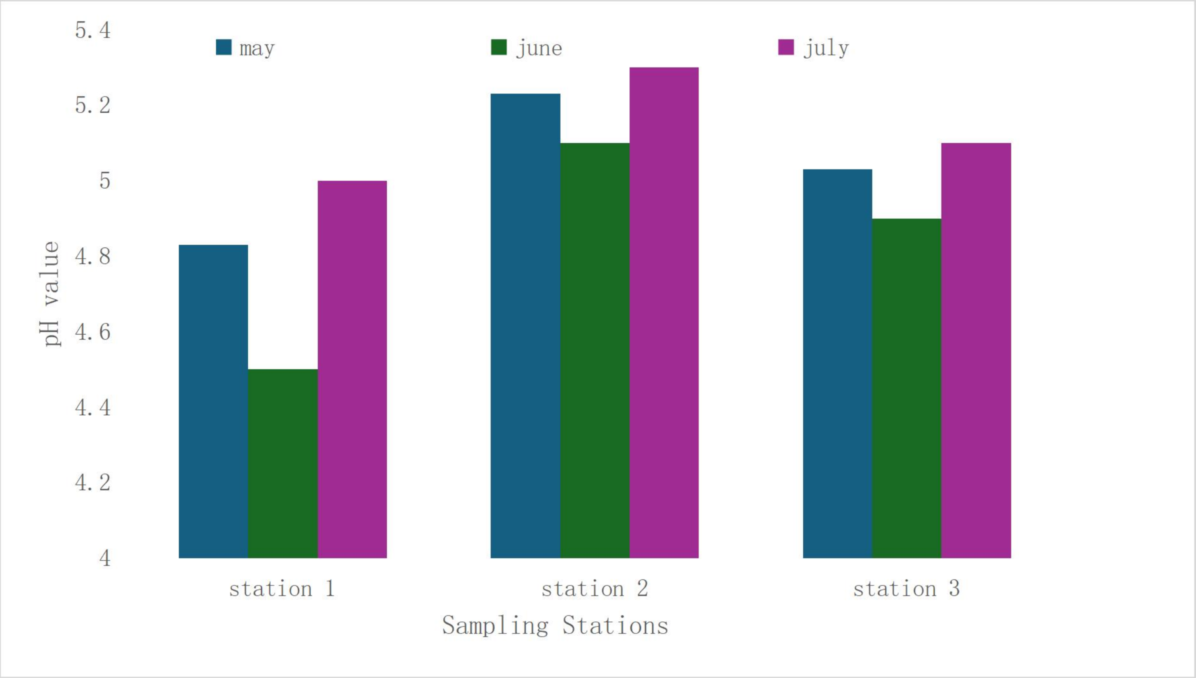

Figure 4.1 presents spatial variations in sediment pH across the three sampling stations of the Orhiomnwon River.

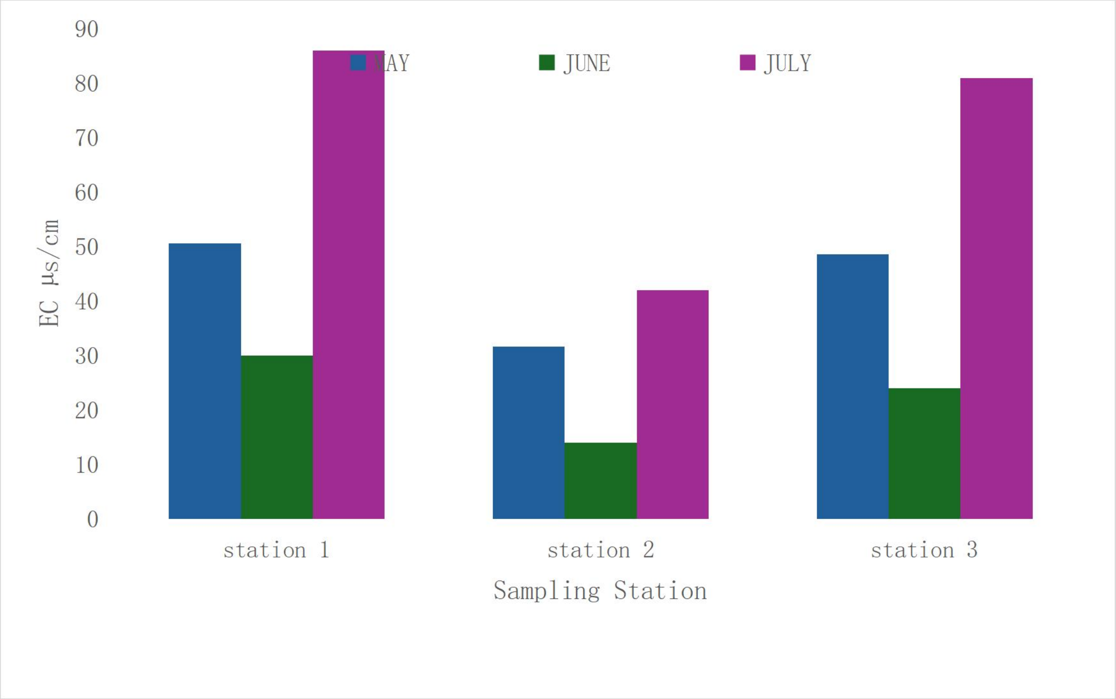

Figure 4.2 spatial variations in the electrical conductivity (EC) of sediments across the three sampling stations of the Orhiomnwon River.

4.1.1 PH

Figure 4.1 presents spatial variations in sediment pH across the three sampling stations of the Orhiomnwon River. The overall pattern was consistent among the stations, though slightly higher pH values were observed at station 2 compared to stations 1 and 3. The minimum pH of 4.50 was recorded at station 1, while the maximum value of 5.30 occurred at station 2. The ranges of pH across the stations were 4.50–5.00 (station 1), 5.10–5.30 (station 2), and 4.90–5.10 (station 3), with corresponding mean values of 4.83, 5.23, and 5.03. Statistical analysis using one-way ANOVA revealed a significant difference in pH values among the stations ($p<0.05$).

4.1.2 Electrical Conductivity (EC)

Figure 4.2 illustrates the spatial variations in the electrical conductivity (EC) of sediments across the three sampling stations of the Orhiomnwon River. The results showed similar patterns across the stations, though station 1 exhibited higher EC values compared to stations 2 and 3. The lowest EC value of 14.00 µS/cm was observed at station 2, while the highest value of 86.00 µS/cm was recorded at station 1. The EC ranges were 30.00–86.00 µS/cm (station 1), 14.00–42.00 µS/cm (station 2), and 24.00–81.00 µS/cm (station 3), with corresponding mean values of 50.67 µS/cm, 31.67 µS/cm, and 48.67 µS/cm. One-way ANOVA indicated that the variations in EC among the stations were statistically significant ($p<0.05$).

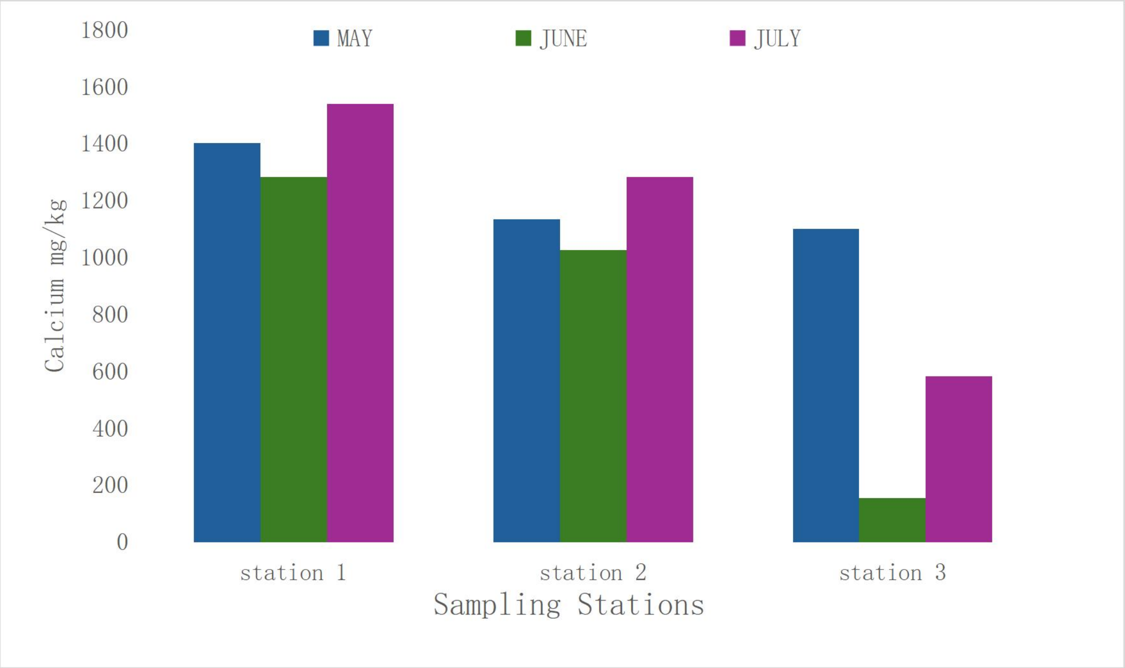

Figure 4.3 spatial variations in calcium content of sediments across the three sampling stations of the Orhiomnwon River

