

**HEALTH RISK ASSESSMENT OF SURFACE WATER FROM ORHIONMWON
RIVER, SOUTHERN NIGERIA.**

BY:

EMMANUELLA MIKPEMINESHI ITSUOKOR (MISS)

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**AN UNDERGRADUATE PROJECT SUBMITTED TO THE DEPARTMENT OF
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BACHELOR OF SCIENCE (B.Sc) DEGREE IN ENVIRONMENTAL
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CERTIFICATION

This is to certify that this research titled **“HEALTH RISK ASSESSMENT OF SURFACE WATER FROM ORHIONMWON RIVER, SOUTHERN NIGERIA.”** was carried out by **“EMMANUELLA MIKPEMINESHI ITSUOKOR (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.

DR. EKENE BIOSE
(PROJECT SUPERVISOR)

DATE

PROF. (MRS.) E.T AISIEN
(HEAD OF DEPARTMENT)

DATE

DECLARATION

I **“EMMANUELLA MIKPEMINESHI ITSUOKOR (MISS)”** declare that **“HEALTH RISK ASSESSMENT OF SURFACE WATER FROM ORHIONMWON RIVER, SOUTHERN 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.

EMMANUELLA MIKPEMINESHI ITSUOKOR

DATE

DEDICATION

This project report is dedicated first and foremost to God Almighty, the source of my strength, wisdom and grace throughout this journey.

To my loving mum, thank you for your endless sacrifices, prayers and unwavering support, you are my greatest inspiration. To my wonderful siblings, your encouragement and belief in me kept me going, even on the toughest days. To Samuel, thank you for always being there with your support, love and motivation. And to my dear friends, your kindness, understanding, and words of encouragement meant more than I can express. This work is for all of you.

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ABSTRACT

This study assessed the health risk assessment of surface water from Orhionmwon River, Southern Nigeria. A total of 18 water samples were collected at each location from May 2025 to July 2025. From upstream to downstream, water samples were taken from three locations in accordance with normal guidelines. While certain heavy metals were identified using the method of the association of analytical chemistry, the physicochemical properties of surface water were analysed using normal laboratory procedures. The average mean concentration of physicochemical and heavy metal properties in surface water were 30.12 ± 0.20 (temperature), 6.97 ± 0.13 (pH), 20.00 ± 1.20 (EC), 9.89 ± 0.51 (TDS), 4.50 ± 0.17 (TSS), 14.39 ± 0.48 (TS), 6.38 ± 0.27 (turbidity), 5.76 ± 0.59 (alkalinity), 4.84 ± 0.32 (DO), 3.71 ± 0.08 (BOD), 33.78 ± 11.04 (COD), 6.61 ± 0.78 (chloride), 7.61 ± 2.34 (NO_3), 0.47 ± 0.25 (PO_4), 1.84 ± 0.19 (SO_4), 6.92 ± 0.31 (hardness), 1.80 ± 0.16 (Ca), 0.63 ± 0.10 (Mg), 0.87 ± 0.06 (Na), 1.50 ± 0.08 (K), 1.24 ± 0.08 (Fe), 0.11 ± 0.01 (Cu), 0.61 ± 0.08 (Zn), 0.06 ± 0.01 (Pb), 0.28 ± 0.08 (Mn), 0.05 ± 0.01 (Cr) and 3.96 ± 0.15 (THC) respectively. Cadmium was not detected in the surface water from Orhionmwon River. The summative water quality index (WQI) for the three sampled stations were classified Grade E indicating that the water from Orhionmwon River is unsuitable for drinking (>100). The comprehensive pollution index across the sampled stations were classified as slightly polluted. Non-carcinogenic target hazard quotients (THQs) for oral exposure for the heavy metals were < 1.0 except for THC across the sampled stations, which suggests that consumers of water from these locations may be at high risk of non-carcinogenic illnesses associated with THC contaminants. The hazard index (HI) values for oral exposure shows that ($\text{HI} > 1$) which indicates that the consumption of the water predisposes them to potential health risk. The result for the integrated carcinogenic risk (ICR) values classified the surface water from Orhionmwon River as Grade VI (high risk – 10^{-3}) which calls for immediate attention and adequate action and should be further investigated for heavy metals such as lead and chromium.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Water is said to be the ‘life-blood of the biosphere’ due to its importance to the survival of all living organisms (Ali *et al.*, 2019). It makes up about 71% of the earth's surface, making it comparatively abundant in nature. However, 1.2 billion people worldwide do not have access to clean water. In poor nations, the situation is worse. According to Nawaz *et al.* (2023), inadequate sanitation and water pollution are responsible for an estimated 2.2 million fatalities per year in developing nations, making water resource pollution one of the main obstacles to the Sustainable Development Goal (Onen *et al.*, 2023). One of the most important chemical substances for life is portable water, which is needed for survival, healthy living, and organ upkeep. Life, agriculture, economic activity, ecosystem health, public health, climate regulation, energy production, cultural and recreational value, conflict and collaboration all depend on water supplies (Caliskan *et al.*, 2024).

The availability and use of these water systems have been impacted by the growing human population, the expansion of industry and agriculture, climate change and the high susceptibility of freshwater systems to contamination (Egun and Oboh 2023). Pollution primarily affects surface water, such as rivers, which are the world's most important freshwater resource (Adesiyani *et al.*, 2018). For both humans and aquatic life, surface water is essential in a number of ways. When it comes to aquatic ecosystems and human health, river water quality is crucial (Bhuyan *et al.*, 2017). High coliform levels are present in many Nigerian rivers. Additionally, as a result of rapid anthropogenic expansion, larger amounts of hazardous chemicals, particularly heavy metals and polycyclic aromatic hydrocarbons (PAHs), are deposited in the surface water, middle layer, bottom layer, and sediments,

accumulating to a certain level and causing toxicity to the water ecosystem (Adeniji *et al.*, 2018).

These pollutants are sunk by rivers, raising the water column's ecological risk. Human civilizations and urban development are significantly impacted by the availability and quality of water (Ahmed *et al.*, 2021). One of the most significant challenges that has a significant impact on ecosystem behavior and human health is water quality, which is extremely sensitive to climatic fluctuation, environmental change, and severe anthropogenic activity (Badola *et al.*, 2022).

Degradation and depletion of water quality have become major worldwide issues that directly affect the environment, agriculture, and public health (Egbuikwem *et al.*, 2021). A scientific technique called health risk assessment is used to calculate the probability that exposure to environmental risks will have a negative impact on one's health. Several evaluation indices have been developed in response to the requirement to convert complex data from water analysis into meaningful information for determining water quality, health risks connected with its consumption, and public health awareness (Egun and Oboh 2023).

1.2 STATEMENT OF PROBLEM

According to De-Araújo-Reis *et al.* (2024), high-risk events that affect surface water supplies in underdeveloped nations include human access, climatic events, and inadequate collection structures. River water quality is declining daily due to anthropogenic and human development activities as well as wastewater discharge. The amount of waste and pollutants produced has increased as a result of increased anthropogenic activity. These contaminants are released into surface water bodies either directly by industries or indirectly by surface runoff from industrial sites, landfills, farms, and other human activities within a watershed (Ostad-Ali-Askari 2022).

Nigerians living in rural areas are more likely to not treat their untreated drinking water and are less likely to have access to better water sources and sanitary facilities (Azeez *et al.*, 2023). One such vital resource in Edo State is the Orhionmwon River, but pollution from both natural and man-made sources is posing a growing threat to it.

Despite its significance, little scientific information is available about the present state of river water quality and the possible health risks to those who depend on it. Long-term usage of polluted water can lead to a variety of acute and chronic health issues (Singh *et al.*, 2017). Communities that depend on the water face direct and indirect health hazards due to its low quality, which frequently results in serious public health problems and higher expenses for water treatment and rehabilitation (He *et al.*, 2019). Consuming contaminated water poses direct health hazards, such as heavy metal contamination, which can result in severe illnesses (Ngo *et al.*, 2021; Raja *et al.*, 2021). When tainted water is utilized for irrigation, it affects horticulture, aquaculture, and agricultural crops, which can lead to the bioaccumulation of toxins in the food chain and indirect health hazards (Edogbo *et al.*, 2020).

Communities in Orhionmwon LGA rely heavily on the Orhionmwon River for drinking, cooking, bathing, washing, small-scale farming, and fishing. However, despite its significance, there hasn't been a concentrated scientific evaluation of the water's quality or the health hazards connected to its consumption.

Given the growing information from nearby water bodies that indicates serious pollution risks, this gap is very important. For instance, extensive research on the Ossiomo River in the same LGA has repeatedly revealed Water Quality Index (WQI) values between 275.8 and 394.0, indicating significant contamination and making the water unfit for home use (Odigie *et al.*, 2022). Concerns over the hazards of waterborne illnesses were raised by these investigations, which found increased microbial contamination, including pathogens including Salmonella,

Shigella, E. coli, and Pseudomonas aeruginosa. Other rivers in Edo State have also been discovered to be contaminated with heavy metals, including as the Owan River, where levels of lead and cadmium were found to be higher than WHO recommendations, resulting in non-carcinogenic hazard quotients exceeding unity particularly concerning for children (Ogbeide *et al.*, 2015).

There is a significant gap between perceived water safety and real risk, as evidenced by the thousands of people who depend on surface water from the Orhionmwon River despite potentially dangerous pollution. Vulnerable populations, such as youngsters who may experience irreversible effects from extended exposure to chemical and microbiological toxins, may experience chronic health problems as a result of this information gap. Therefore, it is not just academic to address this crucial data gap with thorough scientific research; it is essential for maintaining public health, directing local environmental governance, and safeguarding water resources that are essential to community well-being.

1.3 JUSTIFICATION OF THE STUDY

Rivers are essential sources of water for domestic, agricultural, and livelihood purposes in many rural and peri-urban communities throughout Edo State. Despite this, anthropogenic activities—from farming runoff and inappropriate waste disposal to artisanal operations—frequently degrade surface water quality, raising grave implications for both environmental sustainability and public health (Akinnusotu *et al.*, 2023). There is still a dearth of information about the Orhionmwon River itself, despite the fact that other rivers in the Orhionmwon Local Government Area, including the Ossiomo River, have been thoroughly investigated for water quality concerns (Odigie *et al.*, 2022). Local governments, health organizations, and communities lack a scientific foundation for risk mitigation and water safety management in the absence of baseline studies. Surface water systems in Edo State are continuously threatened by microbiological pollution and heavy metals. Despite these

revelations, there is still a significant gap: the Orhionmwon River has not yet undergone a thorough health risk assessment. There is a compelling case for expanding comparable studies to this watercourse given its physical and socioeconomic similarities with Ossiomo and Owan Rivers and the likelihood that residential, agricultural, and wider livelihood activities depend on its water. In order to establish baseline data on the physicochemical and heavy metal status of this river's surface water as well as to provide evidence-based guidance for water resource management, public health interventions, and policy formulation aimed at protecting the health of dependent communities, it is crucial to assess the health risks associated with this water.

1.4 AIMS AND OBJECTIVES OF THE STUDY

The aim of this study is to conduct a comprehensive health risk assessment of surface water from Orhionmwon River in Edo State, Nigeria.

The specific objectives of this study are to determine the:

1. Physicochemical and heavy metal content of surface water from Orhionmwon River.
2. Water quality using water quality index (WQI) and comprehensive pollution index (CPI)
3. Potential non-carcinogenic and carcinogenic health risks associated with the use of the river water.

CHAPTER TWO

LITERATURE REVIEW

The physicochemical properties of surface water from the Idu Ogba River in Rivers State, Nigeria, were calculated by Abali *et al.* (2023). Turbidity, electrical conductivity, total dissolved solids (TDS), total suspended solids (TSS), and temperature are among the physical factors evaluated. The WHO's recommended range of 6.5 to 8.5 NTU is in line with the average turbidity of 6.5 NTU across the stations. The average conductivity was 122 $\mu\text{s}/\text{cm}$, which is marginally higher than the WHO's recommended value of 100 $\mu\text{s}/\text{cm}$. This suggests that ions from dissolved salts may be present. The levels of TDS and TSS were 94.48 mg/L and 65.37 mg/L, respectively. Both metrics show moderate levels of particle matter even if they are below the WHO TDS limit of 500 mg/L. The observed temperature fell between 25.70°C and 26.34°C, which is within the 20–30°C WHO acceptable range. Additionally, chemical factors like pH, alkalinity, and chlorine concentrations were examined. The average pH of the water samples was 5.31, which is below the WHO-recommended range of 6.5 to 8.5. This indicates a slight acidity that could affect aquatic life and the water's corrosivity. Low buffering ability is suggested by the measured alkalinity values of 16.47 mg/L, which are well below the WHO standard of 100 mg/L. The average concentration of chlorine was 7.23 mg/L, which is considerably within the permissible threshold of 250 mg/L. This suggests that there was little chemical disinfection or contamination from chlorinated chemicals. Additionally, gross organic pollutants such as dissolved oxygen (DO), chemical oxygen demand (COD), and biochemical oxygen demand (BOD²) were evaluated. The WHO limit of 10 mg/L was marginally exceeded by the average BOD² value of 10.61 mg/L, which could indicate organic pollution from waste discharge. Organic pollution was further confirmed by COD levels, which were higher than the WHO's recommended limit of 50 mg/L at 51 mg/L. The average dissolved oxygen content was 3.47 mg/L, which is

significantly below than the WHO requirement of 10 mg/L and suggests that aquatic species have limited access to oxygen. Nitrate, phosphate, and sulphate were among the nutrient characteristics that were examined. With an average of 6.29 mg/L compared to the advised 1.0 mg/L, nitrate levels were much higher above WHO standards. Domestic sewage or runoff from agricultural areas could be the cause of this. With an average of 0.513 mg/L, phosphate concentrations stayed considerably within safe bounds when compared to the 50 mg/L criterion. With an average value of 9.4 mg/L, sulphate concentrations were likewise below the allowable limit of 250 mg/L. Overall, the findings show that while certain indicators fall within acceptable ranges, others pH, BOD₂, COD, DO, and nitrate, in particular exceed WHO guidelines, suggesting that the water may not be safe for direct consumption or aquatic life without appropriate treatment.

Okey-Wokeh *et al.* (2023) conducted a study on the anthropogenic effects of heavy metal and physicochemical concentrations in Ogor Hill River Water in Southern Nigeria. Over the course of eight months, during both the dry and rainy seasons, the physicochemical properties of the Ogor Hill River in Southern Nigeria were investigated. Monitored parameters were pH, temperature, salinity, electrical conductivity (EC), turbidity, total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chloride, bicarbonate, and hardness. The pH of the river was somewhat acidic for the majority of the year, peaking at 6.73 in June and falling to 6.06 in April. The majority of these values were below the 6.5–8.5 WHO-recommended threshold for surface water, indicating anthropogenic pollution from sewage discharges and industrial effluents. The temperature of the water varied annually, reaching a maximum of 29.8°C in April during the dry season and falling during the rainy months as a result of less solar exposure. Due to evaporation, salinity was also higher during the dry season and decreased as rainfall increased. Similar seasonal patterns were seen in electrical conductivity and TDS, with higher dry season values signifying higher ionic

content and pollution load. April had the greatest EC (1392.33 $\mu\text{S}/\text{cm}$) and TDS (582.10 mg/L), which are indicative of the inflow of both household and industrial waste. All months saw turbidity levels above WHO guidelines, with a peak of 26.7 NTU in July, most likely as a result of runoff and sand mining. Dissolved oxygen levels were generally low throughout the months, with values below WHO limits, indicating organic pollution, despite being slightly higher during the wet season. Seasonal variations in BOD, which exceeded permissible limits in January, are a sign of excessive levels of biodegradable organic matter, particularly from abattoir emissions. Compared to the lower quantities of Cl⁻ found in June and July, the mean chloride values measured in March and April were much higher. From December to July, every measurement was below the WHO fresh water standard of 250 mg/L. Because there was an abattoir nearby, the Ogbor watercourse had a lot of organic waste, especially animal waste, which is indicated by the presence of chloride in natural water. According to TH's data, the dry season (December–March) yielded greater values than the rainy season (April–July), with January having the greatest mean value and May having the lowest. The study's total hardness (TH) content was generally low and significantly below the WHO's recommended threshold. According to the HCO₃⁻-concentration values, March had the greatest mean (9.36 ± 0.09), while June had the lowest value (1.45 ± 0.29). According to the mean bicarbonate (HCO₃⁻) value, March had the greatest value while June had the lowest. HCO₃⁻-values during the rainy and dry seasons, were below the WHO-established tolerable level of 100 mg/L. Using atomic absorption spectrophotometry, the Ogbor Hill River study examined the amounts of eight heavy metals: cadmium (Cd), lead (Pb), iron (Fe), chromium (Cr), manganese (Mn), copper (Cu), nickel (Ni), and zinc (Zn). The WHO permitted limit of 0.3 mg/L is greatly exceeded by the maximum mean value of 2.68 mg/L that was recorded in April. Iron (Fe) values were continuously high. Natural leaching and industrial operations

like metal workshops were probably the causes of this elevation. Concerning levels of lead (Pb) were also observed, peaking in March at 0.44 mg/L, well above the WHO standard of 0.01 mg/L. Pb levels have been connected to vehicle emissions and battery waste. March saw the highest levels of cadmium (Cd) at 0.052 mg/L, which is more than ten times higher than the permissible limit of 0.003 mg/L and suggests contamination from both industrial and home sources. In certain months, chromium (Cr) levels above the WHO standards of 0.05 mg/L, which is a sign of wastewater discharges from tanneries and other industries. Although levels of manganese (Mn) and nickel (Ni) were generally lower, there were sporadic peaks that above the safe drinking limits of 0.05 mg/L and 0.02 mg/L, respectively, such as Mn at 0.221 mg/L in December and Ni at 0.042 mg/L in the same month. Renal and neurological problems can result from long-term exposure to certain metals. The greatest concentration of Cu^{2+} was reported in February (0.800 ± 0.59 mg/L), while the lowest value (0.023 ± 0.152 mg/L) was recorded in March. The WHO's permissible limit of 2 mg/L was exceeded by the Cu^{2+} concentration found in this investigation. The low Cu^{2+} concentration found in this study was ascribed to minimal anthropogenic input on the discharge of high-Cu minerals into the Ogor water body. There was no discernible variation in the Zn^{2+} content between the sampling months ($p > 0.05$). The Zn^{2+} mean readings for the months of December through July revealed that December had the highest mean. According to the overall Zn^{2+} data, all of the months' mean readings were below the WHO's recommended limit of 3 mg/L for surface water. The physicochemical profile of the Ogor River exhibited notable seasonal changes, greatly impacted by human activity. Elevated concentrations of Fe, Pb, and Cd and deteriorating values of pH, turbidity, EC, TDS, BOD, and DO are signs of excessive anthropogenic pressure, which highlights the necessity of stringent monitoring and control of pollution sources surrounding the river system.

In their investigation of the water quality of the Okpare Community River Ughelli South LGA, Delta State, Nigeria, Edjere *et al.* (2023) discovered that the pH values of the water samples ranged from 6.03 to 6.96, indicating slightly acidic to nearly neutral conditions, generally suitable for aquatic life but highlighting the potential impact of pH fluctuations on ecosystems. The water temperature at the sampling sites regularly varies between 28.9 and 29 degrees Celsius, suggesting that the river has steady thermal conditions, which are crucial for several aquatic activities. The TDS value, which ranged from 15.00 mg/L to 29.00 mg/L, shows that the water's dissolved solids content was comparatively low. The range of electrical conductivity (EC) is 29.00 $\mu\text{S}/\text{cm}$ to 56.00 $\mu\text{S}/\text{cm}$, indicating moderate electrical conductivity. The observed turbidity values, which range from 107.10 NTU to 561.30 NTU, indicate different levels of water cloudiness and may indicate the presence of contaminants or sediments that could affect aquatic life and water quality. Although dissolved oxygen (DO) levels between 2.10 and 5.20 mg/L are within safe limits for aquatic life, they highlight the significance of keeping an eye out for possible oxygen depletion hazards. Total hardness ranges from 7.96 mg/L to 16.70 mg/L (S3 and S1, respectively) according to the ex-situ water quality measurements. When determining whether water is suitable for industrial or drinking use, total hardness which is impacted by calcium and magnesium ion concentrations—is a crucial consideration. Higher hardness levels would need further treatment, although lower levels are typically better for drinking water. Furthermore, there are notable differences in total suspended solids (TSS), which range from 100.00 mg/L to 600.00 mg/L (S3 and S2, respectively). Increased TSS levels may be a sign of poor water clarity, which may be caused by pollution, sedimentation, or other environmental issues. Biological oxygen demand (BOD) measurements range from 1.20 mg/L to 3.40 mg/L (S3 and S2, respectively).