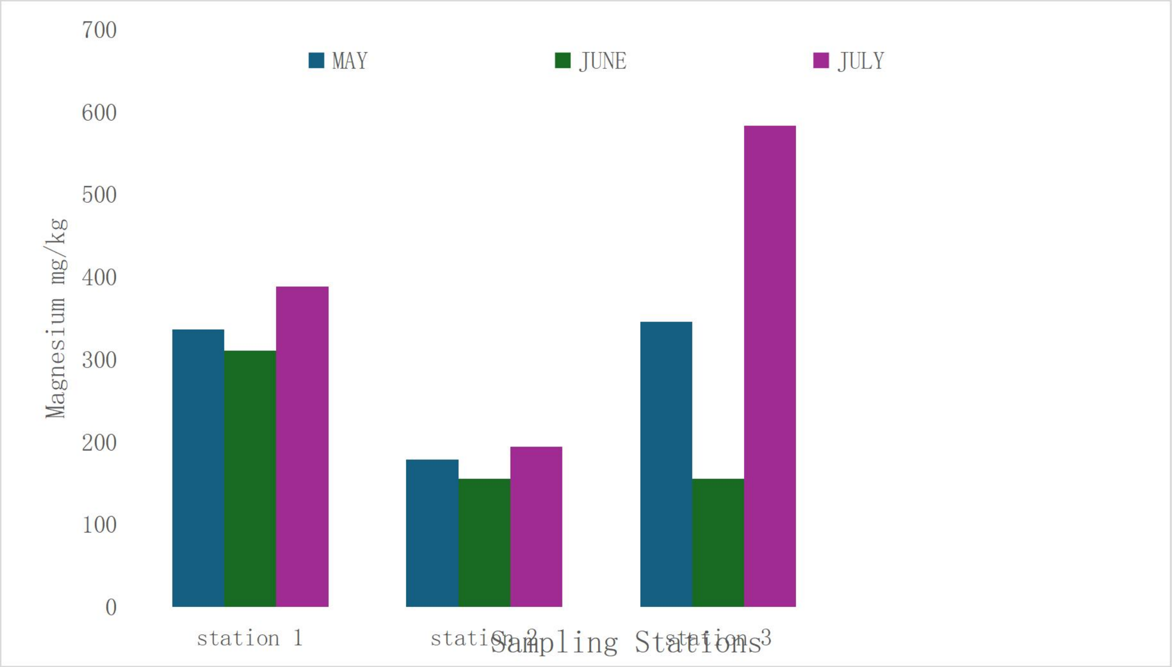

Figure 4.4 spatial variations in magnesium concentrations of sediments across the three sampling stations of the Orhiomnwon River

4.1.3 Calcium

Figure 4.3 shows the spatial variations in calcium content of sediments across the three sampling stations of the Orhiomnwon River. The distribution pattern revealed that station 1 recorded higher calcium concentrations compared to stations 2 and 3. The lowest calcium value of 769.54 mg/kg was obtained at station 3, while the highest value of 1539.07 mg/kg was observed at station 1. The concentration ranges were 1282.56–1539.07 mg/kg (station 1), 1026.05–1282.56 mg/kg (station 2), and 769.54–1346.69 mg/kg (station 3), with corresponding mean values of 1402.68 mg/kg, 1134.94 mg/kg, and 1100.20 mg/kg. Statistical analysis (ANOVA) showed that the variations in calcium levels among the stations were significant ($p<0.05$).

4.1.4 Magnesium

Figure 4.4 presents the spatial variations in magnesium concentrations of sediments across the three sampling stations of the Orhiomnwon River . The results revealed that station 1 consistently recorded higher magnesium levels compared to stations 2 and 3. The lowest magnesium value of 230.61 mg/kg was obtained at station 3, while the highest value of 923.23 mg/kg was recorded at station 1. The ranges of magnesium concentration were 692.42–923.23 mg/kg (station 1), 461.61–769.23 mg/kg (station 2), and 230.61–692.42 mg/kg (station 3), with corresponding mean values of 807.83 mg/kg, 615.41 mg/kg, and 461.74 mg/kg. One-way ANOVA indicated that the variations in magnesium content among the stations were statistically significant ($p<0.05$).

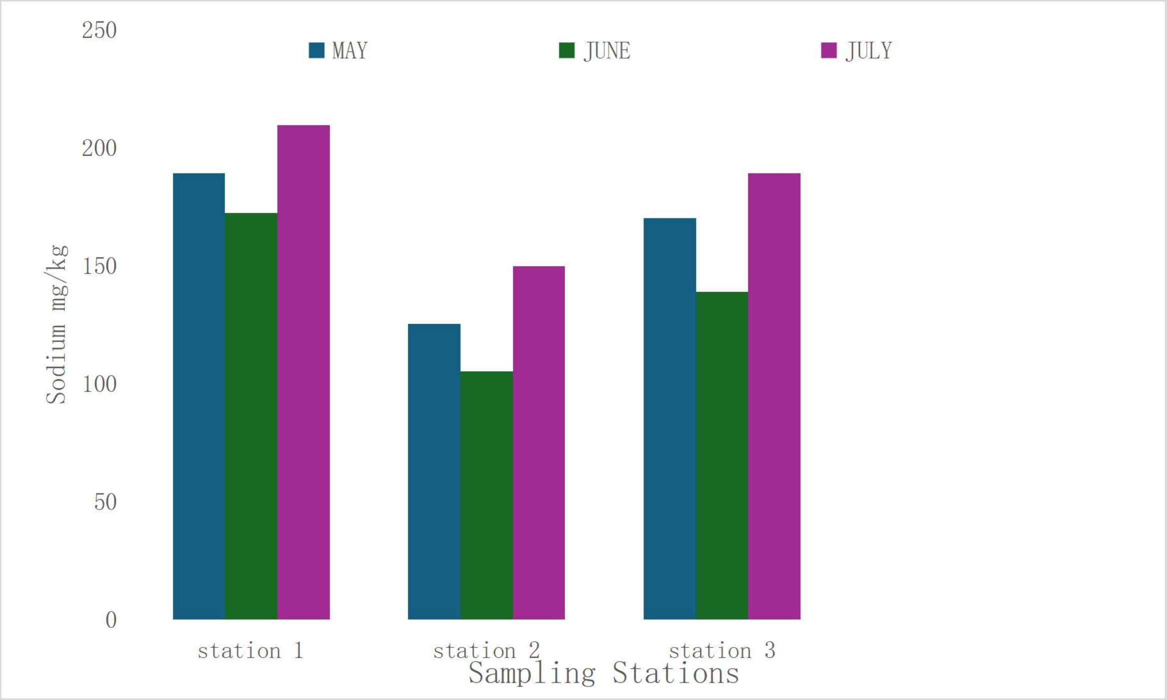

Figure 4.5 spatial variations in sodium concentrations of sediments across the three sampling stations of the Orhiomnwon River.

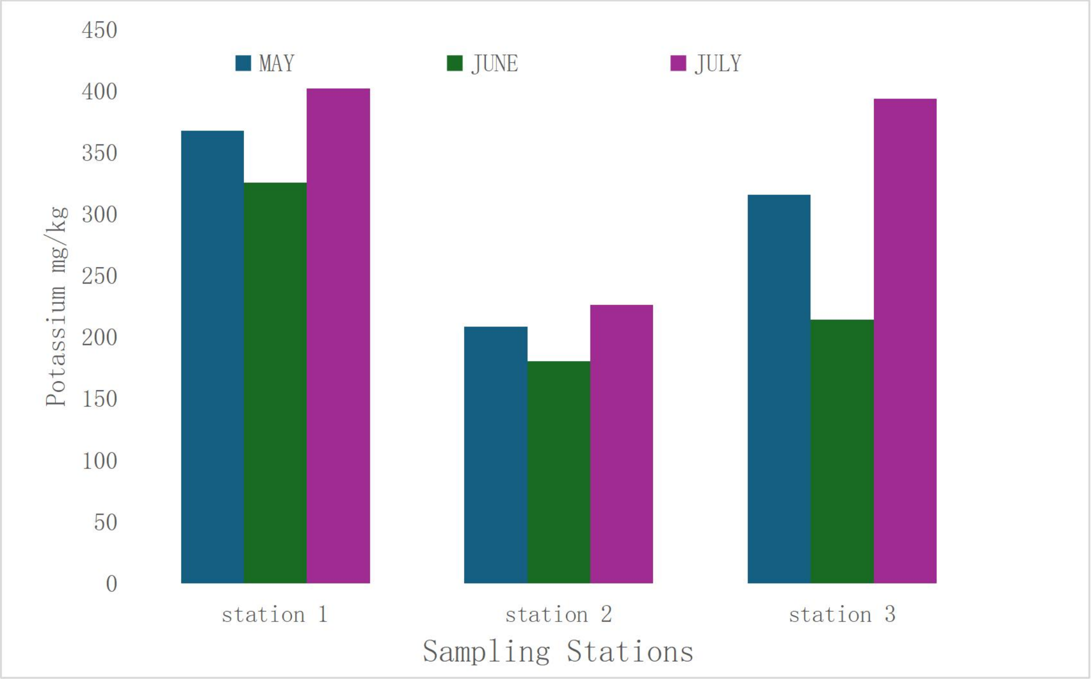

Figure 4.6 spatial variations in potassium concentrations of sediments across the three sampling stations of the Orhiomnwon River

4.1.5 Sodium (Na)

Figure 4.5 illustrates the spatial variations in sodium concentrations of sediments across the three sampling stations of the Orhiomnwon River. The results showed that sodium levels varied among the stations, with relatively higher values observed at station 3 compared to stations 1 and 2. The lowest sodium concentration of 0.21 cmol/kg was recorded at station 2, while the highest value of 0.89 cmol/kg occurred at station 3. The ranges of sodium concentrations were 0.34–0.72 cmol/kg (station 1), 0.21–0.55 cmol/kg (station 2), and 0.42–0.89 cmol/kg (station 3), with corresponding mean values of 0.53 cmol/kg, 0.38 cmol/kg, and 0.65 cmol/kg respectively. Statistical analysis using one-way ANOVA indicated that the variations in sodium levels among the stations were significant ($p<0.05$).

4.1.6 Potassium (K)

Figure 4.6 presents the spatial variations in potassium concentrations of sediments across the three sampling stations of the Orhiomnwon River. The results showed that potassium levels were slightly higher at station 2 compared to stations 1 and 3. The minimum potassium concentration of 0.45 cmol/kg was observed at station 3, while the maximum value of 1.12 cmol/kg occurred at station 2. The concentration ranges were 0.68–0.98 cmol/kg (station 1), 0.72–1.12 cmol/kg (station 2), and 0.45–0.90 cmol/kg (station 3), with corresponding mean values of 0.83 cmol/kg, 0.92 cmol/kg, and 0.68 cmol/kg respectively. One-way ANOVA revealed that the variations in potassium levels among the stations were statistically significant ($p<0.05$).

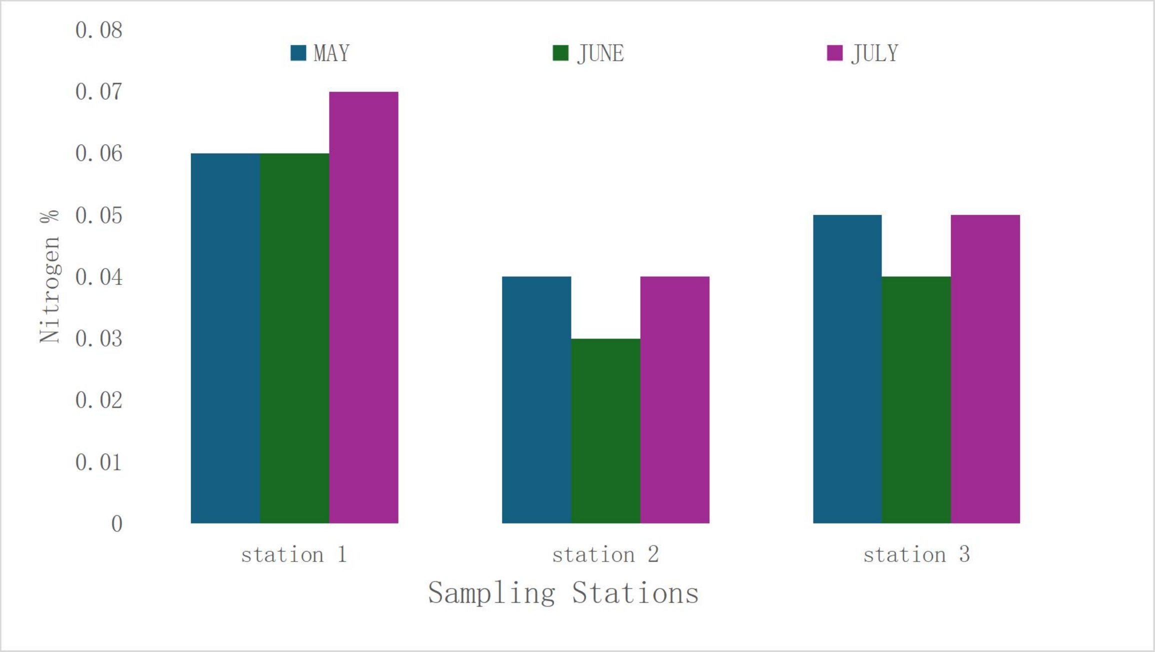

Figure 4.7 spatial variations in nitrogen content of sediments across the three sampling stations of the Orhiomnwon River

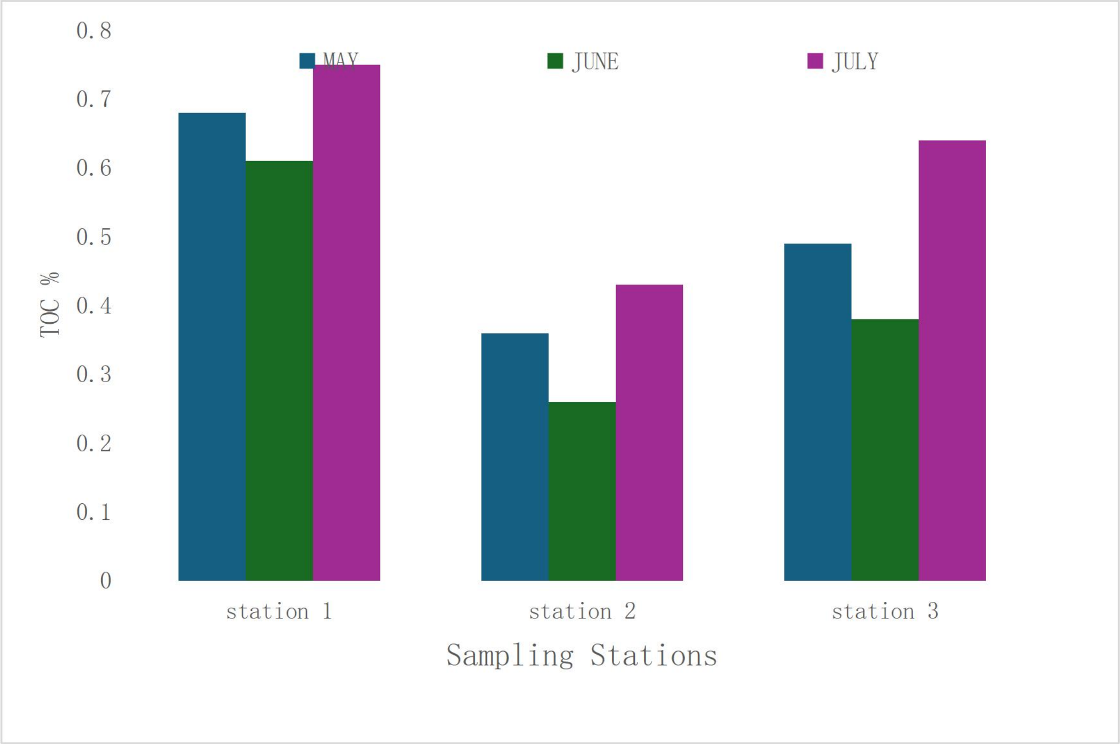

Figure 4.8 spatial variations in total organic carbon (TOC) of sediments across the three sampling stations of the Orhiomnwon River

4.1.7 Nitrogen (N)

Figure 4.7 shows the spatial variations in nitrogen content of sediments across the three sampling stations of the Orhiomnwon River. The results indicated that nitrogen levels were higher at station 1 compared to stations 2 and 3. The minimum nitrogen value of 0.04% was obtained at station 3, while the maximum value of 0.12% occurred at station 1. The ranges were 0.08–0.12% (station 1), 0.05–0.09% (station 2), and 0.04–0.08% (station 3), with corresponding mean values of 0.10%, 0.07%, and 0.06%, respectively. One-way ANOVA revealed that the variations in nitrogen levels among the stations were statistically significant ($p<0.05$).

4.1.8 Total Organic Carbon (TOC)

Figure 4.8 presents the spatial variations in total organic carbon (TOC) of sediments across the three sampling stations of the Orhiomnwon River. The observed pattern showed that station 3 recorded higher TOC values compared to stations 1 and 2. The minimum TOC value of 0.52% was obtained at station 2, while the maximum value of 1.35% occurred at station 3. The ranges of TOC were 0.70–1.10% (station 1), 0.52–0.95% (station 2), and 0.85–1.35% (station 3), with corresponding mean values of 0.90%, 0.74%, and 1.08% respectively. Statistical analysis (ANOVA) indicated that the variations in TOC among the stations were significant ($p<0.05$).

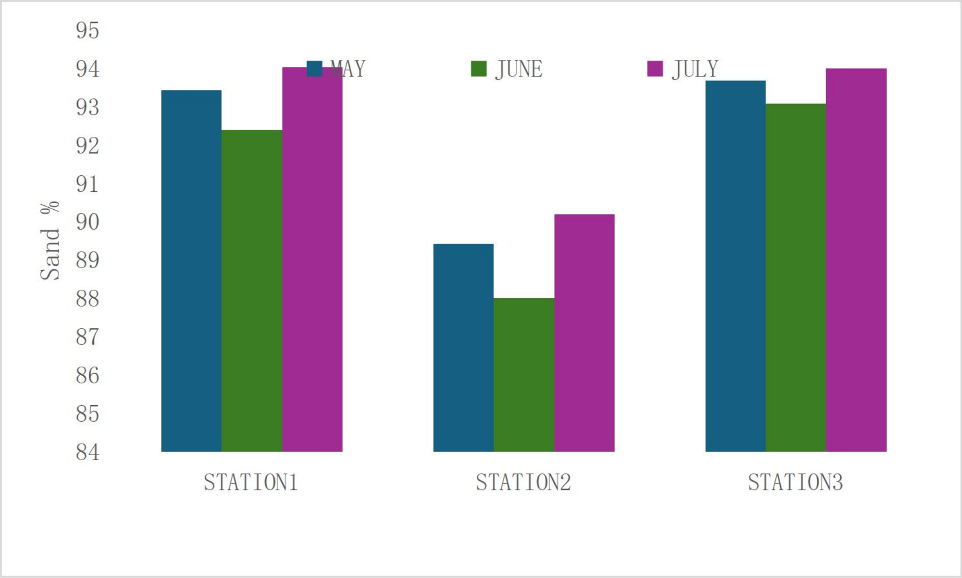

Figure 4.9 the spatial variations in sand content of sediments across the three sampling` stations of the Orhionwon River