In Edo State, Nigeria, Biose *et al.* (2024) evaluated a tropical freshwater body's water quality and related risk to human health. The goal of this extensive study on the Ossiomo River was

to ascertain its viability for both ecological sustainability and human consumption. Regarding Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA) restrictions, the results showed a mix of complying and non-compliant levels. Acidic conditions were found at all test stations, with pH values ranging from 5.8 to 6.5. These results indicated possible corrosiveness, bad taste, and consequences for gastrointestinal health because they were below the NESREA level (6.5–8.5). Toxic metals become more soluble and bioavailable in acidic water, endangering aquatic life and consumers. Other measured parameters, including electrical conductivity (16–55 $\mu\text{S}/\text{cm}$), alkalinity (2.50–8.25 mg/L), total dissolved solids (TDS: 8.00–27.00 mg/L), total suspended solids (TSS: 20.00–330.00 mg/L), and water hardness (4.80–8.01 mg/L), were all within NESREA's allowable limits, indicating that the water's physical characteristics were generally good and barely affected. However, the levels of dissolved oxygen (DO) were low (3.00–4.94 mg/L), not meeting the necessary minimum of 6.00 mg/L. This deficit limits the river's ability to sustain aquatic life because of a substantial organic matter load and possible oxygen depletion. Biochemical oxygen demand (BOD) readings, on the other hand, were low (0.46–2.54 mg/L) and remained below the 3.00 mg/L NESREA limit, indicating mild organic contamination. It was also shown that vital nutrients including sulphate (0.83–3.28 mg/L), phosphate (0.02–0.08 mg/L), and nitrate (0.12–1.74 mg/L) were within safe ranges. Similar to this, ionic constituents like sodium ranged from 0.90 to 1.17 mg/L, with a maximum well below the NESREA limit of 120 mg/L; potassium ranged from 0.47 to 0.83 mg/L, with a maximum well below the 50 mg/L NESREA limit; calcium ranged from 1.04 to 2.37 mg/L, indicating soft water conditions; magnesium ranged from 0.27 to 0.71 mg/L, indicating low mineral hardness; and chloride ranged from 3.45 to 10.64 mg/L, indicating negligible intrusion from domestic sources. These all show that industrial chemicals and fertilizers had a negligible impact during the sample period. The consistently low pH and DO levels,

particularly in severely disturbed areas like Station 2, reflect the detrimental effects of anthropogenic activities like sand dredging, oil spills, waste disposal, and agricultural runoff, even though the majority of physicochemical parameters met regulatory limits. This was verified by using water quality indices such the Water Quality Index (WQI) and the Comprehensive Pollution Index (CPI). Station 2 had a WQI of 765.05, indicating that it was unfit for human consumption (WQI > 100), and a CPI of 1.0 (moderately contaminated).

Surface water samples from three locations along the Ossiomo River were examined for the amounts of seven important heavy metals. Iron (Fe), cadmium (Cd), lead (Pb), manganese (Mn), chromium (Cr), copper (Cu), and zinc (Zn) were among them. Concentrations of iron (Fe) ranged from 0.18 to 2.43 mg/L, with Station 2 recording the highest level that exceeded the 0.3 mg/L NESREA limit. Soil erosion, leaching from geological formations, and industrial runoff are frequently associated with iron pollution in surface water. Iron is necessary for biological activities, but too much of it can harm aquatic life, discolor home fixtures, and make water taste bad. The values of cadmium (Cd), which ranged from 0.01 to 0.11 mg/L and were much higher than the NESREA maximum allowable limit of 0.005 mg/L, were concerning. Station 2 had the greatest amounts. Cadmium is a known toxin that is categorized as a human carcinogen and can lead to skeletal problems and renal impairment. Its high concentrations in the river were ascribed to industrial discharge, leaks from car workshops, and agricultural runoff (perhaps from phosphate fertilizers). The concentrations of lead (Pb) ranged from 0.00 to 0.02 mg/L, with Stations 2 and 3 showing exceedances of the 0.01 mg/L limit. Developmental delays and neurological abnormalities are linked to lead exposure, especially in children. Lead in surface water is frequently associated with fuel burning, waste from battery operations, and inappropriate disposal of lead-containing products. The amount of manganese (Mn) found ranged from 0.02 to 0.27 mg/L, exceeding the 0.05 mg/L NESREA allowable limit at every station. Manganese exposure over time can

damage the neurological system and impair cognitive function. The increased manganese levels were probably caused by runoff from industrial and agricultural operations as well as natural soil leaching. The levels of chromium (Cr) were close to the NESREA threshold of 0.1 mg/L, ranging from 0.02 to 0.11 mg/L. The study's health risk assessment showed that chromium contributed to more than 90% of the overall carcinogenic risk for both adults and children, despite the average concentrations being within acceptable bounds. A well-known carcinogen and significant public health concern is chromium, particularly in its hexavalent form (Cr⁶⁺). Zinc (Zn) and copper (Cu) levels were well within safe bounds, ranging from 0.00–0.04 mg/L for Zn (limit: 3.0 mg/L) to 0.01–0.06 mg/L for Cu (limit: 1.0 mg/L). At trace amounts, these metals are necessary micronutrients, but at higher concentrations, they can become hazardous. According to the study's Comprehensive Pollution Index (CPI), lead, manganese, and cadmium were the main contaminants causing the decline in water quality. At Station 2, the Water Quality Index (WQI) values which incorporate the effects of several pollutants, including heavy metals exceeded 700, indicating exceptionally low water quality that is unfit for human consumption.

Oral ingestion and skin contact exposure methods were also used to evaluate the health concerns associated with heavy metals in surface water from the Ossiomo River. The evaluation took into account both carcinogenic and non-carcinogenic risks for adults and children in accordance with United States Environmental Protection Agency (USEPA) criteria. Target Hazard Quotient (THQ) and Hazard Index (HI) were used to estimate non-carcinogenic risk. HI is the total of THQs for all pollutants across a certain exposure pathway, whereas THQ is the ratio of a contaminant's chronic daily intake (CDI) to its reference dose (RfD). Potential health concerns are indicated by a THQ or HI value greater than 1. According to the study, both adults and toddlers had oral HI values more than 1, suggesting that drinking the water could be harmful to one's health but not cause cancer. Notably, THQ

readings for cadmium (Cd) were higher than the acceptable threshold (1.14 in adults and 2.50 in children). Additionally, the HI for children by dermal exposure was greater than 1, indicating increased risk even through skin contact. Particularly in youngsters, other metals including chromium (Cr) and total hydrocarbon content (THC) also made a substantial contribution to the HI values. These results underscore the susceptibility of youngsters, whose lower body weight and developmental stage make them more vulnerable to heavy metal toxicity. Developmental problems and growth stunting have been associated with an increased non-carcinogenic risk in youngsters.

The incremental lifetime cancer risk model was used to assess the carcinogenic risk (CR) from heavy metals. CR is computed as the product of each metal's cancer slope factor (CSF) and CDI. According to the study, chromium (Cr) accounted for 98.34% of the overall carcinogenic risk in adults and 91.09% in children, making it the primary cause of cancer risk. Chromium concentrations were high (1.19×10^{-2} for adults and 2.61×10^{-3} for children), despite not exceeding NESREA's allowable limits (0.1 mg/L). According to risk classification algorithms, the integrated carcinogenic risk (ICR) values were determined to be 1.21×10^{-2} for adults and 2.48×10^{-3} for children, placing them in Grade VII (very high risk). For people that depend on the river for domestic activities or drinking, these values greatly exceed the USEPA's allowed limit for carcinogenic risk (1×10^{-1} to 1×10^{-1}), indicating a major public health concern. Furthermore, while to a lesser degree than chromium, lead (Pb) and cadmium (Cd) also increased the risk of cancer. Cadmium exceeded the permitted level in both adults and children, although lead CR values were below the acceptable range (1.13×10^{-2} in adults and 3.29×10^{-1} in children). Both carcinogenic and non-carcinogenic dangers exist for adults and children, particularly through oral ingestion, according to the Health Risk Assessment results from the Ossiomo River study. Heavy metals including lead, cadmium, and chromium can cause developmental problems in children as well as an increased lifetime

risk of cancer. These results reinforce the urgent need to identify and mitigate pollution sources within the catchment area, provide alternative sources of drinkable water, and regularly monitor water bodies.

A study on the evaluation of the water quality of the Obueyinomo River in the Ovia North East Local Government Area, Edo State, Southern Nigeria, was carried out by Enuneku *et al.* (2017). The river's physicochemical characteristics were examined. Stations 1, 2, and 3 had mean ambient temperatures of 30.14 ± 1.28 , 29.80 ± 1.19 , and $29.46 \pm 1.73^\circ\text{C}$, respectively. Stations 1, 2, and 3 had mean water temperatures of 26.18 ± 0.93 , 26.04 ± 0.94 , and $25.38 \pm 0.84^\circ\text{C}$, respectively, which were within the Federal Ministry of Environment's (FMEnv) 35°C limit. In stations 1, 2, and 3, the average total dissolved solids readings were 19.43, 9.89, and 7.42, respectively. In stations 1, 2, and 3, the average total suspended solids readings were 4.93 mg/L, 5.40 mg/L, and 9.73 mg/L, respectively. At stations 1, 2, and 3, the average total solids values were 23.70 ± 15.04 , 15.29 ± 10.40 , and mg/l, respectively. The average concentrations of suspended particles and total dissolved solids at each location were within the FMEnv limits for surface water. Turbidity mean values were 8.67 ± 5.65 , 12.07 ± 9.41 , and 16.33 ± 6.06 NTU in stations 1, 2 and 3 respectively. All of the stations' turbidity levels did not meet the FMEnv. recommended standard of 5.00 NTU for surface water. The presence of decomposing organic waste may be the cause of these comparatively high turbidity levels. The pH readings were 6.31 ± 0.45 , 6.12 ± 0.60 , and 6.21 ± 0.40 on average. The Obueyinomo River's somewhat acidic state is characteristic of tropical waterways. The average pH values at each location were below the FMEnv. recommended range of 6.50 to 8.50 for surface water. Station 1 recorded the maximum electrical conductivity value ($80.00 \mu\text{S}/\text{cm}$), whereas all stations recorded the lowest value ($10.00 \mu\text{S}/\text{cm}$) at various time periods. In stations 1, 2, and 3, the average electrical conductivity values were 36.67 ± 31.45 , 18.67 ± 12.61 , and $14.00 \pm 5.48 \mu\text{S}/\text{cm}$, respectively. In stations 1, 2, and 3, the mean hardness

values were 9.33 ± 3.13 , 11.33 ± 4.88 , and 10.27 ± 2.39 mg/l, respectively. There was no discernible difference in the hardness levels between the stations. Stations 1, 2, and 3 had mean alkalinity levels of 9.87 ± 2.38 , 11.60 ± 3.00 , and 16.13 ± 12.80 mg/l, respectively. Stations 1, 2, and 3 had mean DO values of 4.27 mg/L, 2.82 mg/L, and 2.04 mg/L, respectively. The Duncan multiple range test revealed that station 1 was the source of the substantial difference ($p < 0.05$) in the dissolved oxygen values across the stations. The Obueyinomo River's dissolved oxygen levels were below the FMEnv-recommended threshold of 7.50 mg/L for surface water. Station 3 had the highest mean BOD value (1.93 mg/L), while Station 2 had the lowest value (1.23 mg/L). Stations 1, 2, and 3 had mean BOD values of 1.76 ± 0.73 , 1.23 ± 0.63 , and 1.93 ± 0.99 . There was no discernible difference between the three stations' BOD readings ($p > 0.05$). Station 3 had the highest chloride value (21.18 mg/L), whereas Station 1 had the lowest value (11.72 mg/L). In stations 1, 2, and 3, the average chloride readings were 13.17 ± 2.12 , 14.11 ± 1.66 , and 14.58 ± 3.87 mg/l, respectively. Station 1 had the highest mean nitrate value (1.44 mg/L), whereas Station 3 had the lowest (0.96 mg/L). At stations 1, 2, and 3, the nitrate concentrations in the water were 1.44 ± 1.47 , 1.01 ± 0.68 , and 0.96 ± 0.64 mg/l, respectively. In stations 1, 2, and 3, the mean phosphate readings were 0.48 ± 0.66 , 0.56 ± 0.85 , and 0.50 ± 0.69 mg/l, respectively. The study's findings demonstrated that chloride predominated over other anions, such as phosphate and nitrate. Station 2 had the highest mean calcium value (2.03 mg/L), while Station 1 had the lowest (1.81 mg/L). In stations 1, 2, and 3, the mean calcium readings were 1.81 ± 0.40 , 2.03 ± 0.82 , and 1.92 ± 0.44 mg/l, respectively. The concentration of calcium was higher than that of magnesium. The Obueyinomo River's calcium levels were in good agreement with the FMEnv-recommended threshold of 5.00 mg/L for surface water. The mean magnesium levels in stations 1, 2, and 3 were 1.17 ± 0.60 , 1.52 ± 0.84 , and 1.33 ± 0.58 mg/l, respectively. In summary, the physicochemical properties of a section of the Obueyinomo River were evaluated to ascertain

their temporal and geographical variability as well as their quality and appropriateness for human consumption. The remaining physicochemical characteristics were within the Federal Ministry of Environment's surface water norm, with the exception of turbidity, pH, BOD, and DO. This study also showed that because the estimated WQI was more than 100, the water samples from this river should be treated before being consumed by humans.

Egun and Oboh, (2023) investigated the water quality and human health risk of Owan river in Edo State, Nigeria and they found that the water physico-chemical parameters from sampled locations were within their respective National Environmental Standards and Regulation Enforcement Agency (NESRA) permissible limits, with the exception of pH (< 6.5), dissolved oxygen ($< 6.0 \text{ mg L}^{-1}$), cadmium ($> 0.005 \text{ m/L}^{-1}$), manganese ($> 0.05 \text{ mg L}^{-1}$), and total hydrocarbon content (THC) ($>10 \text{ mg L}^{-1}$).

The water body was slightly contaminated and unfit for human consumption (WQI > 50), according to the comprehensive pollution index (0.4–1.0) and water quality index (251.57–765.37) values. According to a health risk assessment, oral exposure to heavy metals predisposed both adults and children to non-carcinogenic risk ($H_{\text{oral}} > 1$) and carcinogenic risk (ICR: $1.21\text{E}-02$ and $2.84\text{E}-03$).

Ibe *et al.* (2019) conducted a study on the Inyishi River in Southeastern Nigeria regarding the use of assessment models for pollution and health risk from effluent discharge into a tropical stream. The pH values of the samples ranged from 4.10 to 8.36, with sample S3 having the lowest value and sample S4 having the highest, according to the physicochemical parameters that were examined. Sample S4 had alkaline behavior due to the untreated alkaline effluent from the aluminum extrusion firm, but sample S3's high pH could be attributed to the sulfuric acid level in the wastewater effluent. Samples S1 and SR likewise showed low pH values, and sample SC's pH level was slightly below the WHO standard. With the exception of

sample S4, none of the samples' pH values met the NSDWQ and WHO requirements for household water. The research area's EC values ranged from 0.05 to 2235 $\mu\text{s}/\text{cm}$; river water samples had lower EC values than wastewater samples, which had much higher EC. With the exception of sample S3, which has high EC values exceeding the two specified levels, all of the samples' EC values are below the NSDWQ and WHO standards for safe drinking water. With the exception of sample SR and SC, all sample locations had high total dissolved solids (TDS) levels that were within the NSDWQ and WHO permitted limits. The TDS readings vary from 16 to 1117500 mg/L, with sample S3 having the highest TDS level and sample SC having the lowest. The TH values were found in the following order: S4 > S1 > SR > S2 > SC. Sample S4 had the greatest TH level, while SC had the lowest. The TH readings reported in the research region ranged from 10.02 to 22.4 mg/L, and they were well below the limits set by the WHO and Nigeria Standard for Drinking Water Quality (NSDWQ).

The results of the investigation into the quantities of heavy metals show that the concentration of Al ranges from 0.04 ± 0.00 mg/L for sample S1 to 64.9 ± 0.03 mg/L for sample S3. The research area's concentrations of aluminum are as follows: S3 > S4 > S2 > SR > S1 > SC. With the exception of S1, S2, SR, and SC, all samples exhibited values above WHO and Nigeria criteria for drinking water quality (NSDWQ). The study area's Cr concentrations varied from 0.008 ± 0.002 to 0.06 ± 0.001 mg/L in the following decreasing order: S2 > S4 > S1 > S3 > SR. The sample location S2 had the highest detected concentration level of Cr. Cr values for five sample locations were determined to be within the levels recommended for residential water consumption by NSDWQ and WHO, except for sample S2 which was slightly higher than the norms. The Zn levels found in the study area varied from 0.001 ± 0.00 mg/L for sample S2 to 30.0 ± 0.02 mg/L for sample S3. Sample S3's zinc concentration was shown to be greater than expected. The concentrations of Cd for all the samples were found to be over the acceptable standards with the values ranging from

0.02 ± 0.00 to 0.065 ± 0.001 mg/L. The observed Cd values are as follows: SR > S3 > S1 > S2 > S4 > SC. Fe values were found at sample locations SC and S1, respectively, ranging from 0.050 ± 0.001 mg/L to 10.57 ± 0.05 mg/L. With the exception of SC, elevated Fe concentrations exceeding the NSDWQ and WHO-recommended tolerable limits were found at every location in the region. The order in which these higher concentrations were noted was S1 > S4 > S3 > S2 > SR > SC. Manganese (Mn) concentrations found in samples throughout the research area varied from 0.45 ± 0.003 mg/L in S1 to 0.68 ± 0.002 mg/L at sample location SR. When compared to other samples, the Inyishi River samples had higher Mn concentrations.

The Inyishi River water's dermal adsorption of heavy metals was less than 1.00 for both adults and children, according to the health risk assessment results, indicating a minimal health risk to the local population. Additionally, the HQ_{derm} values were less than 1.00, indicating that dermal adsorption of the Inyishi River water poses no concern to human health. Both adults and children who were exposed to the water of the Inyishi River through skin contact had a health hazard index (HI) of less than unity. Even when HI is less than 1, long-term exposure may offer major health risks to both adults and children, therefore this should be addressed carefully. Values for HQ and HI are below the safe limit of unity, according to the overall health risk analysis conclusion. This suggests that there might not yet be any cumulative possible harmful health risk from the river water's cutaneous adsorption. In conclusion, more treatment of the wastewater effluents should be taken into consideration in order to lessen its impact on the Inyishi River water, the environment, and the local residents who utilize the Inyishi River water for a variety of domestic purposes.

In the Ogun River in Nigeria, Onoyima *et al.* (2025) evaluated the surface water quality and health risk of a few potentially hazardous elements. From 153.49 ± 5.01 NTU at L1 in Year 1 to 323.67 ± 25.1 NTU at L3 in Year 2, turbidity levels were continuously higher during the

dry season. Turbidity decreased throughout the wet season, reaching as low as 26.38 ± 2.44 NTU at L4 in Year 1. This was mostly caused by increased dilution and sediment settling. Similar seasonal patterns were seen in electrical conductivity (EC), which peaked during the dry season at 9.15 ± 0.00 $\mu\text{S}/\text{cm}$ at L2 in Year 1 and 2.12 ± 0.01 $\mu\text{S}/\text{cm}$ at L3 in Year 2. In contrast, values during the rainy season were significantly lower, such as 0.07 ± 0.01 $\mu\text{S}/\text{cm}$ at L1 in Year 1. During the dry season, total dissolved solids (TDS) peaked at 1665.56 ± 0.8 mg/L at L3 in Year 2. However, during the rainy season, TDS levels drastically dropped, reaching as low as 58.11 ± 5.00 mg/L at L1 in Year 1. The pH ranged from alkaline (8.68 ± 0.05 at L4 in Year 1 dry season) to acidic (6.30 ± 0.08 at L2 in Year 2 dry season). Lower pH values frequently corresponded with increased turbidity and TDS, indicating pollution intake. Higher solids were linked to lower pH, according to correlation analysis, which revealed strong negative connections between pH and turbidity ($r = -0.80$) and between pH and TDS ($r = -0.75$). Cd and pH showed a comparable negative association ($r = -0.64$), indicating higher Cd bioavailability in acidic environments. TDS and turbidity ($r = 0.77$) and TDS and Cr ($r = 0.66$) showed positive associations, suggesting that these measures have similar sources of contamination.