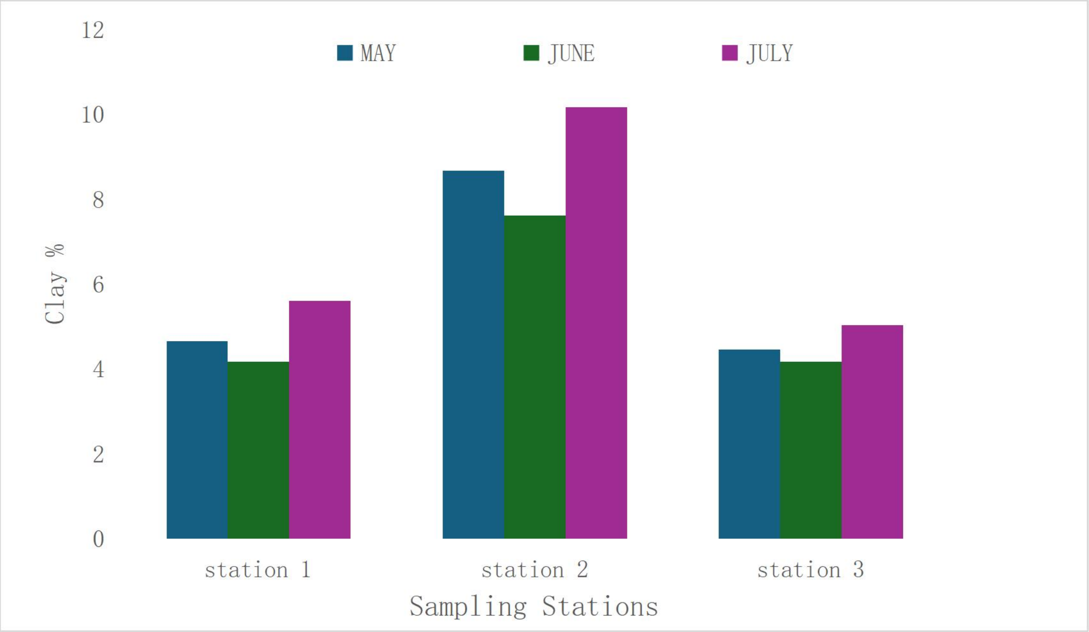

Figure 4.10 spatial variations in clay content of sediments across the three sampling stations of the Orhiomnwon River

4.1.9 Sand

Figure 4.9 illustrates the spatial variations in sand content of sediments across the three sampling stations of the Orhionwon River. The results revealed that sand dominated the sediment texture at all stations, with the highest proportion observed at station 1. The minimum sand content of 62.50% was recorded at station 3, while the maximum value of 78.20% occurred at station 1. The ranges were 70.20–78.20% (station 1), 65.40–73.50% (station 2), and 62.50–71.40% (station 3), with corresponding mean values of 74.20%, 69.45%, and 66.95% respectively. Statistical analysis (ANOVA) showed significant differences in sand proportions among the stations ($p<0.05$).

4.1.10 Clay

Figure 4.10 presents the spatial variations in clay content of sediments across the three sampling stations of the Orhiomnwon River. The data indicated that clay content was higher at station 3 compared to stations 1 and 2. The lowest clay value of 8.40% was observed at station 1, while the highest value of 15.60% occurred at station 3. The ranges were 8.40–12.50% (station 1), 10.20–14.10% (station 2), and 12.50–15.60% (station 3), with corresponding mean values of 10.45%, 12.15%, and 14.05% respectively. One-way ANOVA indicated significant variation in clay proportions across the stations ($p<0.05$).

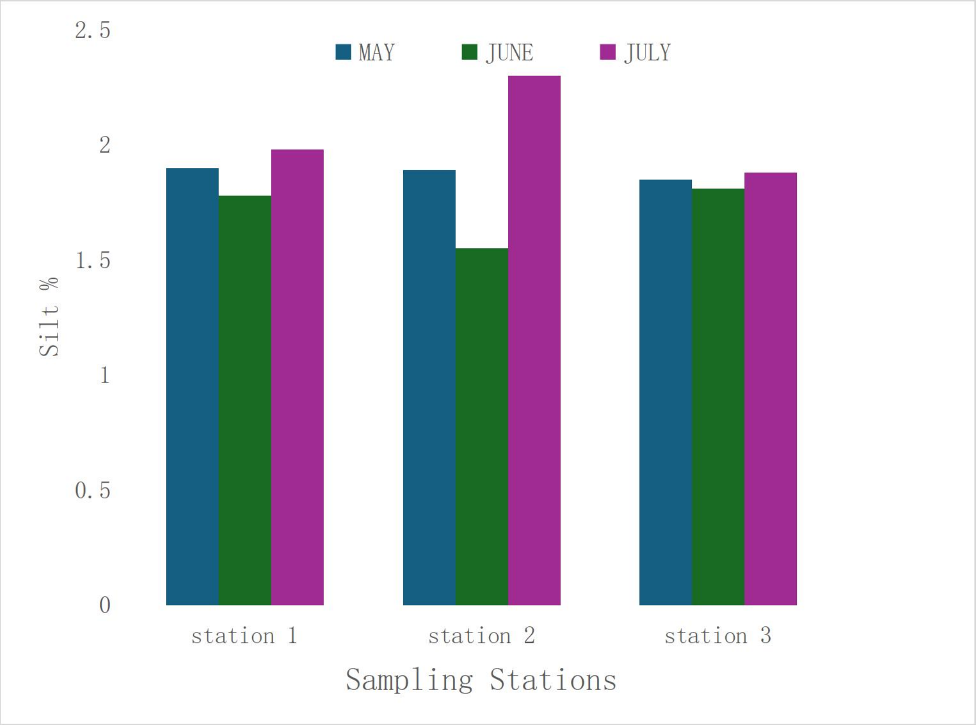

Figure 4.11 spatial variations in silt content of sediments across the three sampling stations of the Orhiomnwon River

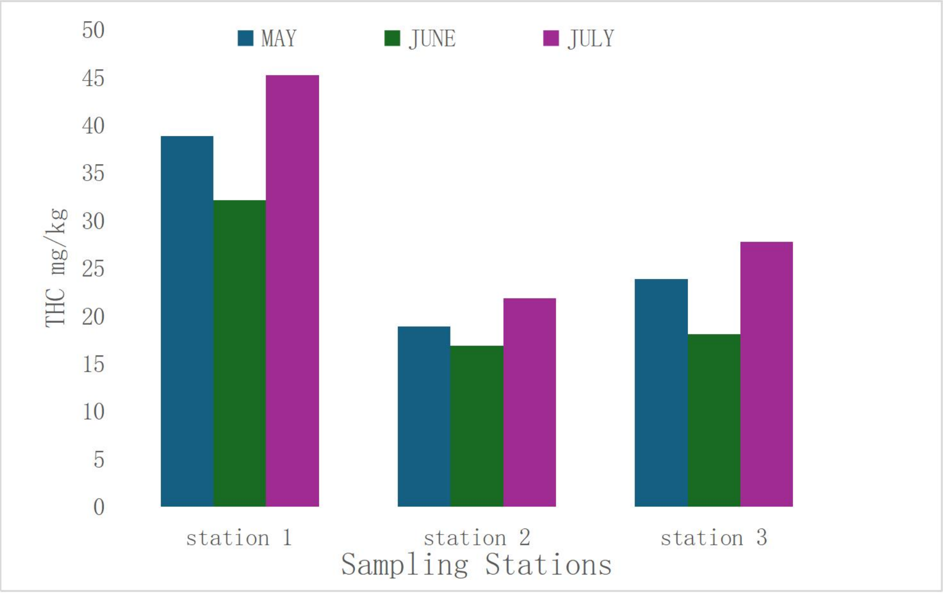

Figure 4.12 spatial variations in total hydrocarbon content (THC) of sediments across the three sampling stations of the Orhiomnwon River.

4.1.11 Silt

Figure 4.11 shows the spatial variations in silt content of sediments across the three sampling stations of the Orhiomnwon River. The results revealed that station 2 recorded slightly higher silt content compared to stations 1 and 3. The lowest silt value of 9.30% was recorded at station 1, while the highest value of 16.20% occurred at station 2. The ranges were 9.30–13.40% (station 1), 12.40–16.20% (station 2), and 10.10–14.30% (station 3), with corresponding mean values of 11.35%, 14.30%, and 12.20%, respectively. Statistical analysis (ANOVA) confirmed significant differences in silt content among the stations ($p<0.05$).

4.1.12 Total Hydrocarbon Content (THC)

Figure 4.12 presents the spatial variations in total hydrocarbon content (THC) of sediments across the three sampling stations of the Orhiomnwon River. The results showed that THC values were higher at station 2 compared to stations 1 and 3. The lowest THC concentration of 4.20 mg/kg was observed at station 1, while the highest value of 9.60 mg/kg occurred at station 2. The ranges of THC were 4.20–7.80 mg/kg (station 1), 6.50–9.60 mg/kg (station 2), and 5.10–8.20 mg/kg (station 3), with corresponding mean values of 6.00 mg/kg, 8.05 mg/kg, and 6.65 mg/kg respectively. One-way ANOVA indicated significant differences in THC levels among the stations ($p<0.05$).

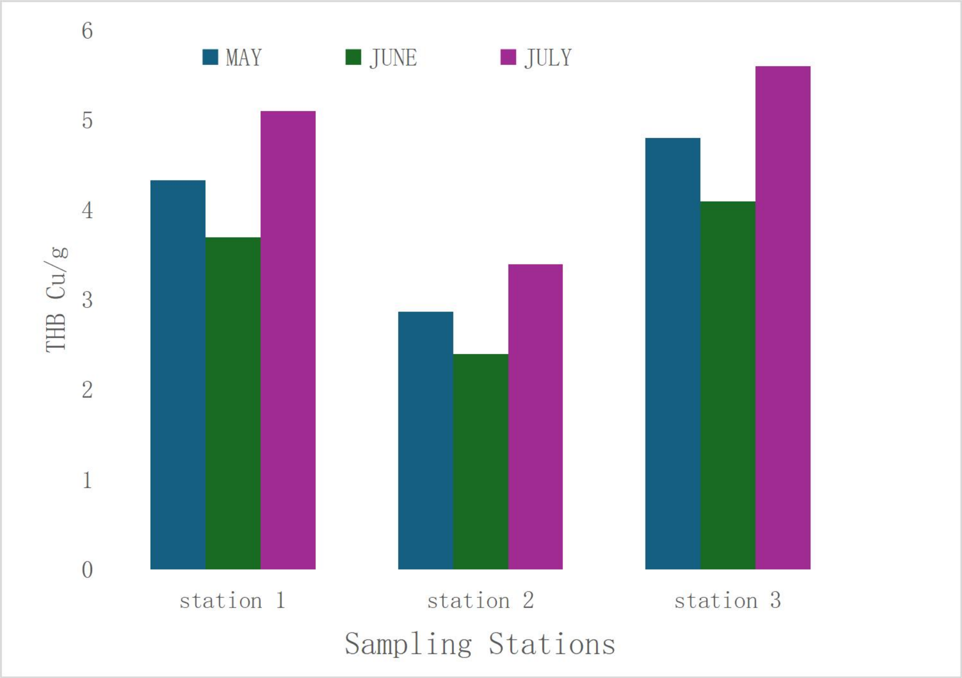

Figure 4.13 spatial variations in total heterotrophic bacteria (THB) in sediments across the three sampling stations of the Orhiomnwon River

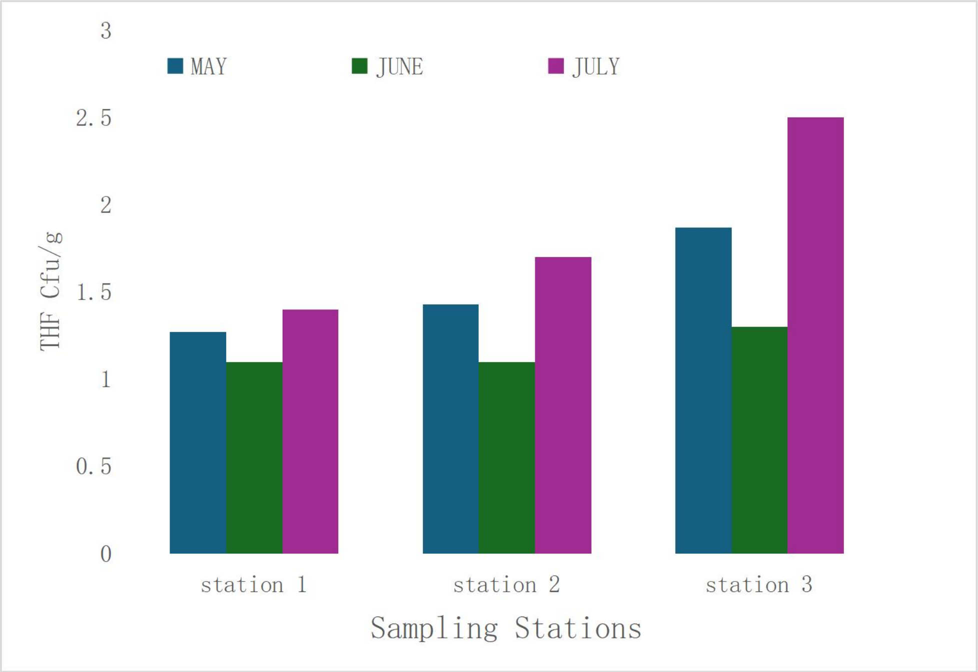

Figure 4.14 spatial variations in total heterotrophic fungi (THF) in sediments across the three sampling stations of the Orhiomnwon River.

4.1.13 Total Heterotrophic Bacteria (THB)

Figure 4.13 shows the spatial variations in total heterotrophic bacteria (THB) in sediments across the three sampling stations of the Orhiomnwon River. The data revealed that THB counts were highest at station 3 and lowest at station 1. The lowest THB count of 1.8 × 10^4 cfu/g was recorded at station 1, while the highest count of 5.2 × 10^4 cfu/g occurred at station 3. The ranges were 1.8–3.5 × 10^4 cfu/g (station 1), 2.5–4.6 × 10^4 cfu/g (station 2), and 3.1–5.2 × 10^4 cfu/g (station 3), with corresponding mean values of 2.7 × 10^4 cfu/g, 3.55 × 10^4 cfu/g, and 4.15 × 10^4 cfu/g respectively. ANOVA analysis revealed statistically significant differences in THB counts among the stations ($p<0.05$).

4.1.14 Total Heterotrophic Fungi (THF)

Figure 4.14 illustrates the spatial variations in total heterotrophic fungi (THF) in sediments across the three sampling stations of the Orhiomnwon River. The results showed relatively higher THF counts at station 2 compared to stations 1 and 3. The minimum THF count of 0.9 × 10^3 cfu/g was observed at station 1, while the maximum value of 2.4 × 10^3 cfu/g occurred at station 2. The ranges were 0.9–1.6 × 10^3 cfu/g (station 1), 1.3–2.4 × 10^3 cfu/g (station 2), and 1.0–2.0 × 10^3 cfu/g (station 3), with corresponding mean values of 1.25 × 10^3 cfu/g, 1.85 × 10^3 cfu/g, and 1.55 × 10^3 cfu/g respectively. One-way ANOVA confirmed significant variations in THF among the stations ($p<0.05$).

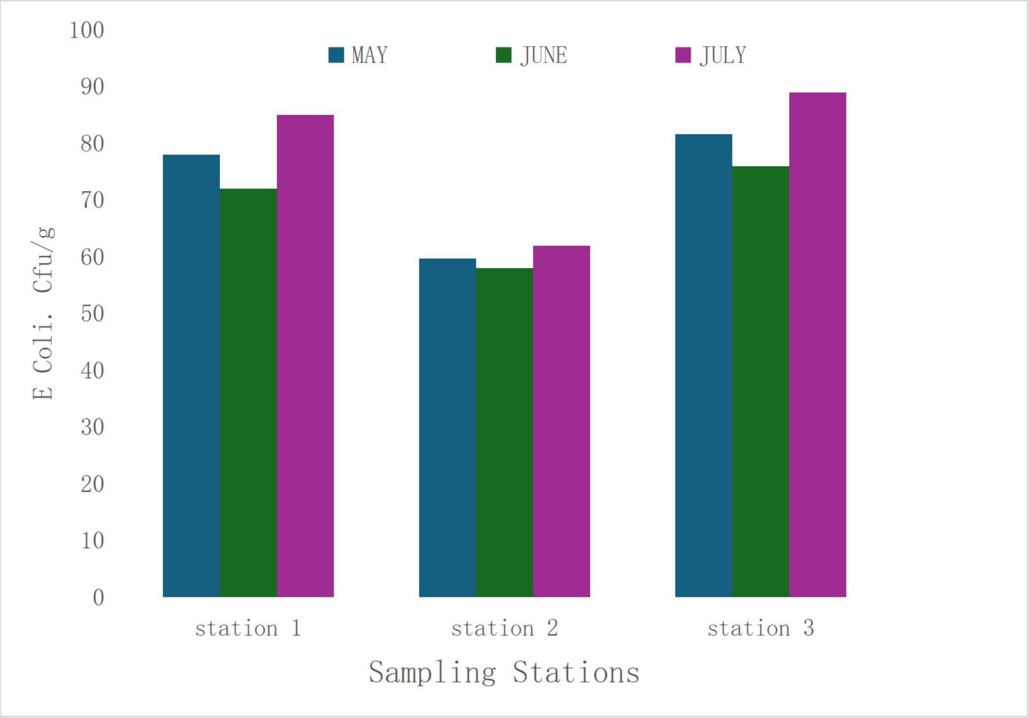

Figure 4.15 spatial variations in E. coli counts of sediments across the three sampling stations of the Orhiomnwon River