The main contaminants were heavy metals, including Cd, Pb, Cr, Cu, and Zn, whose concentrations regularly above permissible levels. The levels of cadmium (Cd) increased significantly during the rainy season, reaching 0.398 ± 0.012 mg/L at L4 in Year 1, and varied from 0.022 ± 0.011 mg/L at L1 in Year 1 dry season to 0.468 ± 0.011 mg/L at L4 in Year 2 dry season. At every site, they were higher than the WHO limit of 0.003 mg/L. Concentrations of lead (Pb) were continuously higher than the 0.01 mg/L WHO standard, 1.452 ± 0.571 mg/L at L1 during the first dry season and 1.392 ± 0.348 mg/L at L4 during the first wet season. In the first dry season, chromium (Cr) was mostly undetectable; nevertheless, in the second dry season, it reached 0.301 ± 0.231 mg/L at L3. Zinc (Zn) varied greatly from

non-detectable levels at L4 in Year 2 dry season to 2.102 ± 1.128 mg/L at L2 in Year 1 rainy season, while copper (Cu) ranged from 0.218 ± 0.001 mg/L at L3 in Year 1 dry season to 0.797 ± 0.302 mg/L at L3 in Year 2 dry season. Seasonal variation showed that stormwater runoff and sediment resuspension caused heavy metals, especially Cd and Pb, to rise in concentration during the wet season. On the other hand, due to dilution, physicochemical characteristics like as TDS and turbidity tended to decline during the wet season. Because of the river's great mobility, which distributes pollutants uniformly, there was little spatial variation in the pollutant concentrations across the locations. The findings indicate that oral exposure to zinc poses no non-carcinogenic risk ($HQ < 1$) for adult and pediatric populations at all sample sites during the study period. With the exception of L3 of February year 2 (Cu exclusively for children and Cr for adults and children), there was also no non-carcinogenic risk associated with Cu and Cr. However, oral exposure to Cd and Pb posed a considerable non-carcinogenic risk ($HQ > 1$) for both adult and pediatric populations across all locales and research periods. The following is the order of the heavy metals' percentage contributions to the overall non-carcinogenic risk from oral exposure: $Cd > Pb > Cr > Cu > Zn$. The findings indicate that Pb and Cd account for 98.27% of the overall risk and are the main contributors to the oral non-carcinogenic risk. Because they play no part in biological processes, Pb and Cd are non-essential metals in living things. The recommended range for carcinogenic risk is between 1×10^{-6} and 1×10^{-4} ; less than 1×10^{-6} implies no risk, and more than 1×10^{-4} indicates a considerable cancer risk. Adults' cancer risk from oral exposure varied from 3.87×10^{-4} to 1.39×10^{-2} for Cd, from 6.43×10^{-5} to 1.45×10^{-4} for Pb, and from 0 to 1.77×10^{-3} for Cr. These findings show that oral exposure to Cd poses a substantial risk of cancer at every sampling site. At 31.25% and 62.50% of the sampling locations, respectively, oral exposure to Pb and Cr posed a considerable cancer risk for the adult populations. For Pb and Cr, respectively, the remaining 68.75% and 37.50% of the locations fall within the

permissible limit. These indicate that these metals should be investigated further as substances of concern for the community under study. Cd ranged from 1.21×10^{-4} to 4.37×10^{-3} , Pb from 3.36×10^{-8} to 7.56×10^{-8} , and Cr from 0 to 7.381×10^{-4} , according to the dermal route data. At every site under investigation, dermal exposure to cadmium posed a substantial cancer risk to the adult population. While Cr presents a major health risk at 31.25% of the sites, CR for Pb shows no significant dermal risk at any of the locations examined. The Ogun River was severely contaminated overall, with over 98% of the non-carcinogenic health concerns being caused by Cd and Pb. In all seasons and at every location, the river was rated as "very poor" or "seriously polluted" by all water quality indices (WWQI, CWQI, CPI, HPI). Heavy metal contamination increased during the wet season, although physicochemical quality improved as a result of dilution. These results highlight the critical need for corrective action to lower Cd and Pb levels and safeguard public health.

Adeleke *et al.* (2022) examined how the concentrations of heavy metals, including lead (Pb), copper (Cu), chromium (Cr), manganese (Mn), iron (Fe), zinc (Zn), nickel (Ni), and cadmium (Cd), varied seasonally in the effluents and receiving waters of the Iguosa and Ikpoba Rivers in Benin City, Edo State. Metal concentrations during the wet and dry seasons were measured using Atomic Absorption Spectrometry (AAS). The findings showed that high levels of heavy metals were present in the effluents from Guinness Nigeria Plc and the 7-Up Bottling Company. The following values were noted for 7-Up effluents during the rainy season: Pb (0.28 mg/L), Cu (2.84 mg/L), Cr (8.16 mg/L), Mn (1.49 mg/L), Fe (7.55 mg/L), Zn (8.57 mg/L), and Ni (1.66 mg/L). Pb (0.75 mg/L), Cu (2.62 mg/L), Cr (2.96 mg/L), Mn (6.63 mg/L), Fe (4.96 mg/L), Zn (7.98 mg/L), and Ni (1.69 mg/L) were among the quantities found in Guinness Plc's wet season effluent. In general, these results were higher above the FEPA and WHO permitted limits, especially for iron, zinc, and chromium.

Interestingly, the seasonal variation significantly affected concentration levels; higher metal concentrations were found during the wet season, most likely as a result of increased runoff and effluent discharge during rainfall. Lead (Pb) and cadmium (Cd) were an exception, with occasionally slightly higher readings during the dry season. The higher quantities of Zn and Cr in particular indicated that these metals might be abundant in industrial raw materials used in manufacturing processes. In comparison to the effluents, downstream water samples displayed lower quantities, suggesting dilution by river flow. The rivers' poor assimilative ability, however, is demonstrated by the fact that downstream concentrations still exceeded advised limits, creating long-term dangers to human health and the environment. Even though cadmium levels were the lowest of all the metals examined, several samples—particularly those from effluent discharges—still had levels beyond accepted safety limits. Although below the 20 mg/L standard, iron concentrations ranged from 0.31 mg/L to 7.55 mg/L, indicating substantial input from industrial sources. The results of Adeleke *et al.* (2022) unequivocally show that heavy metal pollution in Benin City's urban rivers is mostly caused by industrial effluents. The existence of several metals over allowable limits suggests that industrial discharge needs to be better regulated and treated. In order to stop additional deterioration of these surface waters and safeguard the communities that depend on them for residential and recreational purposes, it is imperative that effluent standards be continuously monitored and enforced.

An initial health risk assessment of water from the Asa River in Ilorin, North-Central Nigeria, was carried out by Omotoso *et al.* (2021). The findings showed that while other elements were below allowable limits, iron (Fe), manganese (Mn), and aluminum (Al) had amounts exceeding the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) standards. In particular, the limitations of 0.3 ppm, 0.5 ppm (0.2 ppm for NSDWQ), and 0.2 ppm were exceeded by the average concentrations of 4.801 ppm for Fe,

1.611 ppm for Mn, and 0.791 ppm for Al. Using Mean Composition of World Rivers (MCWR) values as background levels, the contamination factor study revealed very high contamination for Fe (72.7) and extremely high contamination for Mn (3835.4), whereas Al exhibited a moderate contamination factor (2.5). The average degree of contamination for these three metals was 3910.61, which indicates a very high level of pollution, especially in sample points ASA-2, ASA-3, and ASA-4, where there is a lot of anthropogenic and agricultural activity.

Fe (181.37 $\mu\text{g/kg/day}$), Mn (60.85 $\mu\text{g/kg/day}$), Al (29.90 $\mu\text{g/kg/day}$), and barium (Ba) (5.87 $\mu\text{g/kg/day}$) had values over the safe threshold of unity for adults, indicating possible non-carcinogenic concerns, according to the health risk assessment using exposure dosage analysis. Fe (576.12 $\mu\text{g/kg/day}$), Mn (193.30 $\mu\text{g/kg/day}$), Al (94.97 $\mu\text{g/kg/day}$), Ba (18.64 $\mu\text{g/kg/day}$), and zinc (Zn) (1.31 $\mu\text{g/kg/day}$) all exceeded safe limits for children, suggesting that children are more vulnerable because of their lower body weight. These conclusions were further supported by the hazard quotient (HQ) values. While Mn had a substantially higher HQ of 4.20 in children, only Mn (average HQ = 1.32) exceeded the safe value of 1 in adults. Additionally, Fe found that children had HQ values greater than 1 in a few areas (ASA-3, ASA-4, ASA-5, and ASA-9), suggesting site-specific higher hazards. Adults' hazard index (HI) varied from low to high risk among sites, ranging from 0.12 to 5.80 with an average of 1.7. In contrast, children's HI ranged from 0.38 to 18.42, with an average of 5.4, indicating a considerable health risk in many sampling areas. With the exception of Fe in children at certain locations, the average values for all trace elements in both adults and children were generally below 1, according to chronic daily intake (CDI) analysis. In ASA-3 (1.2), ASA-4 (1.6), and ASA-9 (1.8), Fe recorded CDI values greater than 1, indicating long-term ingestion concerns for children in these areas. Despite having high Mn levels, their CDI values were still less than 1. According to the carcinogenic risk (CR) assessment for lead (Pb)

and chromium (Cr), average values for both metals in adults and children were higher above the acceptable risk levels (10^{-1} to 10^{-1}), suggesting that drinkers of the river water may be at risk for cancer. Cr and Pb had average CR values of 0.0002 and 0.02, respectively, for adults and 0.00005 and 0.06 for children. These results indicate that there are both carcinogenic and non-carcinogenic health dangers, with Pb and Cr being the primary carcinogenic hazards and Mn and Fe being the most non-carcinogenic threats.

A study on the health risk assessment of some heavy metals and nitrate in the surface water of the River Kaduna in Nigeria was conducted by Onoyima and Nwoye in 2022. The findings demonstrated that the range of pollutant concentrations (mg/kg dry weight) in the area under study was as follows: Cu (0.157 ± 0.008 – 0.347 ± 0.003), Cd (0.037 ± 0.004 – 0.103 ± 0.034), Cr (0.416 ± 0.106 – 0.786 ± 0.014), Zn (0.009 ± 0.001 – 0.012 ± 0.001), Pb (0.099 ± 0.032 – 0.994 ± 0.081), Fe (22.656 ± 0.179 – 34.500 ± 0.037), and NO₃⁻ (9.467 ± 0.005 – 9.500 ± 0.023). The contaminants' mean concentrations decreased in the following order: Fe > NO₃⁻ > Pb > Cr > Cu > Cd > Zn. Cu, Zn, and nitrate were within the WHO maximum allowable range for drinking water, while Cd, Cr, Pb, and Fe were over it.

Oyetunji *et al.* (2023) carried out a study on the Eleyele River's water quality in Oyo State and evaluated the river's physicochemical properties and heavy metal concentrations at the surface and at a depth of one meter in relation to WHO guidelines. The results showed that the river water was somewhat acidic but still adequate for aquatic life and household use, with pH values of 6.91 at the surface and 6.80 at 1 m deep falling within the approved WHO range of 6.5–8.5. Similar to this, the temperature (26.1–26.2 °C) and total dissolved solids (151.8–170.4 mg/L) were both within allowable bounds, indicating comparatively stable thermal conditions and appropriate dissolved ion concentrations. WHO standards were also satisfied by nutrient measurements such nitrate (0.51–1.006 mg/L), nitrite (0.062–0.078

mg/L), and phosphate (0.036–0.076 mg/L), indicating low nutrient enrichment and a lower danger of eutrophication.

Nevertheless, some metrics were below the suggested limits. In comparison to the WHO norm of 5 mg/L, dissolved oxygen (DO) concentrations were notably low (1.148 mg/L at the surface and 0.804 mg/L at 1 m depth), suggesting potential organic contamination and decreased oxygen availability for aquatic life. Similarly, electrical conductivity (0.308–0.34 $\mu\text{S}/\text{cm}$) was significantly lower than the typical range (50–500 $\mu\text{S}/\text{cm}$), indicating low mineralization and ionic activity that could affect the water body's productivity and buffering ability.

Important issues were brought to light by the heavy metal analysis. Other metals surpassed WHO guidelines, although magnesium (7.27–7.49 mg/L) and chromium (0.041 mg/L at the surface) stayed within permissible bounds. The acceptable limit of 0.3 mg/L was exceeded by iron concentrations (0.672 mg/L at the surface and 0.564 mg/L at 1 m depth), increasing the possibility of discolouration, altered taste, and negative health effects. Lead levels (0.023–0.026 mg/L) were likewise much higher than the standard limit of 0.01 mg/L, and zinc levels (0.0106–0.0258 mg/L) exceeded the guideline of 0.01 mg/L. Because these metals are hazardous and persistent in aquatic environments, elevated amounts of them are alarming. Copper, cadmium, and nickel, on the other hand, were not found, indicating little pollution from these sources. Overall, the study showed that although the majority of the Eleyele River's physicochemical parameters passed WHO requirements, the low DO levels and high iron, zinc, and lead concentrations are important markers of declining water quality. These results highlight the necessity of ongoing Eleyele River monitoring and the use of heavy metal and water pollution indices to measure the river's pollution level and determine if it is suitable for residential, agricultural, and ecological uses.

CHAPTER THREE

MATERIALS AND METHODS

3.1 DESCRIPTION OF THE STUDY AREA

The Orhionmwon River is situated in the southern Nigerian state of Edo State's Orhionmwon Local Government Area. Orhionmwon is located in the southeast of Edo State, which is roughly between latitudes $5^{\circ}44'N$ and $7^{\circ}34'N$ and longitudes $5^{\circ}4'E$ and $6^{\circ}45'E$. The Local Government Area is one of the largest in the Edo South senatorial district, covering an area of roughly 2,382 km². In addition to neighboring local government areas like Uhumwonde and Esan South East to the north and west, respectively, the region is bordered to the east and

south by Delta State. The Orhionmwon Local Government Area is made up of a number of rural and semi-urban communities that are distinguished by subsistence farming, commerce, and fishing, such as Abudu (the administrative center), Ugo, Igbanke, Urhonigbe, and Evboesi. The river provides essential water for home, agricultural, and small-scale industrial applications as it passes through a number of rural and semi-urban communities. The nearby villages also use it for recreational activities including fishing. Farming, fishing, small-scale commerce, and palm oil production are the main jobs in the region. It is important for recreational and religious uses, as well as for irrigation and cattle watering in local agriculture. It has rural communities strewn throughout an area of farms and forests. Based on accessibility, three sampling stations were used to gather water samples from the Orhionmwon River. These locations are:

Station 1: Upstream	N 06°12. 210' E 005°45. 637'
Station 2: Midstream	N 06°12. 118' E 005°45. 567'
Station 3: Downstream	N 06°12. 083' E 005°45. 439'

From May 2025 until July 2025, three (3) months of sampling were conducted. The study area's map is displayed in **Figure 3.1**.

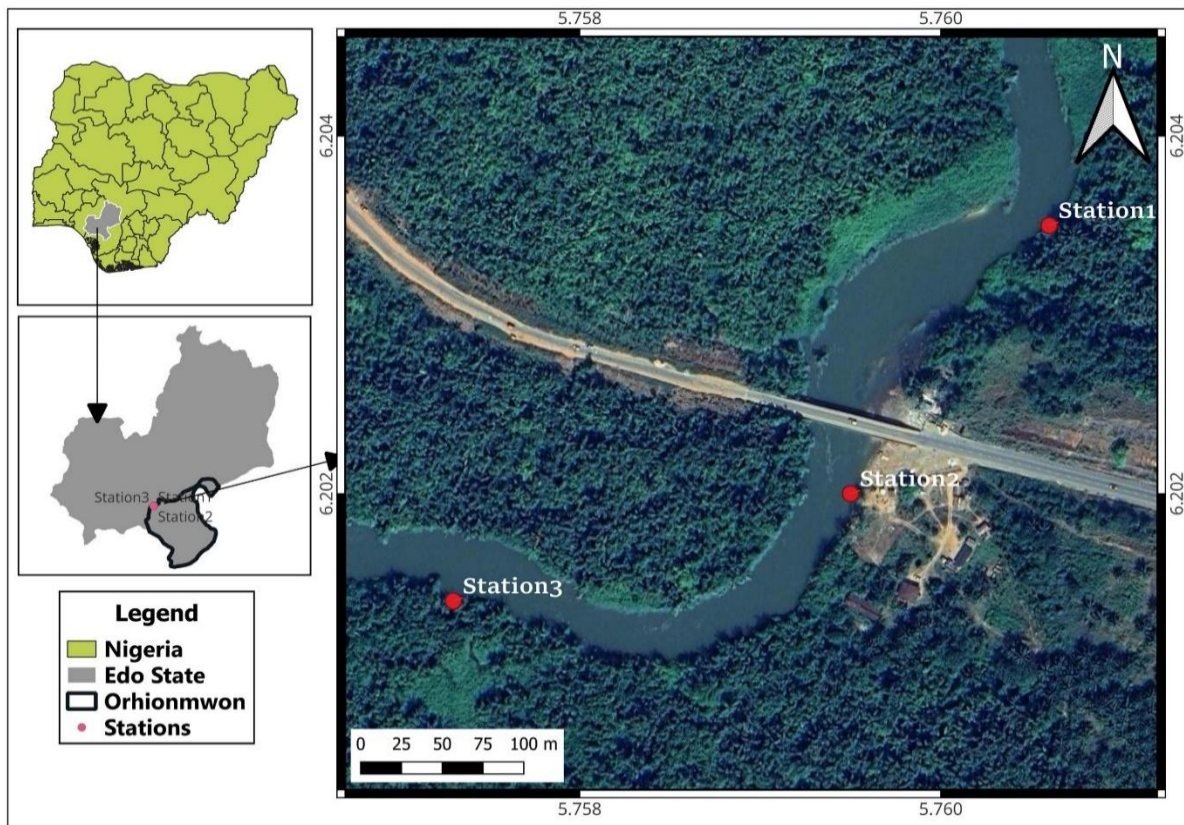


Figure 3.1: Map of Orhionmwon River showing the sampling stations

3.2 MICROCLIMATE OF THE STUDY AREA

The research region is part of Nigeria's vast lowland forest system, which offers substantial biodiversity, dense vegetation, and a humid environment that promotes biodiversity and water retention. The region has a tropical rainforest environment with two distinct seasons: the dry season, which runs from November to March, and the wet season, which usually lasts from April to October. The heaviest precipitation is usually recorded in July and September, with an average annual rainfall of 1,500 to 2,500 mm. During the rainy season, the average temperature is between 25°C and 32°C, while the relative humidity is between 70% and 85%. The climate promotes agriculture and affects the Orhionmwon River's hydrological regime.

During the rainy season, there is a lot of surface runoff, which can increase the number of pollutants that wash into the river system from waste disposal sites, open defecation zones, and agricultural fields. This could have an impact on the water quality of the river.

3.3 COLLECTION OF SURFACE WATER SAMPLES

The Orhionmwon River in Edo State was chosen as the source of typical water samples for this investigation. Based on human activity and possible sources of pollution, three sampling stations were carefully chosen: an upstream (control) station, a midstream station close to residential areas and agricultural zones, and a downstream station. All sampling tools and containers were completely cleaned and labeled before sampling. Using conventional protocols, water samples were taken from each of the three (3) monitoring stations for chemical and physical analysis. Water samples were taken at a depth of roughly 10 cm below the river's surface. Surface water was collected in amber bottles with stoppers for the study of dissolved oxygen (DO) and biochemical oxygen demand (BOD). To fill the bottles, the stopper was taken off. The bottles were then immersed at a temperature of roughly 10 degrees Celsius below the water's surface to collect water samples. To avoid trapped air bubbles, the cork was restored right away. The Winkler solution method was used to determine the amounts of dissolved oxygen (DO). The samples were mixed with 1 millilitre of Winkler A solution (magnesium sulphate) and Winkler B solution (potassium iodide-sodium hydroxide). Water samples were taken in clear, clean reagent vials for the heavy metals analysis, and 1 millilitre of nitric acid (HNO₃) was added to fix the metal contents. Additionally, water samples were gathered in clear, clean reagent bottles for the total hydrocarbon analysis. After being collected, water samples were brought to the lab on ice for physicochemical parameter analysis. When the water samples arrived at the lab, they were refrigerated at 4°C prior to solid phase extraction. Every piece of field equipment was thoroughly examined and

calibrated in compliance with the manufacturer's specifications. The water samples collected are shown in **Plate 3.1**.



Plate 3.1: Water samples from study area

3.4 SAMPLING STATIONS

Three (3) sampling stations were strategically selected along the Orhionmwon River based on human activities and potential pollution sources. It was decided that Station 1 was upstream, Station 2 was midstream, and Station 3 was downstream. A Global Positioning System (GPS) was used to georeference the sampling stations.

3.4.1 STATION 1 (UPSTREAM)

Station 1 was situated near the river's upper course, which is between latitude N 06°12. 210' and longitude E 005°45. 637' (**Plate 3.2**). Because it is located upstream, far from populated areas and human activity, this station functioned as the control point. The surrounding area is ideal for determining the river's baseline water quality because it is mostly made up of naturally occurring flora with little modification. Tall oil palm trees (*Elaeis guineensis*) and thick undergrowth dominated the vegetated riverbed. The serene river in the foreground has somewhat brownish water, which could be a sign of organic debris from the nearby plants or silt runoff. A tropical rainforest ecosystem with significant rainfall and constant humidity is shown by the luxuriant vegetation. Oil palm trees, distinguished by their high trunks and long, feathery fronds, are the predominant flora in the background. These palms are widespread in both cultivated and natural environments and are indigenous to West Africa. Their existence implies that the region may be near human activities, such as small-scale farming, or it may be a naturally occurring forest rich in palm trees. The undergrowth is dense with a variety of green vegetation beneath the palm canopy, including herbaceous shrubs, creeping vines, and large-leafed plants like *Colocasia* (elephant ears). These plants are typical of riparian zones and flourish in the damp, shady habitat that the higher trees provide. Their dense growth serves as a barrier against soil erosion, filters runoff that enters rivers, and creates habitats for both terrestrial and aquatic wildlife.



Plate 3.2: Station 1 lies between latitude N 06°12. 210' and longitude E 005°45. 637'

3.4.2 STATION 2 (MIDSTREAM)

Station 2 was located at latitude N 06°12. 118' and longitude E 005°45. 567' in the middle of the river (**Plate 3.3**). Station 2 is situated in close proximity to the Orhionmwon River bridge, residential communities, and agricultural and palm oil processing operations. Small-scale trade, home garbage disposal, and fishing are among the human activities that have the greatest impact on this region. Under an overcast sky, Station 2 features a riverine scene with thick vegetation bordering the riverside. Clusters of oil palm trees (*Elaeis guineensis*), distinguished by their long, feather-like fronds and tall, erect stems, dominate the riverfront. With a variety of crawling vines, shrubs, and grasses, many of which are typical of moist tropical regions, the undergrowth is dense and luxuriant. The ecological health of the water body and the stability of the riverbank are greatly enhanced by the vegetation depicted.



Plate 3.3: Station 2 lies between N 06°12. 118' and longitude E 005°45. 567'

3.4.3 STATION 3 (DOWNSTREAM)

Station 3 was situated at latitude N 06°12. 083' and longitude E 005°45. 439' on the river's lower course (**Plate 3.4**). Because runoff flows downstream, the downstream station is essential for assessing the overall effect of human activity on the river's water quality. The region is known for its wide range of semi-aquatic and water-loving plants that flourish in damp, tropical climates. Large, heart-shaped leaves that resemble *Colocasia* or *Alocasia* species also referred to as taro or elephant ear plants stand out among the greenery. Tall, thin grasses or sedges possibly *Cyperus* species that are typical of marshy and wet environments can also be seen. Numerous creeping vines and climbers that rely on the surrounding vegetation for support are interwoven with the dominating plants. Additionally, there are indications of low-lying leafy plants and semi-aquatic bushes growing just at the water's edge. These include species like wild pepper vines and *Ipomoea aquatica*, or water spinach.



Plate 3.4: Station 3 lies between latitude N 06°12. 083' and longitude E 005°45. 439'

3.5 SAMPLING PERIODICITY

Three sampling excursions will be made over the course of three months, from May 2025 to July 2025. The dry season and the rainy season were included in the study period. On each sampling day, water samples were taken between 7:00 and 9:00 am. Samples were collected from a designated area of the river. On each sampling day, the Orhionmwon River sampling started at station 1 and ended at station 3. This was done in order to account for the hydrological differences between the rainy and dry seasons. At each location, six (6) water samples were taken.

3.6 LABORATORY ANALYSIS

3.6.1 Physicochemical Parameters

The standard procedures outlined in APHA (2005) were used to physicochemically analyze water samples. Every analysis was done in triplicate, and the average outcomes were noted.

3.6.1.1 Temperature (°C)

A calibrated thermometer or digital probe is used to measure the temperature in situ as soon as the sample is collected. Numerous chemical and biological properties of water are influenced by temperature.

3.6.1.2 pH

A pH meter with a composite glass electrode was used to measure water samples. Standard buffer solutions (pH 4.0, 7.0, and 10.0) were used to calibrate the pH meter. After stirring the water sample to stabilize the temperature, the electrode was submerged and the stable readings were recorded. pH is essential for treating water since it shows acidity or alkalinity.

3.6.1.3 Electrical Conductivity (EC) ($\mu\text{S}/\text{cm}$)

A conductivity meter was used to determine the electrical conductivity. Standard potassium chloride (KCl) solutions were used to calibrate the meter. Following the mixing of the

materials, the probe was submerged in the sample container until a consistent reading was achieved, which was then recorded in $\mu\text{S}/\text{cm}$. It gives an approximation of the water's overall ionic content.

3.6.1.4 Total Dissolved Solids (TDS) (mg/L)

A pre-weighed membrane filter was used to filter 100 milliliters of the water samples into a beaker. In a basin that had been previously weighed for dissolved particles, the filtered samples were heated until they were completely dry. After the water had dried, the basin was weighed once more, and the concentration of dissolved solids was determined using the weight difference.

$$\text{TDS (mg/L)} = \frac{(W_2 - W_1) \text{mg} \times 1000}{\text{ml of sample used}} \text{----- equation (1)}$$

Where; W_1 is the initial weight before drying

W_2 is the final weight after drying

Also;

$$\text{TDS} = \text{TS} - \text{TSS} \text{----- equation (2)}$$

Where; TDS is total dissolved solids

TSS is total suspended solids

TS is total solids

3.6.1.5 Total Suspended Solids (TSS) (mg/L)

100 millilitres of the water samples were filtered into a beaker using pre-weighed filter paper. At 103–105 °C, the filtered samples were dried. The dried samples were weighed once again after being left to cool at room temperature.

$$\text{TSS (mg/L)} = \frac{(W_2 - W_1) \text{mg} \times 1000}{\text{ml of sample used}} \text{----- equation (3)}$$

Where; W_1 is the initial weight before drying

W2 is the final weight after drying

Also;

$$TSS = TS - TDS \text{ ----- equation (4)}$$

Where; TSS is total suspended solids

TS is total solids

TDS is total dissolved solids

3.6.1.6 Total Solids (TS) (mg/L)

The gravimetric approach was used to do this. A pre-weighed evaporating plate was filled with 10 milliliters of the samples, which were then oven dried for two and a half hours at a temperature between 103 and 105 degrees Celsius. The dish was weighed after being allowed to cool at room temperature in a desiccator. The weight of the evaporating dish increased, signifying the total solids.

$$TS = TDS + TSS \text{ ----- equation (5)}$$

Where; TS is total solids

TDS is total dissolved solids

TSS is total suspended solids

Also;

$$\text{Total solids (mg/L)} = \frac{(W2-W1)\text{mg} \times 1000}{\text{ml of sample used}} \text{ ----- equation (6)}$$

Where; W1= initial weight of evaporating dish

W2= final weight of the dish (evaporating dish + residue)

3.6.1.7 Turbidity (NTU)

A turbidity meter, also known as a nephelometer, is used to measure it in Nephelometric Turbidity Units (NTU). The turbidity meter was turned on, calibrated, and given time to stabilize. After pouring the sample into a spotless, scratch-free cuvette, the cuvette's outside was cleaned to get rid of any wetness or fingerprints. After inserting the sample cuvette into

the turbidity meter, the lid was shut to prevent interference from stray light. After measuring the scattered light, a reading was obtained. To assure accuracy, the process was carried out three times, and the average was noted.

3.6.1.8 Alkalinity (mg/L)

Titration was used to assess the water samples' alkalinity. Three (3) drops of phenolphthalein, the indicator, were put to a conical flask containing 50 milliliters of the sample. The sample was titrated against 0.025M H₂SO₄ until it lost its color. The titration volume, which shows the concentration of bicarbonate, carbonate, and hydroxide, was used to compute the total alkalinity.

3.6.1.9 Dissolved Oxygen (DO) (mg/L)

A modified Winkler technique was used to determine the amount of dissolved oxygen in the water samples. Before being taken to the lab, 1 milliliter of Winkler A and B reagent was added at the sampling location. Two milliliters of sulfuric acid (H₂SO₄) were used in the lab to dissolve the fixed samples. Five (5) drops of 1% starch were applied as an indication to a conical flask containing 100 milliliters of the sample. The sample was titrated until it turned colorless using 0.2N sodium thiosulphate (titrant). The following formula was used to determine dissolved oxygen:

$$\text{DO (mg/L)} = \text{number of digits on digital titrator} \times \text{digit multiplier (0.04)} \text{ ----- equation (7)}$$

3.6.1.10 Biochemical Oxygen Demand (BOD) (mg/L)

A modified Winkler approach was used to determine the biochemical oxygen demand in the water samples. The water samples were incubated for five days at 20°C in the dark before 1 milliliter of Winkler A and B reagent was added. The precipitates were dissolved using two milliliters of concentrated sulfuric acid (H₂SO₄). Five (5) drops of 1% starch were applied as an indication to a conical flask containing 100 milliliters of the sample. The sample was

titrated until it turned colorless using 0.2N sodium thiosulphate (titrant). The following formula was used to determine biochemical oxygen demand:

$$DO_5 \text{ (mg/L)} = \text{number of digits on digital titrator} \times \text{digit multiplier (0.04)} \text{ ----- equation (8)}$$

$$BOD = DO \text{ initial} - DO \text{ after 5 days (DO}_5\text{)} \text{ ----- equation (9)}$$

3.6.1.11 Chemical Oxygen Demand (COD) (mg/L)

The COD of the water samples was ascertained using the reflux method. Ten millilitres of the water samples were put into round-bottom flasks, and glass beads were added to keep them from bumping. To reduce chloride interference, 1g of mercuric sulphate (HgSO₄) and 5ml of 0.025N potassium dichromate (K₂Cr₂O₇) solution were added to each flask. After adding 15 millilitres of concentrated sulfuric acid with silver sulphate catalyst (AgSO₄ in H₂SO₄), the mixture was gently stirred. On a hotplate, the mixture was broken down for two hours. Following digestion, three drops of ferroin indicator were added to the flasks after they had cooled. A 0.025M ferrous ammonium sulphate solution was used to titrate the excess dichromate until the color shifted from blue-green to reddish-brown. The same procedure was used to a blank made by substituting distilled water for the sample. COD was computed using the following formula:

$$COD(\text{mg/l}) = \frac{(V_b - V_s) \times M \times 8000 \times DF}{V_{\text{sample}}} \text{ ----- equation (10)}$$

Where;

V_b = volume used in the blank titration

V_s = volume used in sample titration

M = molarity of ferrous ammonium sulphate

V_{sample} = volume of sample used

DF = dilution factor

3.6.1.12 Chloride (Cl⁻) (mg/L)

Argentometric titration (Mohr's technique) was used to determine it. Silver nitrate (AgNO₃) was utilized as the titrant in this experiment, and a 10% potassium permanganate (K₂Cr₂O₄) solution served as the end point indicator. The samples that contained the chloride ion precipitated white silver chloride. A conical flask was filled with 0.2 ml of 0.02M silver nitrate and 1 ml of potassium chromate. To create a reddish-brown color comparison blank, 100 milliliters of distilled water were also added. It was left aside to settle after being gently shook. One milliliter of potassium chromate indicator was applied to a conical flask containing 100 milliliters of the water sample. After that, the mixture was titrated with 0.02M silver nitrate while being continuously stirred until a light crimson precipitate developed. The chloride ion concentration was calculated using:

$$\text{Cl}^-(\text{mg/L}) = \frac{\text{Molarity} \times \text{Titre} \times \text{Molecular weight}}{\text{Aliquot taken}} \text{----- equation (11)}$$

3.6.1.13 Nitrate (NO₃⁻) (mg/L)

Ion chromatography or UV spectrophotometry are two methods used to quantify nitrate. A 50 ml flask was filled with 5 ml of the sample, 1 ml of brucine, and 5 ml of concentrated sulfuric acid (H₂SO₄). The solution was shaken after 14 milliliters of distilled water were added to bring it to 25 milliliters. A visible spectrophotometer was used to measure the absorbance at 470 nm.

$$\text{NO}_3(\text{mg/L}) = \frac{\text{instrument reading} \times \text{slope reciprocal} \times \text{final volume}}{\text{aliquot taken}} \text{----- equation (12)}$$

3.6.1.14 Phosphate (PO₄³⁻) (mg/L)

The colorimetric approach is used to determine it. A 50 ml volumetric flask was filled with 5 ml of the sample, 1 ml of ascorbic acid, and 19 ml of distilled water to reach a final volume of 25 ml. After 30 minutes, the blue solution was examined at 880 nm using a visual spectrophotometer.

$$\text{PO}_4(\text{mg/L}) = \frac{\text{instrument reading} \times \text{slope reciprocal} \times \text{final volume}}{\text{aliquot taken}} \text{----- equation (13)}$$

3.6.1.15 Sulphate (SO₄²⁻) (mg/L)

The turbidimetric method is used to measure it. A conical flask was filled with 5 milliliters of the sample. The volume was increased to 25 milliliters by adding 1 milliliter of gelatine-barium chloride (BaCl₂) reagent and 14 milliliters of distilled water. Between adding reagents, the mixture was thoroughly shaken. Next, a visible spectrophotometer was used to detect the absorbance at 420 nm:

$$\text{SO}_4(\text{mg/L}) = \frac{\text{instrument reading} \times \text{slope reciprocal} \times \text{final volume}}{\text{aliquot taken}} \text{----- equation (14)}$$

3.6.1.16 Hardness (Total Hardness) (mg/L)

Ethylenediaminetetraacetic acid (EDTA) titration was used to measure the total hardness while taking calcium and magnesium into account. A conical flask was filled with 50 milliliters of the sample, 1 milliliter of ammonium buffer solution, and a little amount of Eriochrome Black T (EBT) indicator. Until the color changed from wine red to pure blue, the solution was titrated against a normal 0.8M EDTA solution. The unit of measurement for total hardness is mg/L CaCO₃.

$$\text{Total hardness (mg/L as CaCO}_3) = \frac{V \times M \times 50000}{v} \text{----- equation (15)}$$

Where;

V= volume of EDTA used

M= molarity of EDTA

v= volume of sample

3.6.1.17 Calcium (Ca) and Magnesium (Mg) (mg/L)

Ethylenediaminetetraacetic acid (EDTA) titration is used to ascertain this. Flasks were filled with 50 milliliters of the water samples. The solution changed color after 1 milliliter of sodium hydroxide solution (NaOH), 0.2 grams of ammonium purpurate (C₈H₈N₆O₆), and

sodium chloride (NaCl) were added. Using NaOH solution as an indicator, the resultant combination was titrated with 0.01M EDTA. The following formula was used to determine the calcium concentration:

$$\text{Ca}^{2+}(\text{mg/L}) = \frac{M_{\text{EDTA}} \times V \times M_{\text{Ca}} \times 1000}{v} \text{----- equation (16)}$$

Where;

M_{EDTA} = molarity of EDTA titrant (0.01M)

V = volume of EDTA used

M_{Ca} = molar mass of Ca (40.078g/mol)

v = volume of sample

The magnesium concentration was calculated by subtracting the Ca value from the total hardness. The formula to find magnesium is:

$$\text{Mg}^{2+}(\text{mg/L}) = \frac{(n_{\text{T}} - n_{\text{Ca}}) \times M_{\text{Mg}} \times 1000}{v} \text{----- equation (17)}$$

Where;

n_{T} = total number of moles

n_{Ca} = calcium moles

M_{Mg} = molar mass of Mg (24.305g/mol)

v = volume of sample

3.6.1.18 Sodium (Na) and Potassium (K) (mg/L)

They were measured by atomic absorption spectrometry due to their emission lines. A clean, dry tube was filled with 5 milliliters of the water sample. The sample was diluted using deionized water, and the dilution factor was noted. Potassium (K) was calibrated at 768 nm and sodium (Na) at 589 nm using a flame photometer. Next, the amounts of potassium and sodium were measured in milligrams per liter (mg/L).

3.6.1.19 Nitrogen (N) (mg/L)

Colorimetric analysis was used to determine it. A conical flask was filled with 5 milliliters of the sample. A total of 25 milliliters were obtained by adding 2.5 milliliters of alkaline phenol, 1 milliliter of sodium potassium tartrate, 2.5 milliliters of bleach, and 14 milliliters of distilled water. A visible spectrophotometer was used to measure the solution at 636 nm, and the results were compared to a N standard.

$$N \left(\frac{\text{mg}}{\text{L}} \right) = \frac{\text{instrument reading} \times \text{slope reciprocal} \times \text{final volume}}{\text{aliquot taken}} \text{----- equation (18)}$$

3.6.2 Heavy Metals Analysis

The Quality Analytical Laboratory in Benin City, Edo State, Nigeria, tested water samples for heavy metals. 250 milliliters of the thoroughly mixed water samples were put into a glass beaker. After adding 10 milliliters of concentrated nitric acid (HNO₃) gradually, the mixture was heated on a hotplate at 50 to 70 degrees Celsius for 30 to 60 minutes to start the digestive process. Following the initial digestion, 5 milliliters of perchloric acid (HClO₄) were added in little amounts, and the temperature was gradually raised to create a light-colored solution. To dissolve the residue, 10 milliliters of nitric acid (HNO₃) were added and heated slowly. Following digestion, the digest was moved to a volumetric flask, allowed to cool, and then 100 milliliters of distilled water were added. If any particle matter remained, the mixture was filtered. The concentrations of Fe, Cu, Zn, Cd, Pb, Mn, and Cr were then measured in the combination using an Atomic Absorption Spectrophotometer (AAS). The concentrations of metals are expressed in mg/L.

3.7 WATER QUALITY INDEX (WQI)

The water's appropriateness for domestic use and human consumption was assessed using the Water Quality Index (WQI). Based on the combined influence of multiple water quality parameters, the WQI converts complicated water quality data into a single number (grade)

that represents overall water quality at a certain location and time. The Weighted Arithmetic Water Quality Index Method was used to calculate the WQI (Biose *et al.*, 2024). The WQI computation was based on the National Environmental (Surface and Groundwater Quality Control) Regulation Guidelines (NESREA 2011). The following formula was used to determine WQI:

$$WQI = \frac{\sum W_i Q_i}{\sum W_i} \text{----- equation (19)}$$

The following formula was used to determine the quality rating scale (Qi) for each parameter:

$$Q_i = 100 \left[\frac{V_i - V_o}{S_i - V_o} \right] \text{----- equation (20)}$$

V_i = Estimated Concentration of the i th parameter of interest in the analysed water

V_o = The ideal value of the i th parameter in pure water

$V_o = 0$ (except pH = 7.0; DO = 14.6 mg l⁻¹)

S_i = Recommended Standard value of the i th parameter (NESREA 2011).

The unit weight (W_i) for each water quality parameter:

$$W_i = \frac{K}{S_i} \text{----- equation (21)}$$

where K = proportionality constant:

$$K = \frac{1}{\sum \left(\frac{1}{S_i} \right)} \text{----- equation (22)}$$

The rating of water quality according to WQI is given in **Table 3.1**.

Table 3.1: Water quality ratings according to the Weighted Arithmetic Water Quality index method

Levels	Rating of water quality	Grading
0–25	Excellent	A
25–50	Good	B
51–75	Poor	C
76–100	Very poor	D
> 100	Unsuitable for drinking	E

Source: (Egun and Oboh, 2021).

3.8 COMPREHENSIVE POLLUTION INDEX (CPI)

According to Zhang (2017), a thorough evaluation of water quality using the CPI shows the level of total contamination of a body of water in a community and pinpoints the primary causes of pollution. The CPI is determined by taking the arithmetic mean of n water pollution indices (PI) and it is calculated as follows:

$$CPI = \frac{1}{n} \sum_{i=1}^n P_i \text{----- equation (23)}$$

P_i = the pollution index of pollutant i

The PI (excluding DO) increases with the pollutant's concentration and its equation is as follows:

$$P_i = \frac{C_i}{S_i} \text{----- equation (24)}$$

C_i = the measured concentration of the pollutant (mg L^{-1})

S_i = National water quality standard permissible limit for the pollutant in surface water (NESRA 2011).

n = the number of chosen pollutants

Table 3.2: Standard grades for single-factor pollution index (PI)

Single Factor Pollution Index (PI)	Pollution grades
Less than 0.4	Unpolluted
0.4–1.0	Slightly polluted
1.0–2.0	Medium pollution
2.1–5.0	Heavily polluted
More than 5.0	Seriously polluted

Source: (Biose *et al.*, 2024).