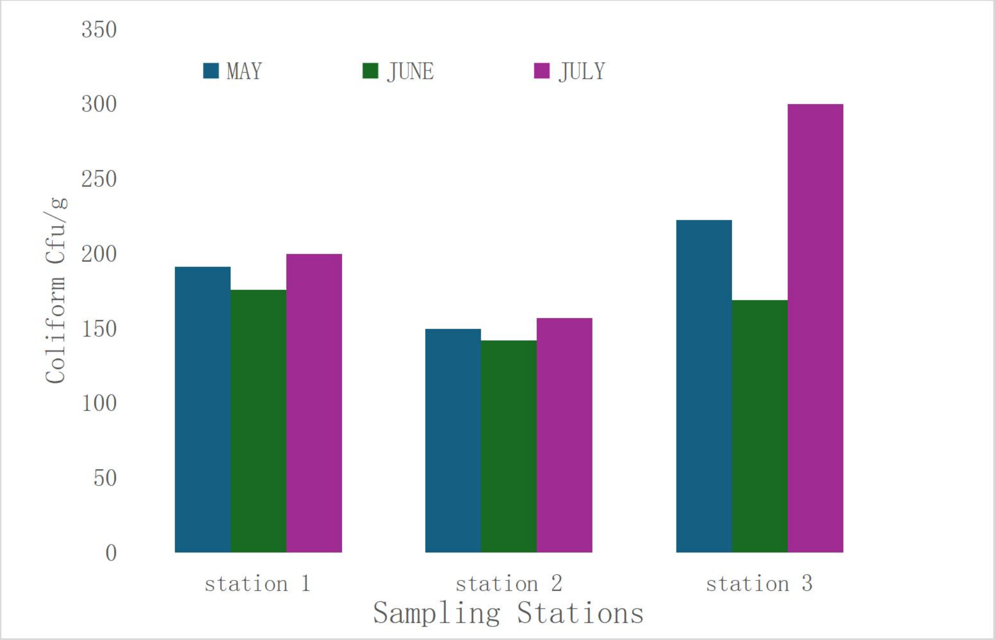

Figure 4.16 spatial variations in total coliform counts of sediments across the three sampling stations of the Orhiomnwon River

4.1.15 Escherichia coli (E. coli)

Figure 4.15 shows the spatial variations in E. coli counts of sediments across the three sampling stations of the Orhiomnwon River. The results indicated that E. coli was present in varying levels at all stations, with the highest counts recorded at station 3. The lowest E. coli count of 0.6×10^3 cfu/g was obtained at station 1, while the highest value of 1.8×10^3 cfu/g occurred at station 3. The ranges were $0.6–1.2 \times 10^3$ cfu/g (station 1), $0.8–1.4 \times 10^3$ cfu/g (station 2), and $1.0–1.8 \times 10^3$ cfu/g (station 3), with corresponding mean values of 0.9×10^3 cfu/g, 1.1×10^3 cfu/g, and 1.4×10^3 cfu/g respectively. ANOVA showed significant differences in E. coli counts among the stations ($p<0.05$).

4.1.16 Total Coliform

Figure 4.16 presents the spatial variations in total coliform counts of sediments across the three sampling stations of the Orhiomnwon River. The distribution showed relatively higher coliform counts at station 2 compared to the other stations. The lowest coliform count of 1.2×10^3 cfu/g was recorded at station 1, while the highest count of 3.5×10^3 cfu/g occurred at station 2. The ranges were $1.2–2.4 \times 10^3$ cfu/g (station 1), $1.8–3.5 \times 10^3$ cfu/g (station 2), and $1.5–2.9 \times 10^3$ cfu/g (station 3), with corresponding mean values of 1.8×10^3 cfu/g, 2.65×10^3 cfu/g, and 2.2×10^3 cfu/g respectively. Statistical analysis using one-way ANOVA revealed significant differences in coliform counts among the stations ($p<0.05$).

4.3 Cluster Analysis for Physicochemical, Microbial, and Sediment Parameters

Table 4.2 presents the Euclidean distance matrix, which quantifies the dissimilarity in physicochemical, microbial, and sediment properties among the three sampling stations. The results indicate a clear spatial pattern. The lowest dissimilarity value (220.34) was observed between Stations 2 and 3, signifying that they are the most similar in terms of their overall environmental characteristics. In contrast, Station 1 demonstrated a higher degree of dissimilarity from both Station 2 (359.38) and Station 3 (309.77), suggesting it possesses a distinct sediment composition and contaminant profile.

This spatial relationship is visually confirmed by the dendrogram in Figure 4.29, which clusters Stations 2 and 3 together at a low linkage distance. Station 1 is separated from this cluster at a much higher distance threshold, reinforcing its unique status. This pattern implies that Stations 2 and 3 are subject to comparable environmental influences, such as similar pollution sources or hydrological regimes, whereas the conditions at Station 1 are markedly different, potentially due to localized anthropogenic impacts or distinct hydrological features.

A further dendrogram analysing the parameters themselves (Figure 4.30) reveals meaningful groupings among the measured variables. One distinct cluster comprises Total Hydrocarbon Content (THC), Total Heterotrophic Bacteria (THB), E. coli, and Total Coliform. This strong association points to a common origin related to organic and microbial contamination, likely from wastewater or faecal sources. A second cluster, grouping Sodium (Na), Nitrogen (N), and Total Organic Carbon (TOC), highlights a connection between nutrient enrichment and organic input, often associated with agricultural runoff or the decomposition of organic matter. Finally, sand, silt, and clay form a third, expected cluster, representing the fundamental textural components of the sediment that are governed by physical processes like erosion and deposition.

In summary, the cluster analysis successfully elucidates both the spatial variability across the sampling stations and the functional relationships among the parameters. The clear distinction of Station 1, coupled with the logical clustering of variables related to contamination, nutrients, and sediment texture, provides a comprehensive picture of the complex interactions that govern sediment quality in the study area.

Table 4.2 Euclidean distance matrix from sampling stations

	Station 1	Station 2	Station 3
Station 1	**0**	**359.38018**	**309.76862**
Station 2	**359.38018**	**0**	**220.34367**
Station 3	**309.76862**	**220.34367**	**0**

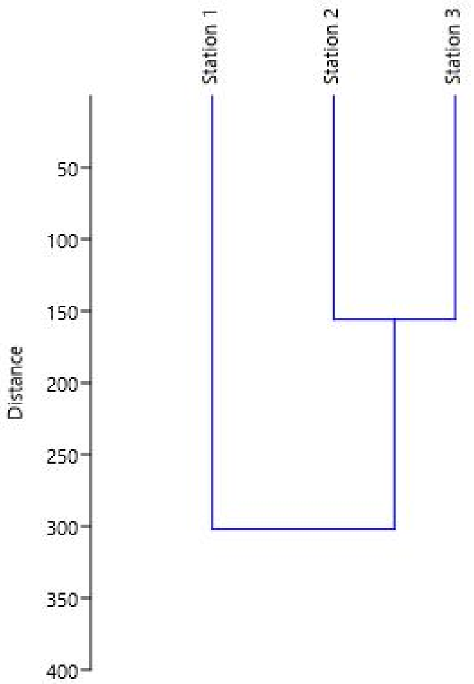

Figure 4.17 Dendogram cluster analysis based on the concentration of all the parameters analysed in sediment samples.

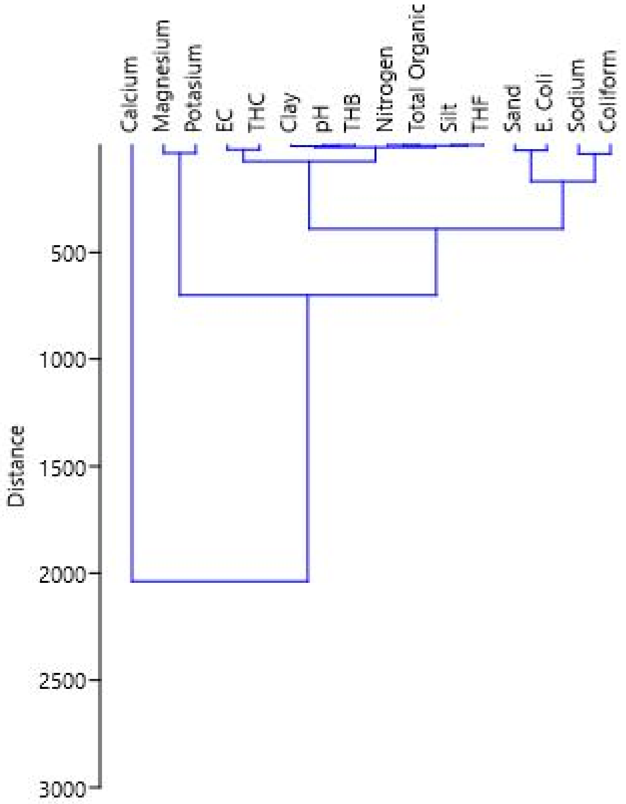

Figure 4.17 Dendogram cluster analysis based on the concentration of all the parameters analysed in sediment samples.

4.3 Identification of Sediment Contaminant Sources via Principal Component Analysis

Principal Component Analysis (PCA) of Sediment Samples

The Principal Component Analysis (PCA) for the sediment samples (as shown in Figure 4.19 and Figure 4.20) was conducted to determine the key factors influencing variations in the physicochemical and microbial parameters of the sediments. Four principal components with eigenvalues greater than 1 were extracted, accounting for a cumulative variance of 90.42%, which indicates that these components effectively explain most of the total variability among the measured parameters.

Component 1 contributed the highest proportion of variance (28.88%) and was strongly associated with Sand (0.707), Clay (−0.703), Coliform (0.957), THF (0.767), and THB (0.838). This component represents the natural sediment composition and organic load. The strong loading of sand and clay reflects the influence of textural composition on microbial distribution, while the association with THB, THF, and coliform indicates that organic matter and particle size significantly affect microbial abundance within the sediment.