Table 3.3: Standard surface water quality categories based on CPI

The Comprehensive Pollution Index (CPI)	Level	Explanation of the water quality grades
Less than 0.2	I	Clean
0.21–0.4	II	Sub-clean
0.41–1.0	III	Slight pollution
1.01–2.0	IV	Moderate pollution
More than 2.01	V	Severe pollution

Source: (Biose *et al.*, 2024).

3.9 HUMAN HEALTH RISK ASSESSMENT

3.9.1 Exposure Assessment

Exposure to toxic heavy metals could also be of significant concern to humans living close to contaminated aquatic ecosystems. This study takes into account the oral (ingestion) and cutaneous contact modes of exposure. The following formula was used to determine the Chronic Daily Intake (CDI) resulting from oral and cutaneous contact (USEPA 2012):

$$CDI_{\text{oral}} = \frac{C_m \times IR \times EF}{B_w} \text{----- equation (25)}$$

Where;

C_m = mean concentration of element in water (mg L⁻¹)

IR = ingestion rate of water (2L day⁻¹ for adults and 1L day⁻¹ for children)

EF = exposure factor B_w is the body weight (approximate average of 70 kg for adults and 16 kg for children)

$$EF = \frac{Efr \times ED}{AT} \text{----- equation (26)}$$

Efr = frequency of exposure (days year⁻¹ using 365 days year⁻¹)

ED = exposure duration (conventional life expectancy of the study population was 70 years for adults and 9 years for children (Egun and Oboh, 2023).

AT = averaging time; for non-carcinogenic risk, AT is equal to ED × 365 days. For carcinogenic risk, AT is the average life expectancy of people. Average life expectancy is 55 years for adults in Nigeria (Egun and Oboh, 2023).

$$CDI_{dermal} = \frac{C_m \times SA \times K_p \times ET \times Efr \times ED}{B_w \times AT} \text{----- equation (27)}$$

Where;

SA is the exposed body surface area available for dermal contact (adults is 1.82 m², children 1.18 m² (MedIndia 2017).

Kp is the permeability coefficient of the contaminant.

ET is exposure time (hours day⁻¹) (an average of 2 hours per day for bathing, washing, etc.)

3.9.2 Non–carcinogenic Risk Assessment

The Target Hazard Quotient (THQ) and Hazard Index (HI) were used to characterize the possible non-cancer risk of heavy metal concentrations in the surface water (USEPA 2012):

$$\frac{THQ_{oral}}{dermal} = \frac{CDI_{oral/dermal}}{RfD_{oral/dermal}} \text{----- equation (28)}$$

Where: RfD (mg kg⁻¹ day⁻¹) = reference dose level of a particular metal for oral and dermal contact (USEPA 2021).

Hazard Index (HI):

$$HI = \sum THQ_{oral/dermal} \text{----- equation (29)}$$

When HI is less than 1.0, the exposed population is deemed safe to health risk; when HI is greater than 1.0, possible non-cancer health effects may be of concern (Saha and Paul 2018).

3.9.3 Carcinogenic Risk Assessment

The incremental or excess individual lifetime cancer risk was used to calculate the possible carcinogenic risk (CR) of heavy metals in the water. CR is calculated by multiplying the cancer slope factor (CSF) by the daily exposure dosage (CDI):

$$CR_i = CDI_i \times CSF_i \text{----- equation (30)}$$

Where;

CR_i is the carcinogenic risk of heavy metals through oral or dermal absorption

CDI_i is the daily exposure dose of carcinogenic pollutants

CSF_i is the cancer slope factor of carcinogenic pollutants

The integrated carcinogenic risk (ICR) can also be identified as the sum of CR exposure by various pollutants via different pathways, with the assumption that there is no antagonism or synergism between pollutants.

$$ICR = \sum_{i=1}^n CR_i \text{----- equation (31)}$$

The risk assessment and classification using the Delphi method and based on the USEPA and ICRP criteria was used (Table 3.4).

Table 3.4: Carcinogenic Risk evaluation and classification based on the Delphi method

Risk Grades	Risk Levels	Range of Risk value	Acceptability
Grade I	Extremely low risk	$< 10^{-6}$	Completely accept
Grade II	Low risk	$(10^{-6}, 10^{-5})$	Not willing to care about the risk
Grade III	Low-medium risk	$(10^{-5}, 5 \times 10^{-5})$	Do not mind about the risk
Grade IV	Medium risk	$(5 \times 10^{-5}, 10^{-4})$	Care about the risk
Grade V	Medium-high risk	$(10^{-4}, 5 \times 10^{-4})$	Care about the risk and willing to invest
Grade VI	High risk	$(5 \times 10^{-4}, 10^{-3})$	Pay attention to the risk and take action to solve it
Grade VII	Extremely high risk	$> 10^{-3}$	Reject the risk and must solve it

Source: (Li *et al.*, 2017).

3.10 STATISTICAL ANALYSIS

Descriptive statistical analysis for central tendency and dispersion to characterize stations in terms of physicochemical conditions. To determine whether there was a substantial change in the physicochemical parameters, interstation comparisons were performed. Using the computer program SPSS 16.0 and Microsoft Excel 2010 for Windows, the Duncan Multiple

Range (DMR) test was used to locate the significant difference if a significant value ($p < 0.05$) was found. PAST 4 was used for multivariate analysis, including principal component analysis (PCA) and cluster. MS-Excel 2013 for Windows was used to determine the carcinogenic risk, non-carcinogenic risk, and comprehensive pollution index (CPI).

CHAPTER FOUR

RESULTS

4.1 PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS CONTENT OF SURFACE WATER FROM ORHIONMWON RIVER

Table 4.1 provides an overview of the physicochemical parameters and heavy metal concentration of surface water samples collected from three locations along the Orhionmwon River. For every parameter examined at the three stations, the mean, standard deviation, minimum, and maximum values are provided. the Duncan multiple range (DMR) test, which represents the post hoc analysis, and the analytical variance (ANOVA) p-value. When the ANOVA shows significant differences, the superscript is displayed.

The physicochemical characteristics listed in Table 4.1 include temperature, pH, electrical conductivity, total dissolved solids, total suspended solids, total solids, Chemical oxygen demand, nitrate, and potassium showed a significant difference ($p < 0.05$) between the sampled stations along the Orhionmwon River, whereas turbidity, alkalinity, dissolved oxygen, biochemical oxygen demand, chlorine, phosphate, sulphate, hardness, calcium, magnesium, and sodium showed no significant difference ($p > 0.05$). Additionally, there was no significant difference ($p > 0.05$) in the heavy metals iron (Fe), copper (Cu), zinc (Zn), cadmium (Cd), lead (Pb), manganese (Mn), chromium (Cr), and total hydrocarbon (THC) amongst the three Orhionmwon sample stations.

4.1.1 Temperature (°C)

The geographical and temporal temperature changes at three sampling sites along the Orhionmwon River are displayed in **Figure 4.1**. All of the stations showed comparatively similar trends, however station 2 showed a rising pattern. Station 1 had the lowest temperature value of 29.60 and Station 2 had the highest temperature value of 31.00 according to the intraspecific variances. At stations 1, 2, and 3, the Orhionmwon River surface water temperature ranged from 29.60-30.50, 29.80-31.00, and 29.70-30.10, with mean values of 30.10, 30.33, and 29.93, respectively. One-way analysis of variance (ANOVA) of the temperature data from the three stations revealed no significant difference ($p>0.05$).

4.1.2 pH

The geographical and temporal pH variations at three Orhionmwon River sampling stations are displayed in **Figure 4.2**. At stations 1 and 2, the patterns were somewhat similar, but at station 3, they declined. Station 1 had the greatest pH value of 7.74, while Station 3 had the lowest pH value of 6.30. At stations 1, 2, and 3, the pH of the surface water from the Orhionmwon River varied between 6.45-7.74, 6.35-7.73, and 6.30-7.60, respectively. For stations 1, 2, and 3, the average mean pH values were 7.10, 6.99, and 8.83, respectively. There was no discernible difference ($p>0.05$) in the pH values obtained from the three sampling stations of variance (ANOVA).

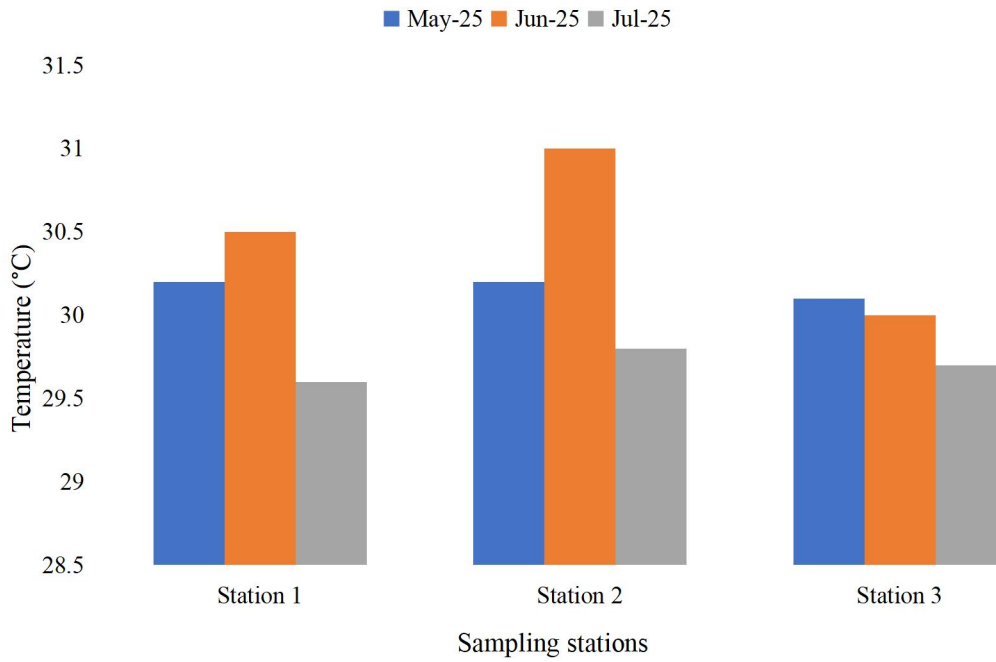


Figure 4.1: Geographical and temporal variation of Temperature in surface water from Orhionmwon River.

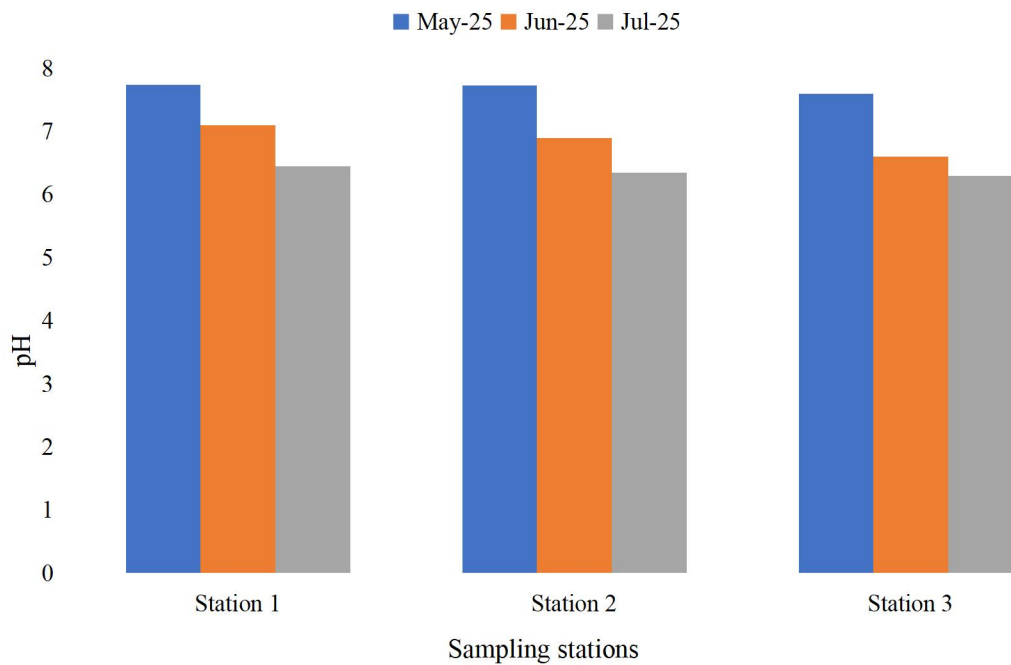


Figure 4.2: Geographical and temporal variation of pH in surface water from Orhionmwon River.

4.1.3 Electrical Conductivity (EC) ($\mu\text{S}/\text{cm}$)

The geographical and temporal changes in electrical conductivity at three sampling locations along the Orhionmwon River are depicted in **Figure 4.3**. The patterns for stations 1 and 3 were similar, however station 2 showed an upward tendency with a higher value in June 2025. The intraspecific variations revealed that station 2 had the greatest EC value of 28.00 while station 3 had the lowest EC value of 16.00. At stations 1, 2, and 3, the electrical conductivity values of the surface water from the Orhionmwon River varied from 18.00-23.00, 17.00-28.00, and 16.00-22.00, respectively, with mean values of 20.33, 21.00, and 18.67. The EC values across the three stations when subjected to one way analysis of variance (ANOVA), showed no significant difference ($p>0.05$).

4.1.4 Total dissolved solids (TDS) (mg/L)

The geographical and temporal fluctuations for total dissolved solids at three Orhionmwon River sampling locations are displayed in **Figure 4.4**. Station 2 showed an increasing pattern, although stations 1 and 3 showed similar tendencies. The variance revealed that station 2 had the highest TDS value of 14.00 while station 3 had the lowest value of 8.00. At stations 1, 2, and 3, the total dissolved solids value of the Orhionmwon River surface water varied from 9.00-11.00, 8.00-14.00, and 8.00-11.00, respectively. For each of the three locations, the average mean TDS levels were 10.00, 10.33, and 9.33, in that order. One-way analysis of variance (ANOVA) of the three stations' total dissolved solids measurements revealed no significant difference ($p>0.05$).

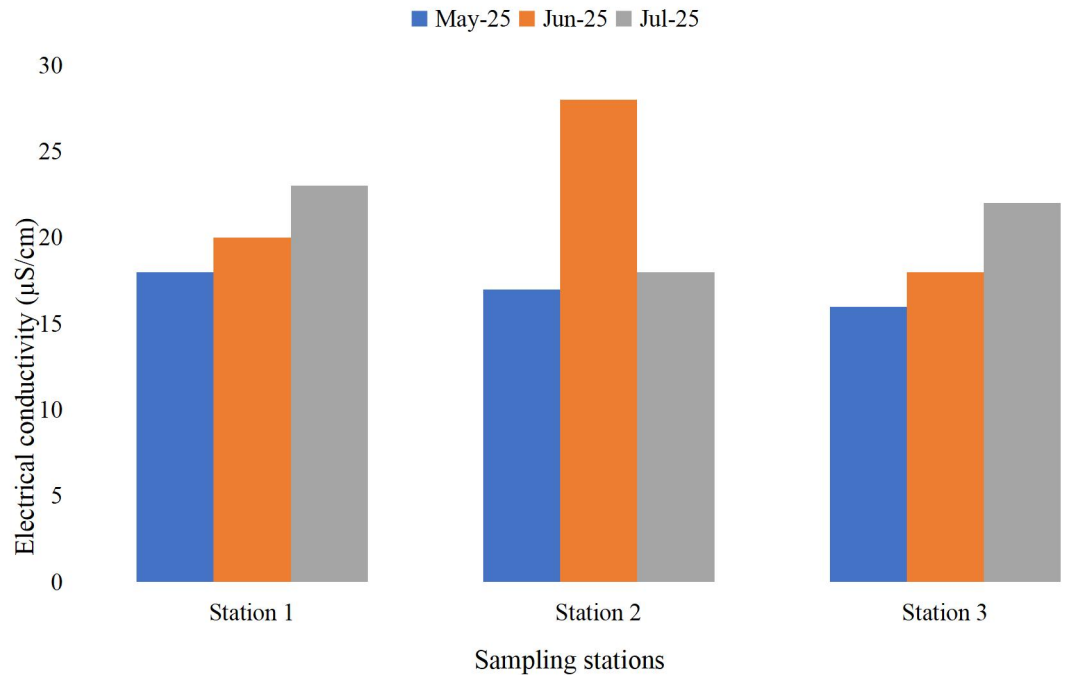


Figure 4.3: Geographical and temporal variation of Electrical conductivity ($\mu\text{S}/\text{cm}$) in surface water from Orhionmwon River.

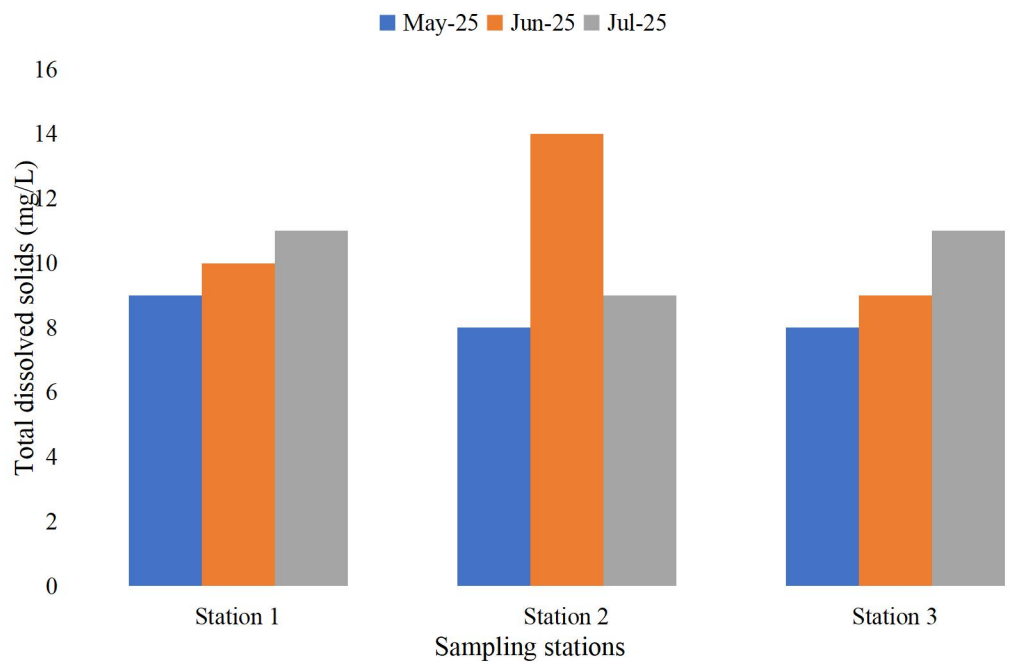


Figure 4.4: Geographical and temporal variation of Total dissolved solids (mg/L) in surface water from Orhionmwon River.

4.1.5 Total suspended solids (TSS) (mg/L)

The geographical and temporal variations for total suspended solids at three Orhionmwon River sampling sites are displayed in **Figure 4.5**. All of the stations showed somewhat similar tendencies. In May, the variation revealed the lowest TSS value of 6.30 at station 2 and the highest TSS value of 5.10 at stations 1 and 2. At stations 1, 2, and 3, the total suspended solids of the Orhionmwon River surface water varied between 4.10-5.10, 3.90-5.10, and 4.30-4.80, respectively. For stations 1, 2, and 3, the average mean TSS values were 4.67, 4.33, and 4.50, respectively. There was no significant difference ($p>0.05$) in the total suspended solids values reported across the three measured stations of variance (ANOVA).

4.1.6 Total Solids (TS) (mg/L)

Figure 4.6 shows the geographical and temporal variations for total solids at three sampled stations along the stretch of Orhionmwon River. Different trends were noted at each location, with station 2 showing a rising tendency in July. The intraspecific variations revealed that station 2 had the highest total solids value of 19.10 in July and the lowest total solids value of 11.90 in May. At stations 1, 2, and 3, the total solids of the surface water from the Orhionmwon River ranged from 13.10-16.10, 11.90-19.10, and 12.30-15.80, with mean values of 14.67, 14.67, and 13.83, respectively. One-way analysis of variance (ANOVA) of the three stations' total solids values revealed no significant difference ($p>0.05$).

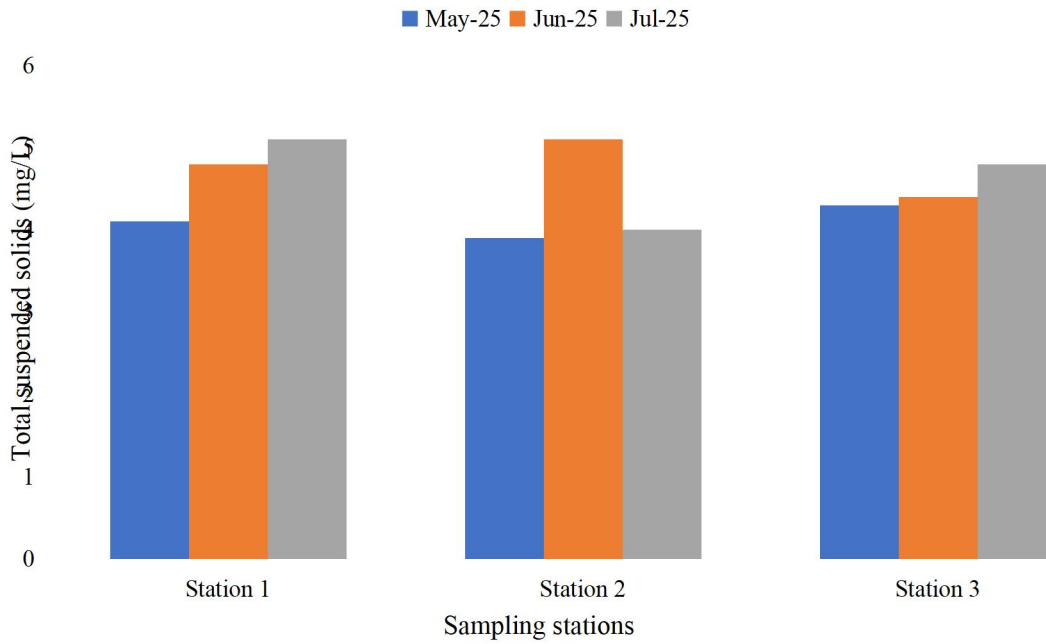


Figure 4.5: Geographical and temporal variation of Total suspended solids (mg/L) in surface water from Orhionmwon River.

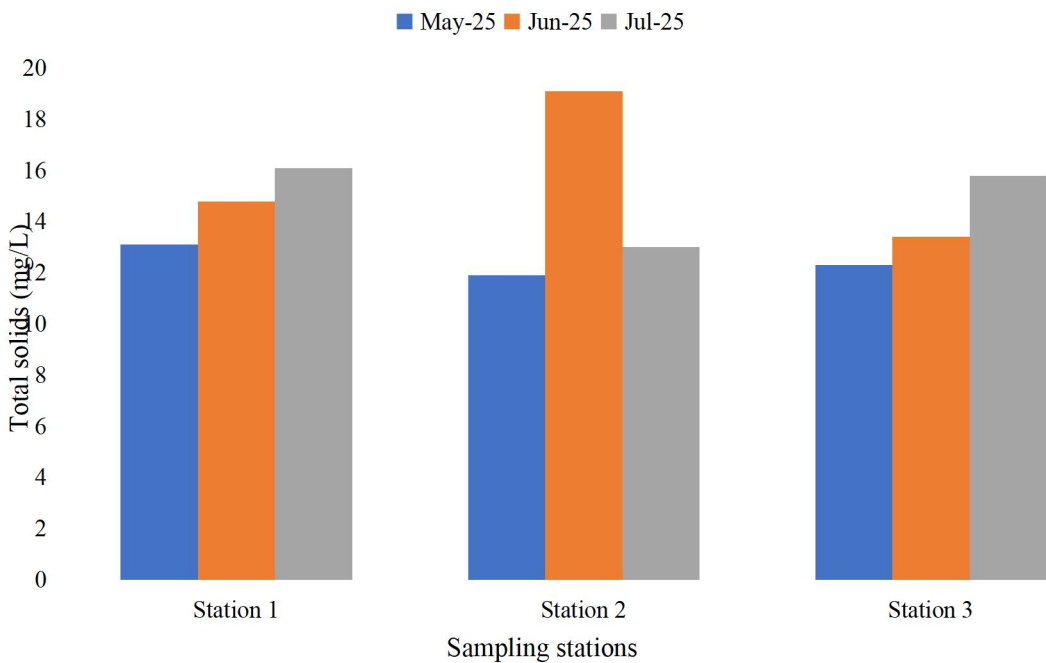


Figure 4.6: Geographical and temporal variation of Total solids (mg/L) in surface water from Orhionmwon River.

4.1.7 Turbidity (NTU)

The geographical and temporal fluctuations in turbidity at three sampling stations in the Orhionmwon River are displayed in **Figure 4.7**. All of the stations' trends were somewhat comparable, however station 2's trends were higher. The variance revealed that station 2 had the lowest turbidity value of 4.05 in May and the maximum turbidity value of 9.85 in July. At stations 1, 2, and 3, the Orhionmwon River's surface water turbidity readings ranged from 4.63-7.82, 4.05-9.85, and 5.21-9.27, with mean values of 6.09, 6.43, and 6.62, respectively. One-way analysis of variance (ANOVA) of the turbidity values across the three stations revealed no significant difference ($p>0.05$).

4.1.8 Alkalinity (mg/L)

The geographical and temporal fluctuations for alkalinity at three sampled stations along the Orhionmwon River stretch are displayed in **Figure 4.8**. The trends seen at each location varied, with station 1 showing an increasing pattern. In May, the variation revealed the maximum alkalinity value of 9.15 at station 1 and the lowest alkalinity value of 3.05 at stations 1 and 2. At stations 1, 2, and 3, the alkalinity value of the surface water from the Orhionmwon River varied from 3.05-9.15, 3.05-6.10, and 6.10-6.10, with mean values of 6.10, 5.08, and 6.10, respectively. One-way analysis of variance (ANOVA) of the three stations' alkalinity values revealed no significant differences ($p>0.05$).

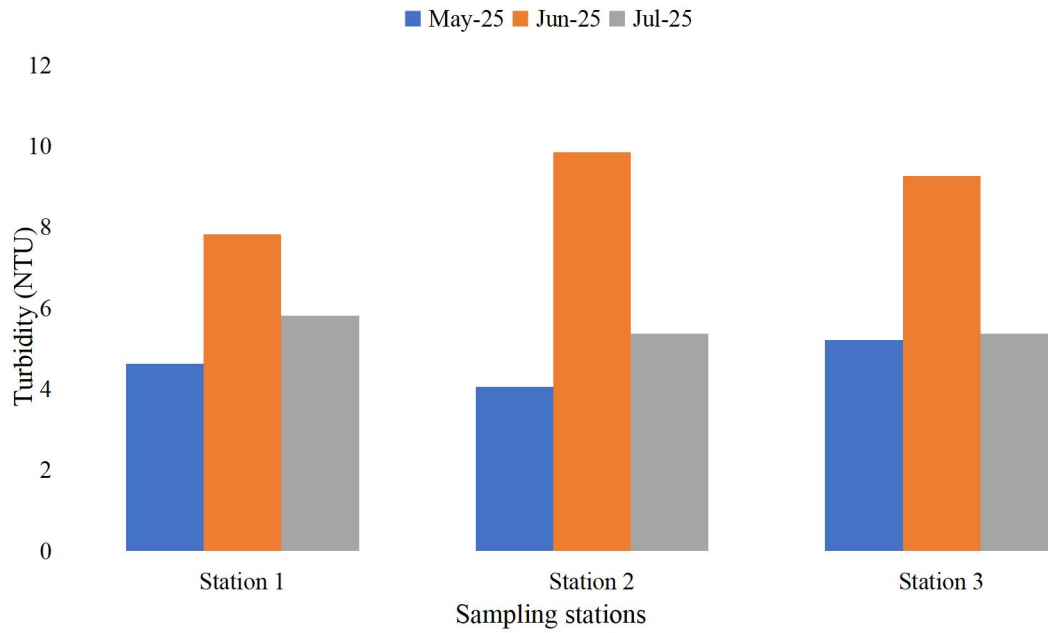


Figure 4.7: Geographical and temporal variation of Turbidity (NTU) in surface water from Orhionmwon River.

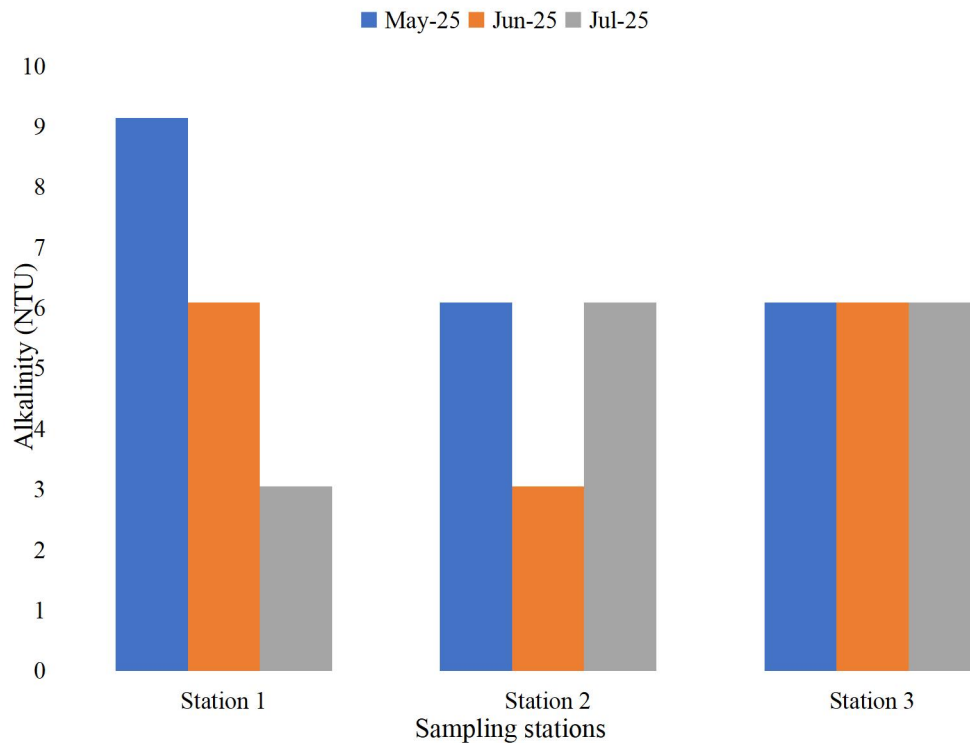


Figure 4.8: Geographical and temporal variation of Alkalinity (mg/L) in surface water from Orhionmwon River.

4.1.9 Dissolved Oxygen (DO) (mg/L)

Figure 4.9 shows the geographical and temporal variations for dissolved oxygen at three sampled stations in Orhionmwon River. The patterns seen at each location were comparatively comparable, with station 1 showing more fluctuation. The variation revealed that station 1 had the greatest DO value (5.80) while stations 2 and 3 had the lowest DO value (4.20). At stations 1, 2, and 3, the total suspended solids of the Orhionmwon River surface water varied between 4.80-5.80, 4.20-4.80, and 4.20-5.00, respectively. For stations 1, 2, and 3, the average mean dissolved oxygen readings were 5.20, 4.60, and 4.73, respectively. There was no significant difference ($p>0.05$) in the dissolved oxygen values reported across the three measured stations of variance (ANOVA).

4.1.10 Biochemical oxygen demand (mg/L)

Figure 4.10 shows the geographical and temporal variations for biochemical oxygen demand at three sampled stations in Orhionmwon River. All of the stations showed similar tendencies. The variance revealed that station 3 had the lowest BOD value of 3.00 in June and the highest BOD value of 4.00 in May and July. At stations 1, 2, and 3, the BOD values of the surface water from the Orhionmwon River varied from 3.40–3.80, 3.80–3.80, and 3.00–4.00, respectively. For stations 1, 2, and 3, the average mean BOD values were 3.67, 3.80, and 3.67, respectively. There was no discernible difference ($p>0.05$) in the biochemical oxygen demand values obtained from the three sampled stations of variance (ANOVA).

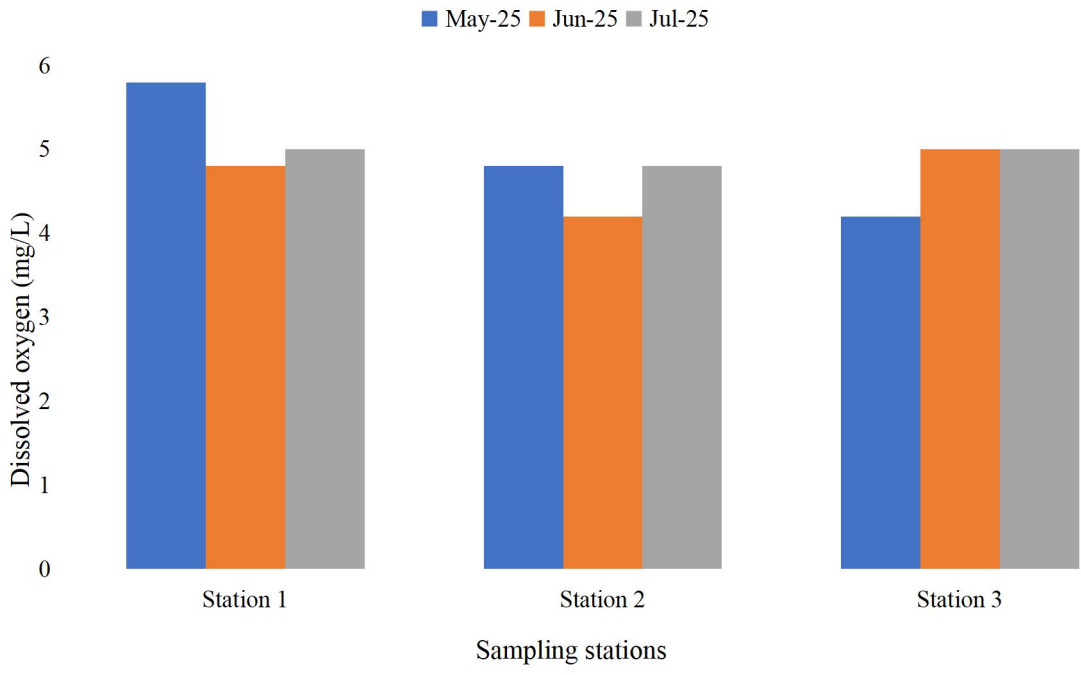


Figure 4.9: Geographical and temporal variation of Dissolved oxygen (mg/L) in surface water from Orhionmwon River.

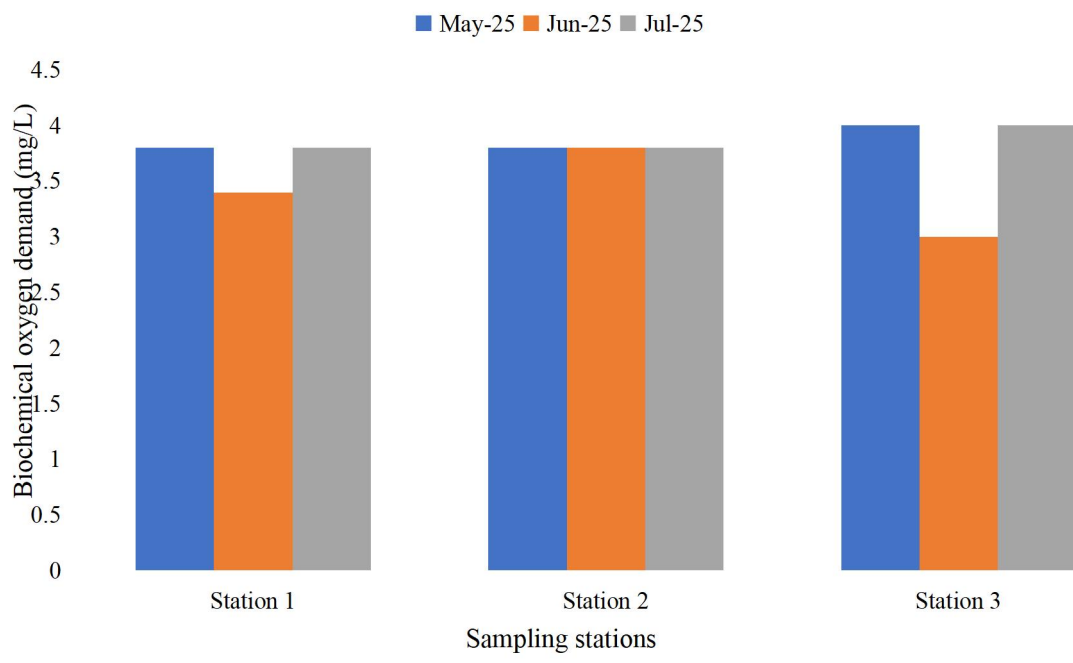


Figure 4.10: Geographical and temporal variation of Biochemical oxygen demand (mg/L) in surface water from Orhionmwon River.

4.1.11 Chemical oxygen demand (COD) (mg/L)

The geographical and temporal changes for chemical oxygen demand (COD) at three measured sites along the Orhionmwon River stretch are displayed in **Figure 4.11**. Different trends were noted at each station, with station 3 showing an increasing pattern. The intraspecific differences revealed that station 2 had the lowest COD value of 12.00 and station 3 had the highest COD value of 92.00. At stations 1, 2, and 3, the chemical oxygen demand values of the surface water from the Orhionmwon River varied from 26.00-44.00, 12.00-40.00, and 20.00-92.00, respectively, with mean values of 32.67, 23.33, and 45.33. One-way analysis of variance (ANOVA) revealed a significant difference ($p < 0.05$) in the chemical oxygen demand values among the three sites.

4.1.12 Chloride (Cl) (mg/L)

Figure 4.12 shows the geographical and temporal variations for chloride (Cl) at three sampled stations in Orhionmwon River. All of the stations showed rather similar trends, with station 2 having the lowest value in May. The intraspecific variations revealed that station 1 had the greatest chloride value of 7.09 in May and June, station 2 in July, and station 3 for all three months, while station 2 had the lowest chloride value of 4.61. At stations 1, 2, and 3, the surface water from the Orhionmwon River exhibited mean values of 7.03, 5.70, and 7.09, respectively, with chloride values ranging from 6.90-7.09, 4.61-7.09, and 7.09-7.09. One-way analysis of variance (ANOVA) of the three stations' chloride readings revealed no significant difference ($p > 0.05$).

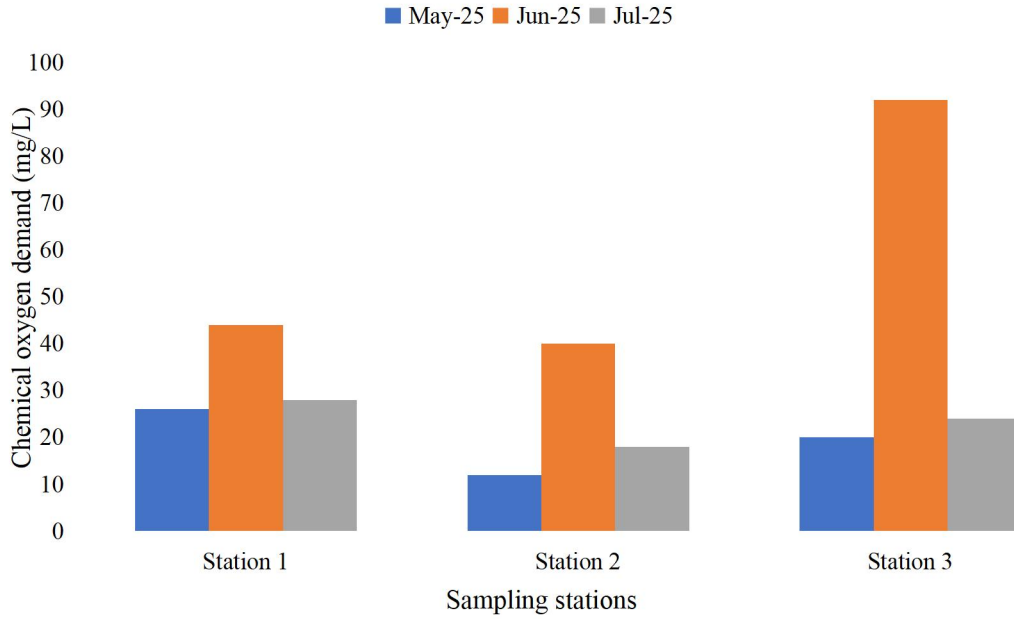


Figure 4.11: Geographical and temporal variation of Chemical oxygen demand (mg/L) in surface water from Orhionmwon River.