Component 2 explained 28.16% of the total variance and showed high loadings for pH (0.887), Electrical Conductivity (0.795), Nitrogen (0.754), and Na (0.644). These parameters are typically linked to ionic strength and nutrient enrichment, implying contributions from runoff, domestic discharge, or natural geochemical interactions that alter sediment chemistry and nutrient dynamics.

Component 3, which contributed 23.60% of the variance, was characterized by high positive loadings for Calcium (0.757), Magnesium (0.655), and Potassium (0.827). This grouping reflects geogenic and lithogenic influences, most likely resulting from mineral weathering and the natural composition of the surrounding geological formations. These cations may also signify ion exchange processes occurring between the sediment and the overlying water.

Component 4 accounted for 9.78% of the total variance and was moderately loaded by Total Organic Carbon (0.521), E. coli (0.516), and Silt (−0.883). This component may represent localized organic pollution and the influence of fine sediment particles that promote microbial activity and organic accumulation.

Overall, the PCA results demonstrate that both natural textural properties and anthropogenic inputs play significant roles in shaping the sediment characteristics. The observed groupings of parameters highlight how mineral composition, nutrient content, and microbial activity interact to determine sediment quality and ecological conditions within the study area.

Table 4.3: Eigenvalues for sediment samples

Rotated Component Matrixa	**Component**				
	1	2	3	4	Extraction
pH	-0.268	-0.887	-0.268	0.19	0.966
EC	0.029	0.795	0.205	-0.248	0.737
Ca	-0.391	0.379	0.757	-0.059	0.873
Mg	0.138	-0.051	0.954	-0.1	0.942
K	0.178	0.485	0.827	-0.024	0.95
Na	0.245	0.64	0.662	0.116	0.921
N	0.312	0.754	0.249	0.414	0.9
TOC	0.483	0.621	0.1	0.512	0.891
Sand	0.707	0.459	0.45	0.1	0.924
Clay	-0.703	-0.472	-0.458	-0.021	0.926
Silt	-0.05	0.14	0.083	-0.883	0.808
THC	0.028	0.591	0.642	0.203	0.803
THB	0.848	0.451	0.106	0.14	0.953
THF	0.767	-0.383	-0.304	-0.365	0.96
Ecoli	0.857	0.434	0.2	0.076	0.968
Coliform	0.957	-0.034	-0.105	0.132	0.946
Total	**4.62**	**4.505**	**3.776**	**1.565**	
% of Variance	**28.877**	**28.158**	**23.602**	**9.784**	
Cumulative %	**28.877**	**57.036**	**80.638**	**90.422**	

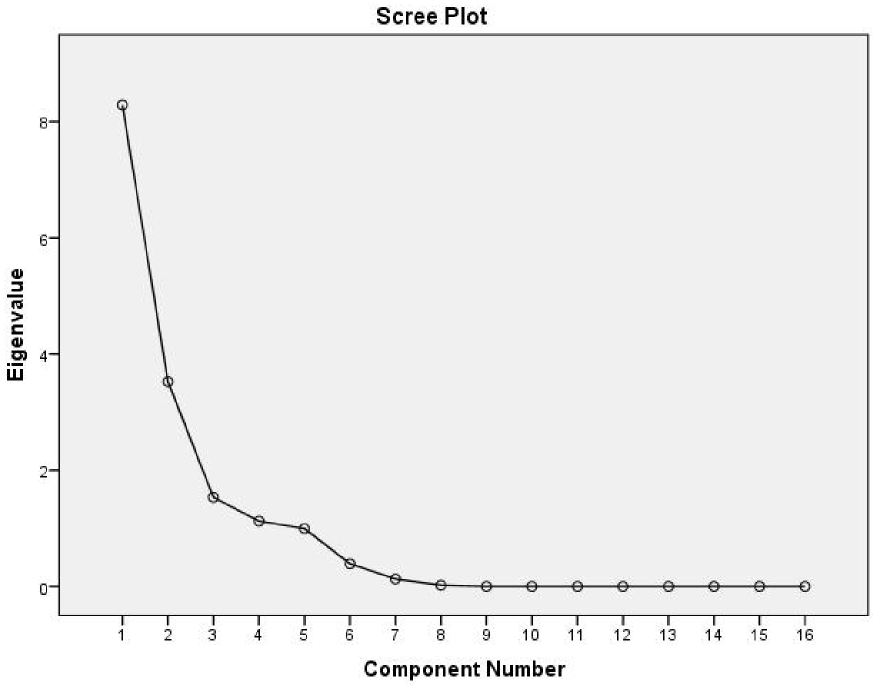

Figure 4.18 screen plots of the principal component analysis (PCA) after varimax rotation

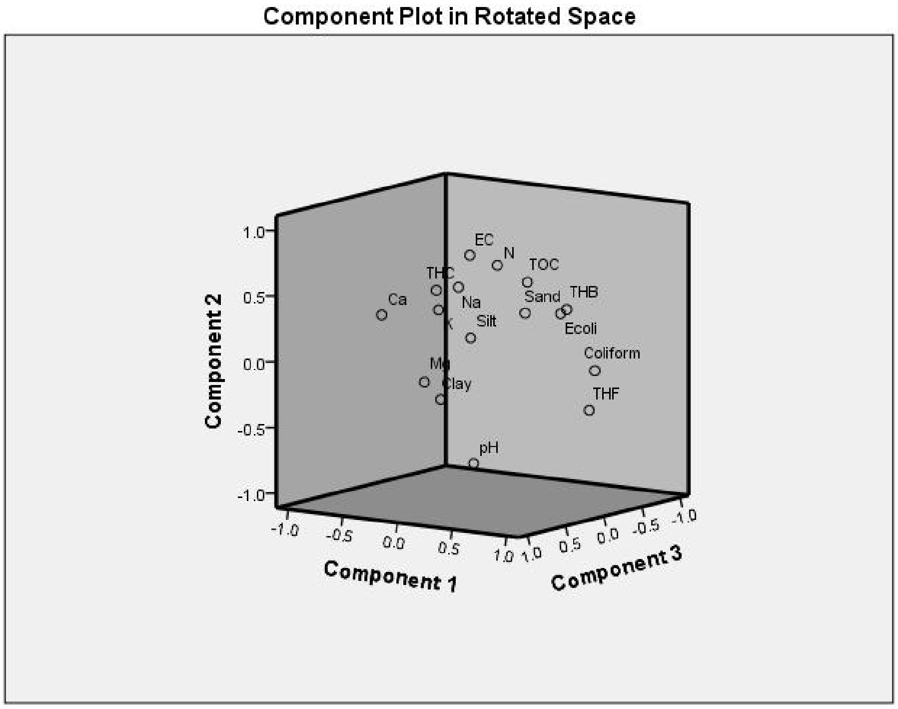

Figure 4.19 screen plots of the principal component analysis (PCA) after varimax rotation

4.4 Correlation Analysis

Figure 4.21 presents the correlation matrix, which elucidates the interrelationships among the physicochemical parameters and microbial indicators within the sediment samples. In this visualization, positive correlations are denoted by blue circles and negative correlations by red, with the size and colour intensity of each circle corresponding to the strength of the relationship.

The analysis revealed several key patterns. The parameter pH exhibited strong negative correlations with EC, magnesium, potassium, sodium, nitrogen, and total organic carbon (TOC). Conversely, it was positively associated with sand, clay, and microbial indicators such as E. coli and coliform. Electrical conductivity (EC) demonstrated strong positive correlations with the major cation’s calcium, magnesium, potassium, and sodium as well as with nitrogen, indicating that elevated ionic concentrations are a primary driver of conductivity in the sediment.

Calcium showed significant positive relationships with magnesium, potassium, sodium, and nitrogen, suggesting a shared geochemical origin and comparable mobility. Magnesium correlated positively with potassium, sodium, and nitrogen, but displayed negative correlations with sand, clay, and TOC. This implies a greater prevalence of magnesium in coarser-textured sediments that are lower in organic content. A similar trend was observed for potassium and sodium, which were strongly positively linked to each other and to nitrogen, while showing weaker or inverse relationships with the textural components.

Total Organic Carbon (TOC) was positively correlated with nitrogen and the microbial indicators (E. coli and coliform), reflecting the critical role of organic matter in nutrient enrichment and supporting microbial habitats. In contrast, TOC correlated negatively with EC, magnesium, potassium, and sodium, suggesting that sediments rich in organic matter tend to be less influenced by mineralisation processes. The textural parameters followed expected trends, with sand correlating negatively with clay, and clay showing a positive association with silt.

The microbial indicators, E. coli and coliform, were strongly positively correlated with one another, pointing towards a common faecal source or similar survival dynamics. Their positive relationships with TOC and nitrogen further indicate that microbial proliferation is favoured in nutrient-enriched, organic-rich sedimentary environments.

Overall, the correlation matrix reveals a clear distinction between two dominant groupings. The first cluster, comprising EC, Ca, Mg, K, Na, and N, represents a mineral and ionic enrichment pathway. The second cluster, defined by TOC, N, and microbial indicators, represents an organic and biological influence. The prevalent negative correlations between these groups, along with their divergent relationships with sediment texture, underscore the combined role of natural sediment characteristics and external inputs in shaping the nutrient and contaminant dynamics of the study area.

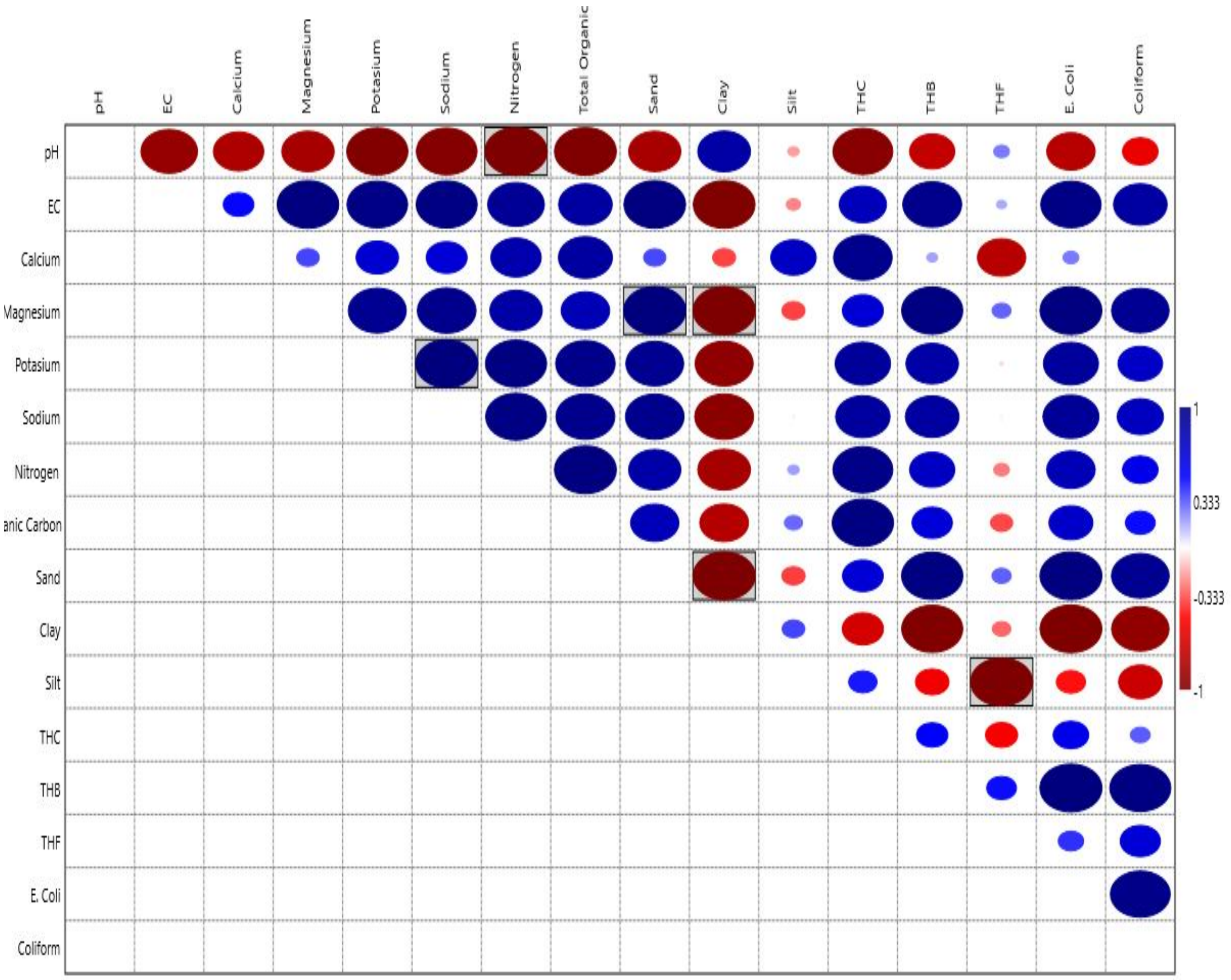

Figure 4.21: Spatial and temporal variation of physicochemical and heavy metal parameters of sediments on Orhionmwon River

CHAPTER FIVE

5.1 DISCUSSION

This chapter provides a detailed interpretation of the physicochemical and microbial results obtained from the sediment samples of the Orhionmwon River. The primary objective is to elucidate the spatial patterns observed across the three sampling stations and to link these variations to natural geochemical processes and anthropogenic influences. A critical component of this discussion is the evaluation of these findings against national (NESREA) and international (WHO) environmental quality guidelines to provide a robust, real-world assessment of the pollution status and its implications for ecosystem and public health.

The slightly acidic nature of the sediments (pH 4.83–5.23) aligns with the characteristic profile of tropical freshwater systems influenced by organic-rich deposits from dense riparian vegetation. The decomposition of this organic matter releases organic acids, such as fulvic and humic acids, which lower the sediment pH. The significantly higher pH recorded midstream (Station 2) could be attributed to reduced organic deposition at that specific locale, potentially due to flow dynamics around the bridge structure, or increased oxidation processes that consume hydrogen ions. Similar acidic trends have been widely reported in Nigerian aquatic systems; for instance, Adedeji *et al.* (2023) in Owalla Reservoir and Adesuyi *et al*. (2016) in Nwaja Creek documented comparable acidic conditions, linking them to catchment geology and organic matter decomposition.

The Electrical Conductivity (EC) values across the stations were generally low (14.00 - 86.00 µS/cm), indicating limited dissolved salts and ions in the sediment pore water. This finding is consistent with observations by Otolo *et al*. (2017) in the Ethiope River, which described similar low-conductivity environments characteristic of freshwater systems not heavily impacted by industrial or saline pollution. The differences across stations are likely linked to localized runoff conditions, with the slightly higher values at Stations 1 and 3 suggesting minor inputs from surrounding soils and human activities.

The significant spatial variation in major cations (Calcium, Magnesium, Potassium, Sodium) is a result of complex soil erosion and deposition dynamics within the catchment. The notably higher values of Calcium and Magnesium upstream (Station 1) strongly suggest a dominant input from the natural weathering of the surrounding geological formations, specifically the sandy Benin Formation, supplemented by vegetation decay. This pattern aligns with findings by Agathe *et al.* (2025), who observed that spatial differences in cation concentrations were significantly influenced by proximity to catchment activities and runoff.

The distribution of Total Organic Carbon (TOC) and Total Hydrocarbon Content (THC) further illuminates the river's status. The high TOC upstream (0.68%) is likely from natural allochthonous input (leaf litter), while the significant drop at Station 2 reflects its transitional nature. The presence of THC, though at relatively low levels (18.92 - 38.91 mg/kg), is a potential indicator of petrogenic pollution from non-point sources like runoff from roads or agricultural machinery. While NESREA standards for sediments are limited, the elevated organic matter has direct implications for water quality. High TOC can lead to oxygen depletion upon decomposition, adversely affecting aquatic life. Although there is no specific NESREA sediment standard for THC, its detectable presence signals anthropogenic influence and warrants monitoring to prevent further ecosystem degradation, aligning with the agency's mandate to control all forms of environmental pollution.

The microbial analysis reveals a clear and concerning trend, with significant implications for public health. The high counts of Total Heterotrophic Bacteria (THB), E. coli, and Total Coliforms across all stations, culminating in the highest coliform count (222.33 CFU/g) at the downstream station (Station 3), provide undeniable evidence of widespread and cumulative faecal contamination. To contextualize the severity, the results were compared against established national and international guidelines. Although NESREA does not have specific sediment microbial standards, its surface water quality guidelines provide a critical benchmark, as contaminated sediments act as a permanent reservoir that continuously impairs water quality. The NESREA permissible limit for faecal coliforms in recreational water is 0 CFU/100ml. The persistent presence of high levels of E. coli (up to 89 CFU/g) and total coliforms (up to 300 CFU/g) in the sediments signifies a severe and continuous violation of this standard for the overlying water body. An international perspective further solidifies this risk assessment. The World Health Organization (WHO) guidelines for safe recreational water quality recommend very low levels of E. coli, typically below 100 CFU/100ml. The densities found in the Orhionmwon River's sediments far exceed this guideline, categorizing it as a significant public health risk. This finding is consistent with other Nigerian studies; Fagorite *et al*. (2019) and Amachree *et al*. (2025) similarly reported sediment microbial loads that breached safety standards, linking them directly to inadequate sewage disposal and poor waste management. The presence of these pathogens means the river sediment is a reservoir for diseases like cholera, typhoid, and dysentery, posing a direct threat to communities that rely on the river.

A holistic view reveals a critical synergy between the physicochemical and microbial components of the sediment. The acidic pH and elevated organic carbon (TOC) create an environment that not only reflects pollution but actively sustains it. The organic matter acts as a nutrient source, promoting the survival and proliferation of faecal bacteria like E. coli and coliforms. This creates a vicious cycle where anthropogenic activities introduce both organic waste and pathogens, and the sediment chemistry enables this contamination to persist, acting as a long-term source for re-contaminating the water column.

5.2 CONCLUSION

This study successfully provides a comprehensive assessment of the Orhionmwon River's sediment quality. The results clearly show that the sediments are moderately polluted, with a distinct spatial variation from upstream to downstream. The acidic pH and varying cation levels reflect the river's natural geology but also point to human influences. Most critically, the high counts of E. coli and total coliforms found throughout the river are undeniable evidence of serious faecal contamination. When these microbial results are held against NESREA and WHO guidelines, it becomes clear that the pollution level poses a real and significant risk to public health. Essentially, the sediments are not just dirt; they act as a reservoir for pathogens, continuously impacting water quality. This study therefore fills a critical knowledge gap by establishing this important baseline data for the Orhionmwon River. Based on these findings, I strongly believe that future environmental monitoring in Edo State must include regular sediment analysis. To safeguard community health, immediate actions should focus on improving local waste management and sanitation practices near the river. Ultimately, protecting this vital water resource is essential for both the ecosystem's sustainability and the well-being of the people who depend on it.

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