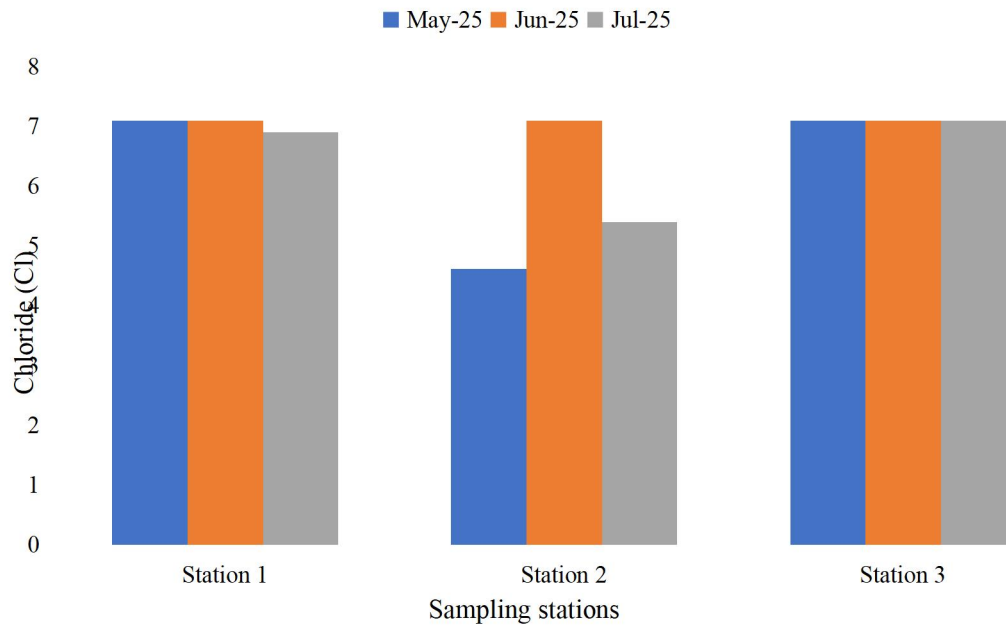


Figure 4.12: Geographical and temporal variation of Chloride (mg/L) in surface water from Orhionmwon River.

4.1.13 Nitrate (NO₃) (mg/L)

The geographical and temporal fluctuations of nitrate at three Orhionmwon River sample locations are displayed in **Figure 4.13**. All of the stations showed rather similar tendencies, with station 1 showing an increasing tendency. The variation revealed that station 1 had the highest nitrate value of 11.44 and station 2 had the lowest nitrate value of 3.65. At stations 1, 2, and 3, the surface water nitrate levels from the Orhionmwon River varied from 6.87-11.44, 3.65-7.12, and 6.63-9.64, respectively. For stations 1, 2, and 3, the average mean nitrate readings were 9.49, 4.99, and 8.35, respectively. There was a significant difference ($p < 0.05$) in the nitrate values reported across the three sampled stations of variance (ANOVA).

4.1.14 Phosphate (PO₄) (mg/L)

The geographical and temporal fluctuations of phosphate at three Orhionmwon River sample locations are displayed in **Figure 4.14**. With station 2 having the lowest phosphate readings, the trends seen at all the stations were somewhat similar. The variation revealed that station 2 had the lowest phosphate value (0.13) and station 1 had the highest phosphate value (1.35). At stations 1, 2, and 3, the phosphate levels in the surface water from the Orhionmwon River varied from 0.39-1.35, 0.13-0.28, and 0.38-0.61, respectively. For stations 1, 2, and 3, the average mean phosphate values were 0.72, 0.22, and 0.48, respectively. There was no significant difference ($p > 0.05$) in the phosphate values recorded across the three sampled stations of variance (ANOVA).

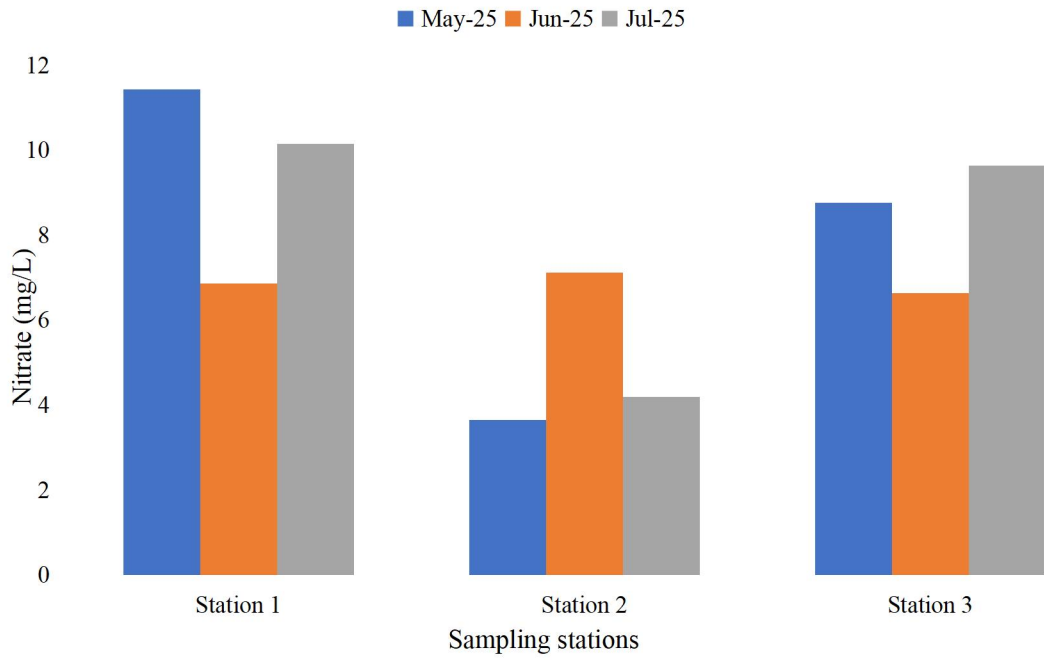


Figure 4.13: Geographical and temporal variation of Nitrate (mg/L) in surface water from Orhionmwon River.

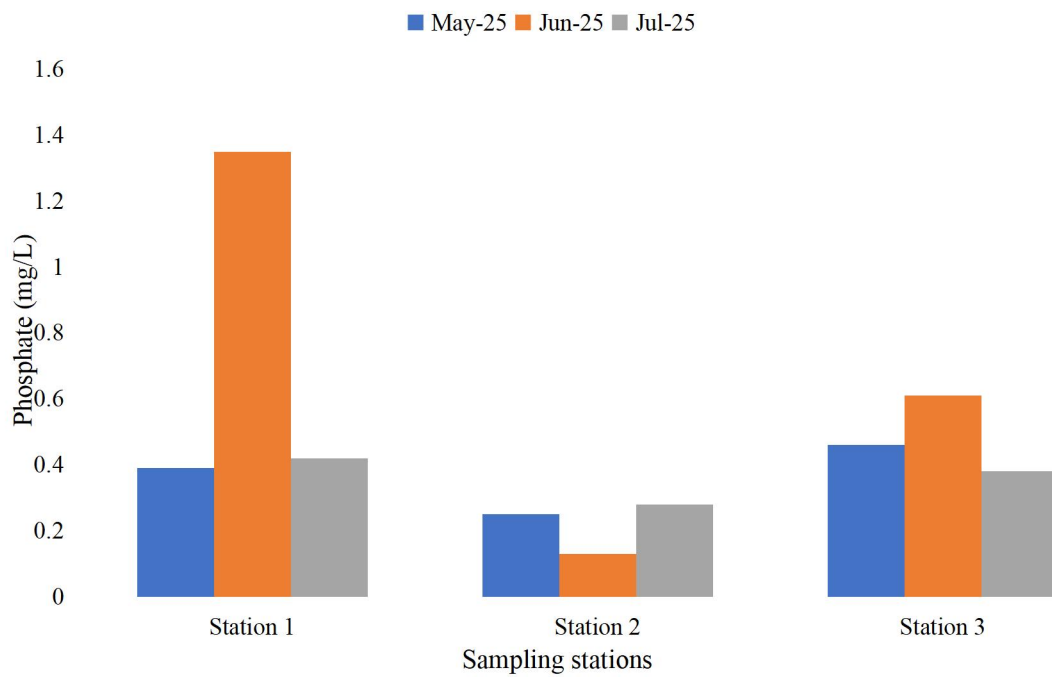


Figure 4.14: Geographical and temporal variation of Phosphate (mg/L) in surface water from Orhionmwon River.

4.1.15 Sulphate (SO₄) (mg/L)

The geographical and temporal fluctuations of sulphate at three Orhionmwon River sample locations are displayed in **Figure 4.15**. All three of the sampled stations showed somewhat similar trends. The variance revealed that station 1 had the lowest sulphate value of 0.81 in June and the highest sulphate value of 2.74 in July. At stations 1, 2, and 3, the surface water from the Orhionmwon River had sulphate values ranging from 0.81-2.74, 1.45-2.08, and 1.36-2.16, respectively. Each of the three locations had average mean sulphate readings of 2.03, 1.84, and 1.66, in that order. A one-way analysis of variance (ANOVA) of the three stations' sulphate values revealed no significant difference ($p>0.05$).

4.1.16 Hardness (mg/L)

Figure 4.16 shows the geographical and temporal variations for hardness at three sampled stations in Orhionmwon River. All of the stations showed similar trends, with stations 1 and 3 having the highest values. The variance revealed that the three analyzed stations had the lowest hardness value of 4.80 in June and the maximum value of 8.49 at stations 1 and 3 in May. At stations 1, 2, and 3, the Orhionmwon River's surface water had hardness values between 4.80-8.49, 4.80-8.01, and 4.80-8.49, respectively. In the same order, the three stations' average mean hardness values were 7.10, 6.57, and 7.10. A one-way analysis of variance (ANOVA) of the hardness values across the three stations revealed no significant differences ($p>0.05$).

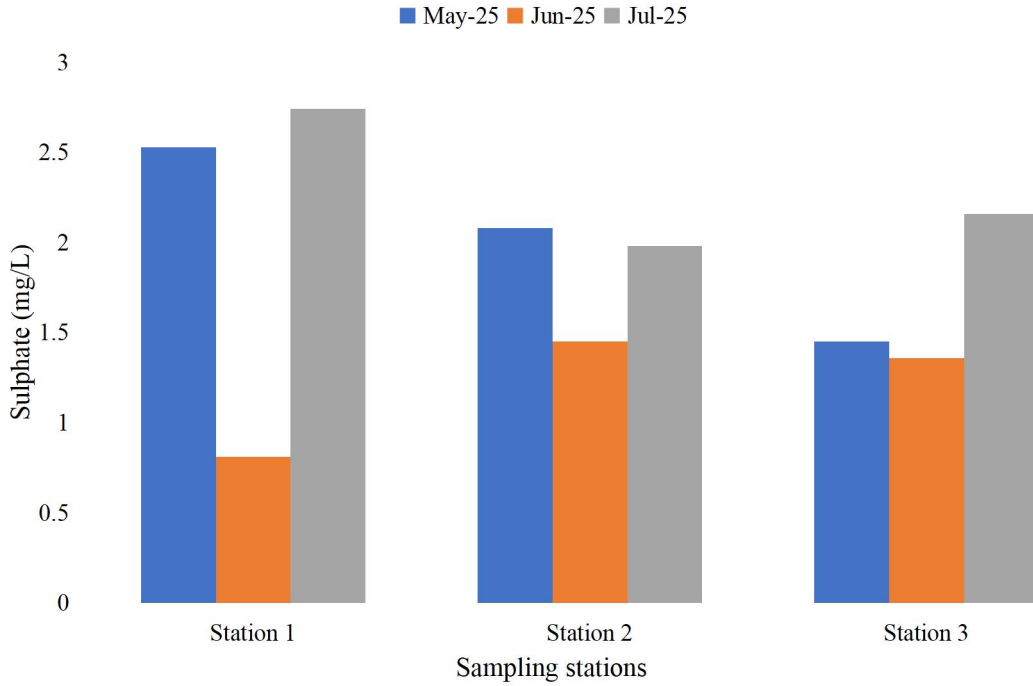


Figure 4.15: Geographical and temporal variation of Sulphate (mg/L) in surface water from Orhionmwon River.

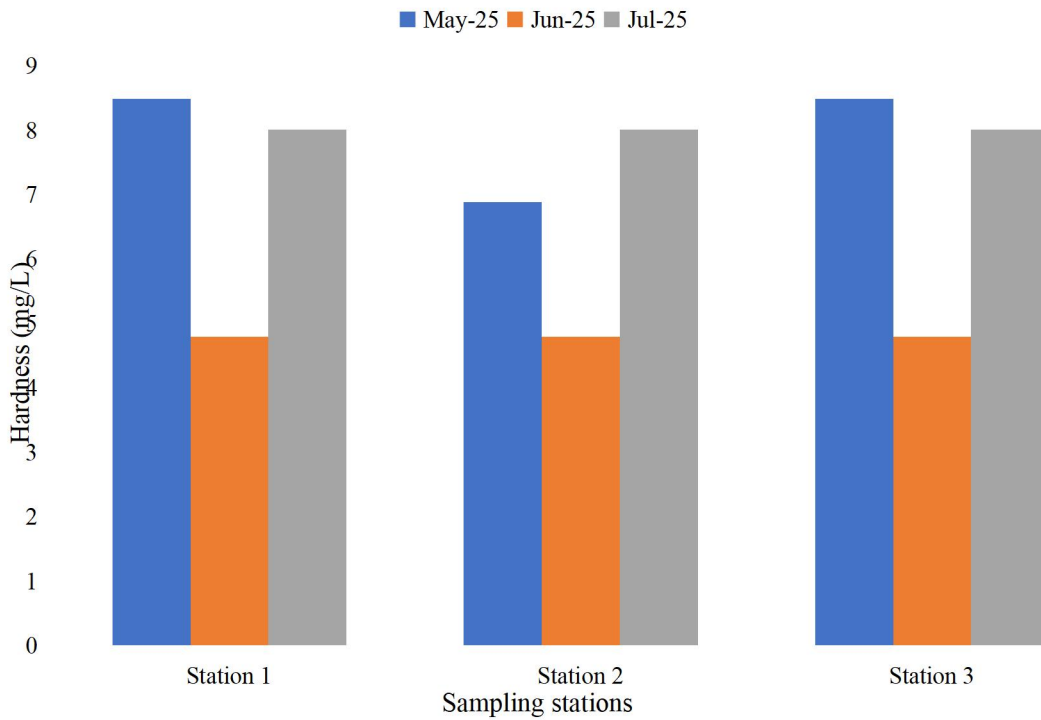


Figure 4.16: Geographical and temporal variation of Hardness (mg/L) in surface water from Orhionmwon River.

4.1.17 Calcium (Ca) (mg/L)

Figure 4.17 shows the geographical and temporal variations for calcium at three sampled stations in Orhionmwon River. All of the stations showed comparatively similar trends, with station 1 having the lowest value in June. The variance revealed that station 1 had the lowest calcium value (0.64) and station 2 had the highest value (3.21) in May. At stations 1, 2, and 3, the surface water from the Orhionmwon River had calcium values ranging from 0.64-3.21, 1.28-3.21, and 1.28-1.92, respectively. For each of the three locations, the average mean calcium readings were 1.71, 1.99, and 1.71 in the same sequence. One-way analysis of variance (ANOVA) of the calcium readings at the three stations revealed no significant difference ($p>0.05$).

4.1.18 Magnesium (Mg) (mg/L)

The geographical and temporal fluctuations of magnesium at three Orhionmwon River sample locations are displayed in **Figure 4.18**. All of the stations showed somewhat similar tendencies. The fluctuation revealed that in July, station 1 had the highest magnesium value of 1.17 and in May, station 1 had the lowest value of 0.12. At stations 1, 2, and 3, the magnesium values of the surface water from the Orhionmwon River varied between 0.12-1.17, 0.39-0.78, and 0.39-0.90, respectively. For each of the three locations, the average mean magnesium readings were 0.69, 0.52, and 0.69 in that order. A one-way analysis of variance (ANOVA) of the three stations' magnesium values revealed no significant difference ($p>0.05$).

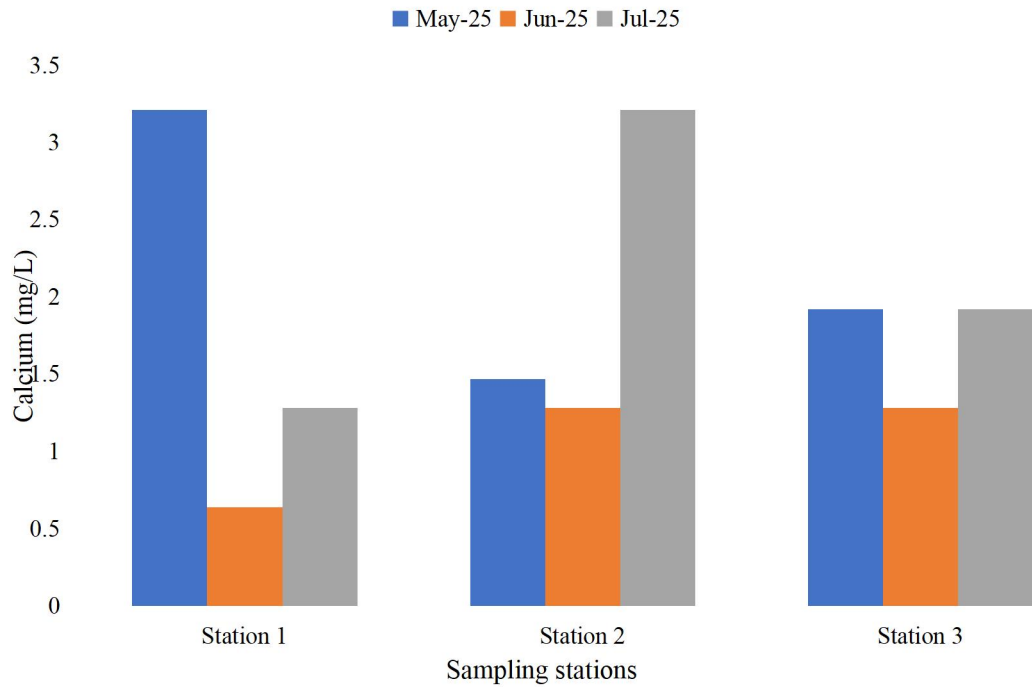


Figure 4.17: Geographical and temporal variation of Calcium (mg/L) in surface water from Orhionmwon River.

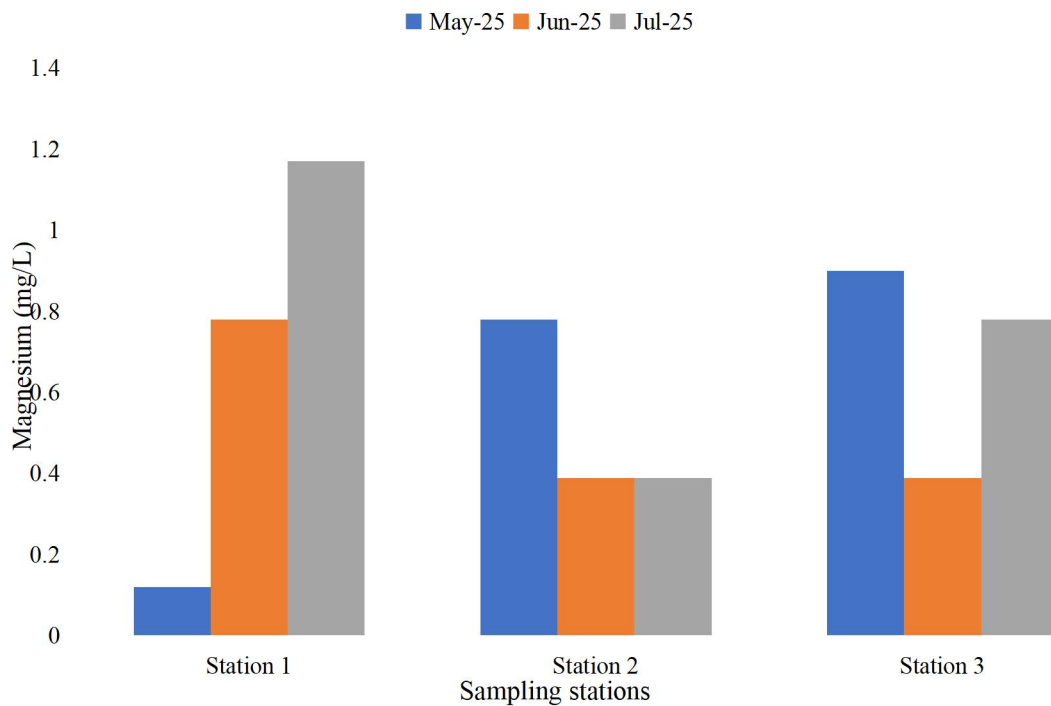


Figure 4.18: Geographical and temporal variation of Magnesium (mg/L) in surface water from Orhionmwon River.

4.1.19 Sodium (Na) (mg/L)

The geographical and temporal fluctuations for sodium at three sampled stations along the Orhionmwon River stretch are displayed in **Figure 4.19**. All of the stations showed comparatively similar patterns, with station 3 having the lowest sodium value. In July, the intraspecific variations revealed the highest sodium value of 1.16 at station 2 and the lowest sodium value of 0.71 at station 3. At stations 1, 2, and 3, the sodium levels of the surface water from the Orhionmwon River varied from 0.82-0.94, 0.76-1.16, and 0.71-0.85, with mean values of 0.90, 0.91, and 0.80, respectively. One-way analysis of variance (ANOVA) of the sodium readings across the three stations revealed no significant differences ($p>0.05$).

4.1.20 Potassium (K) (mg/L)

The geographical and temporal fluctuations for potassium at three Orhionmwon River sample locations are displayed in **Figure 4.20**. All of the stations showed comparatively similar trends. The intraspecific differences revealed that station 3 had the lowest potassium value (1.39) while station 1 had the highest value (1.62). At stations 1, 2, and 3, the potassium levels of the surface water from the Orhionmwon River varied from 1.55-1.62, 1.42-1.51, and 1.39-1.53, with mean values of 1.60, 1.47, and 1.44, respectively. One-way analysis of variance (ANOVA) revealed a significant difference ($p<0.05$) in the potassium values between the three locations.

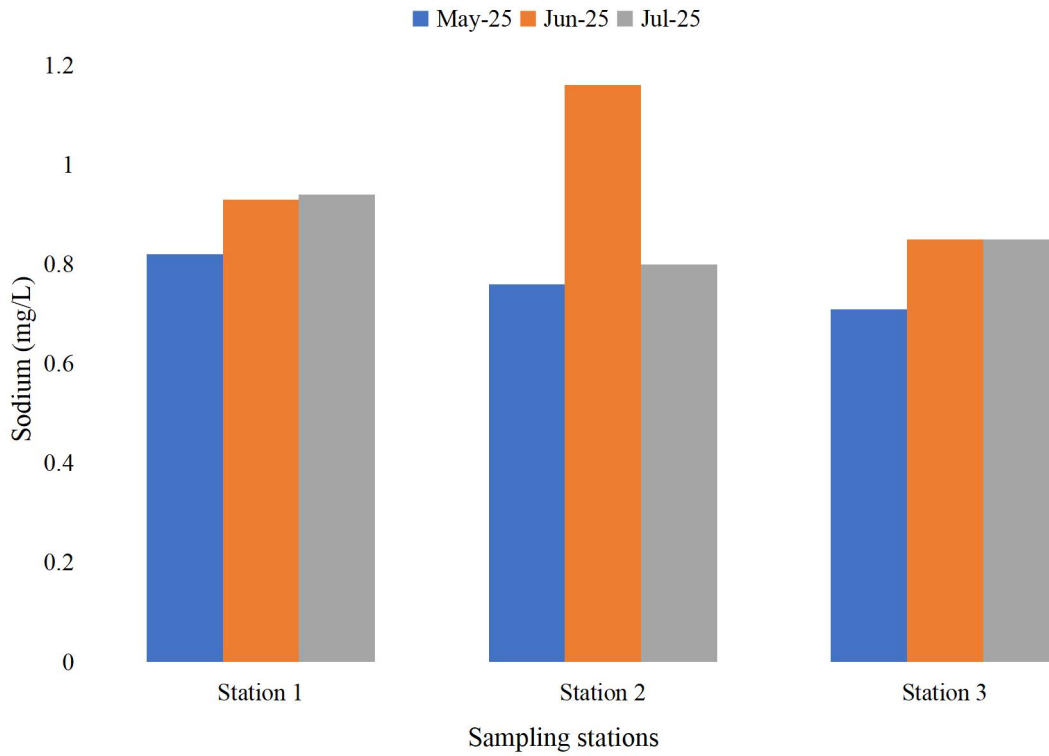


Figure 4.19: Geographical and temporal variation of Sodium (mg/L) in surface water from Orhionmwon River.

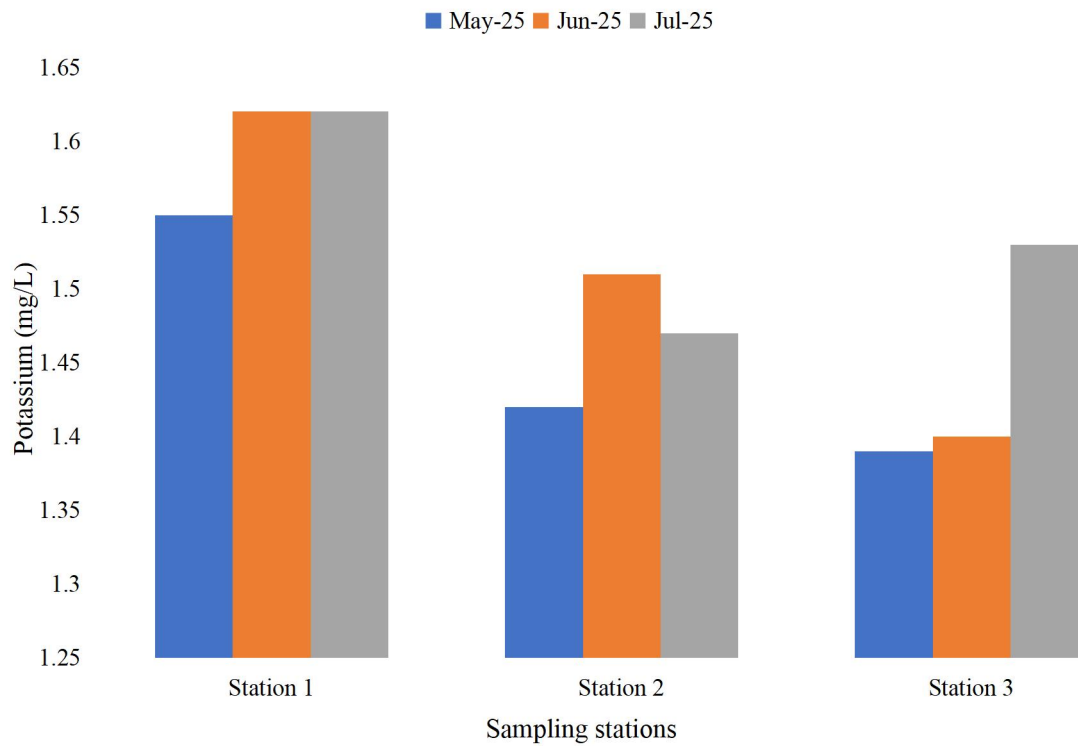


Figure 4.20: Geographical and temporal variation of Potassium (mg/L) in surface water from Orhionmwon River.

4.1.21 Iron (Fe) (mg/L)

The geographical and temporal variations for iron at three Orhionmwon River sample locations are displayed in **Figure 4.21**. All of the stations showed similar trends, with station 3 having the lowest iron value. The variation revealed that station 2 had the greatest iron value (1.38) and station 3 had the lowest iron value (1.08). At stations 1, 2, and 3, the iron values of the surface water from the Orhionmwon River varied from 1.16-1.28, 1.28-1.38, and 1.08-1.28, respectively. For stations 1, 2, and 3, the average mean iron readings were 1.22, 1.33, and 1.18, respectively. There was no significant difference ($p>0.05$) in the iron values reported across the three sampled stations of variance (ANOVA).

4.1.22 Copper (Cu) (mg/L)

The geographical and temporal fluctuations for copper at three Orhionmwon River sample locations are displayed in **Figure 4.22**. All of the stations showed somewhat similar trends, with station 3 showing a declining pattern. The variation revealed that station 3 had the lowest copper value (0.08) and stations 1 and 2 had the greatest copper value (0.15). At stations 1, 2, and 3, the copper content of the Orhionmwon River surface water varied between 0.10-0.15, 0.09-0.15, and 0.08-0.12, respectively. For stations 1, 2, and 3, the average mean copper readings were 0.12, 0.12, and 0.10, respectively. There was no significant difference ($p>0.05$) in the copper values observed across the three examined stations of variance (ANOVA).

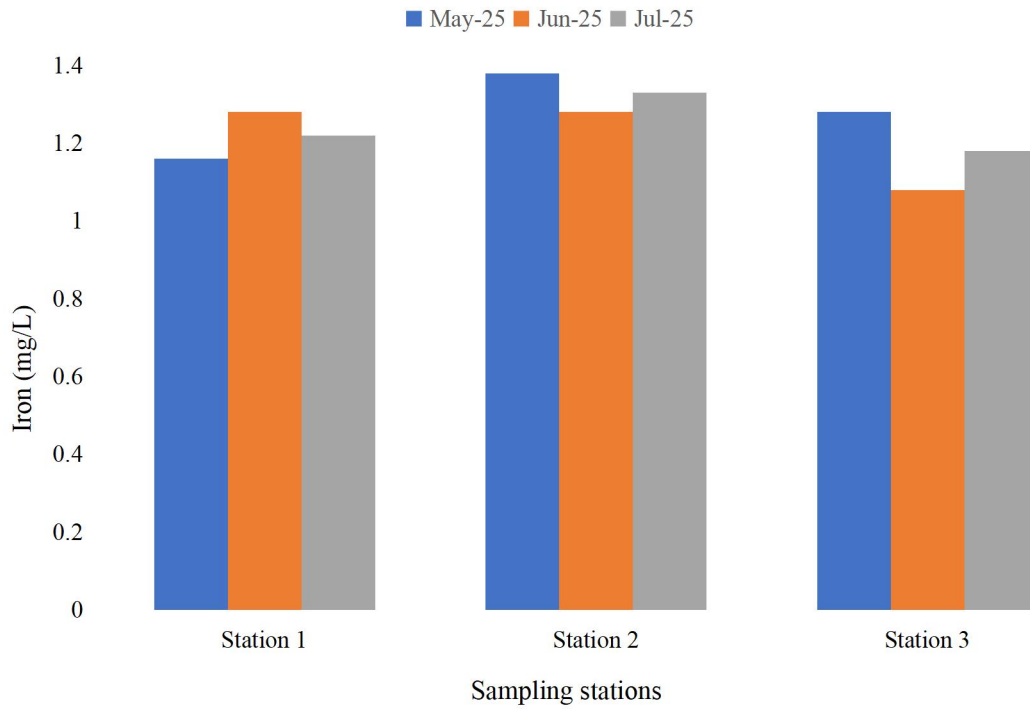


Figure 4.21: Geographical and temporal variation of Iron (mg/L) in surface water from Orhionmwon River.

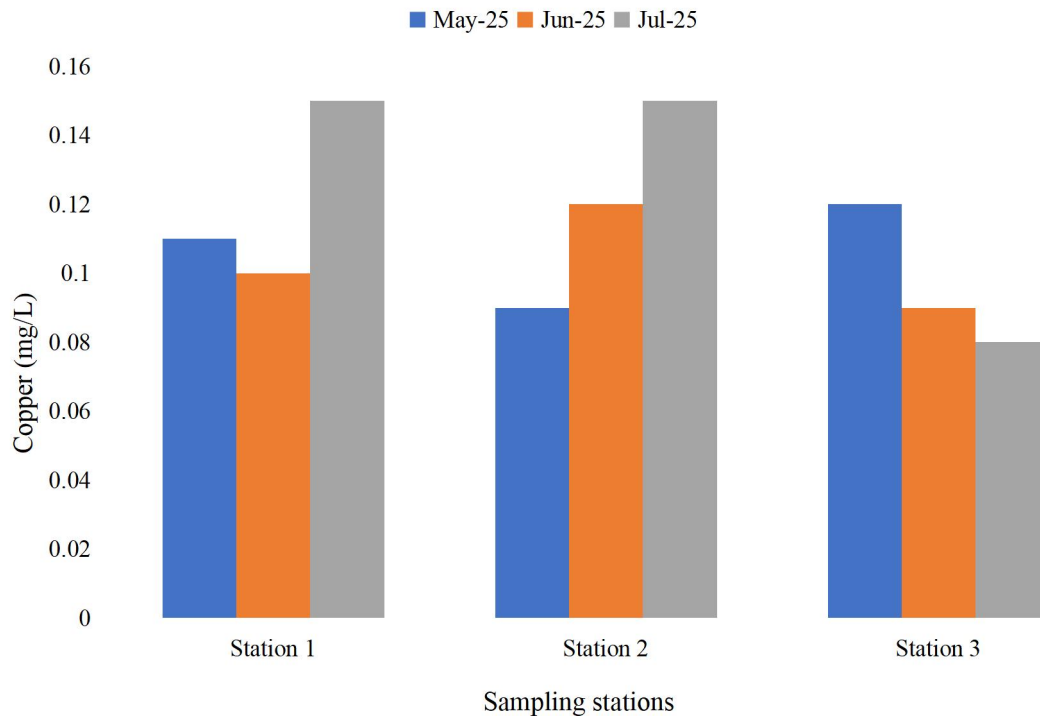


Figure 4.22: Geographical and temporal variation of Copper (mg/L) in surface water from Orhionmwon River.

4.1.23 Zinc (Zn) (mg/L)

Figure 4.22 depicts the geographical and temporal fluctuations in copper at three sampling locations in the Orhionmwon River. The trends observed across the stations were somewhat similar, with a diminishing pattern at station 3. The variation revealed the lowest copper value of 0.08 at station 3, and the highest copper values of 0.15 at stations 1 and 2. Copper concentrations in surface water from the Orhionmwon River varied from 0.10-0.15, 0.09-0.15, and 0.08-0.12 at stations 1, 2, and 3, respectively. The average copper levels for stations 1, 2, and 3 were 0.12, 0.12, and 0.10, respectively. The copper levels obtained throughout the three sampled stations of variance (ANOVA) were not significantly different ($p>0.05$).

4.1.24 Lead (Pb) (mg/L)

The geographical and temporal fluctuations for lead at three sampled stations along the Orhionmwon River stretch are displayed in **Figure 4.24**. All of the stations showed somewhat similar tendencies. The intraspecific variations revealed that station 2 had the lowest lead value (0.04) and station 1 had the highest lead value (0.09). At stations 1, 2, and 3, the lead levels in the surface water from the Orhionmwon River varied from 0.06-0.09, 0.04-0.08, and 0.05-0.08, respectively, with mean values of 0.07, 0.06, and 0.06. One-way analysis of variance (ANOVA) of the lead values from the three stations revealed no significant difference ($p>0.05$).

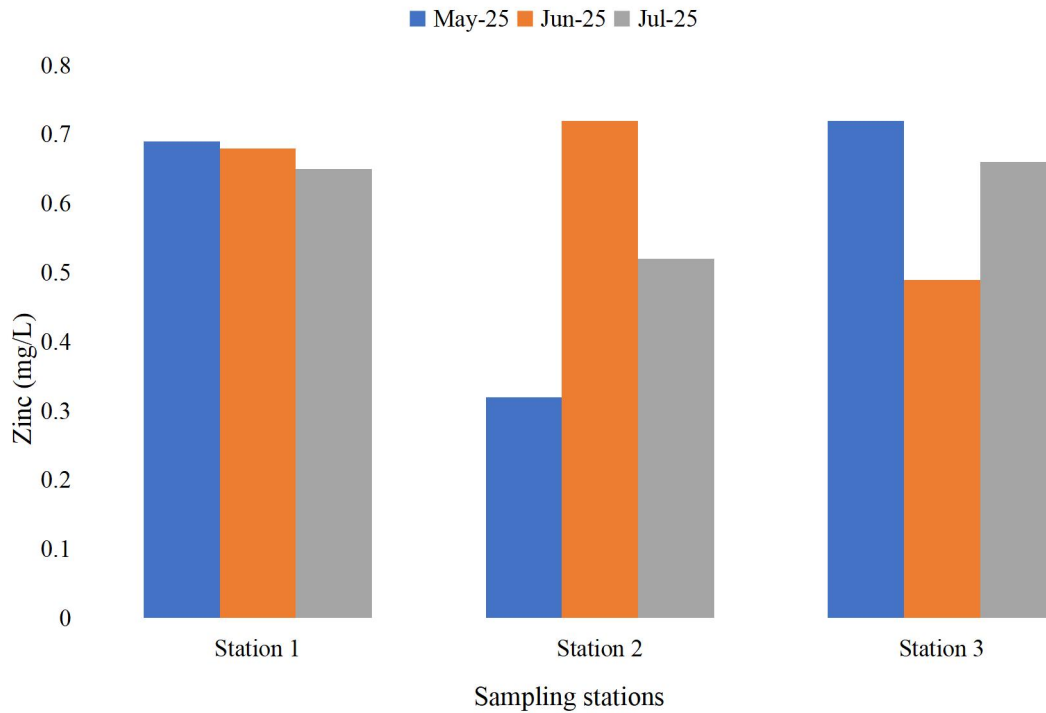


Figure 4.23: Geographical and temporal variation of Zinc (mg/L) in surface water from Orhionmwon River.

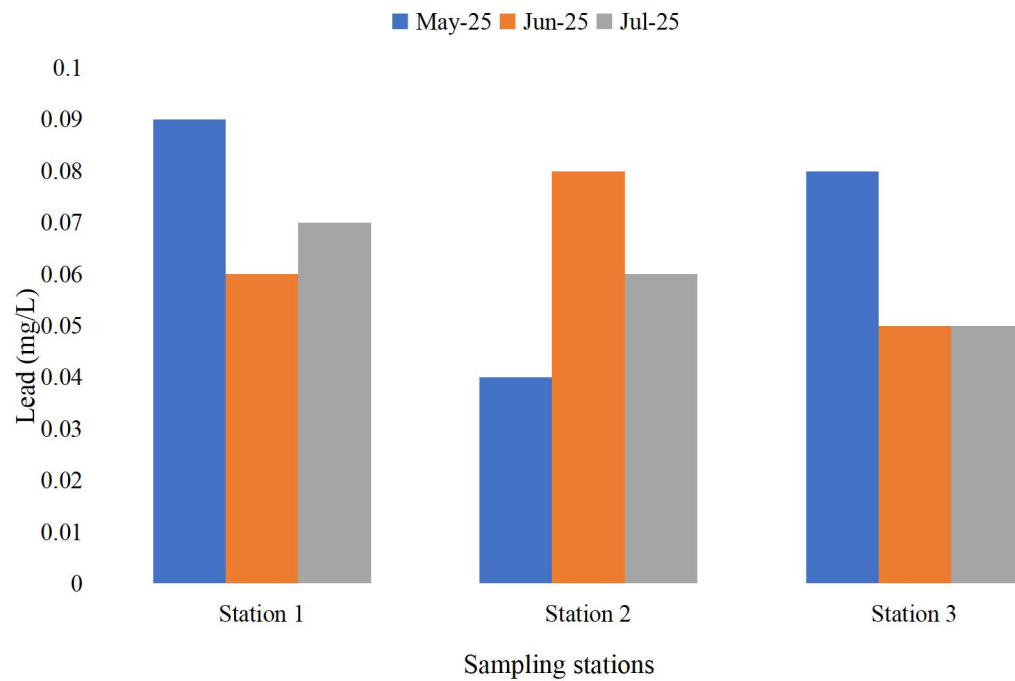


Figure 4.24: Geographical and temporal variation of Lead (mg/L) in surface water from Orhionmwon River.

4.1.25 Manganese (Mn) (mg/L)

The geographical and temporal fluctuations for manganese at three sampled locations along the Orhionmwon River are displayed in **Figure 4.25**. All of the stations showed comparatively similar trends, with station 3 showing an increasing tendency. According to the intraspecific variations, station 2 had the lowest manganese value (0.13) and station 3 had the greatest value (0.48) in the month of June. At stations 1, 2, and 3, the manganese levels of the surface water from the Orhionmwon River varied from 0.18-0.20, 0.13-0.48, and 0.23-0.48, with corresponding mean values of 0.19, 0.30, and 0.35. One-way analysis of variance (ANOVA) of the manganese values across the three stations revealed no significant differences ($p>0.05$).

4.1.26 Chromium (Cr) (mg/L)

Figure 4.26 shows the geographical and temporal variations for manganese at three sampled stations in Orhionmwon River. All of the stations showed rather similar trends, with station 2 having the lowest value. The fluctuation revealed the lowest chromium value of 0.02 at station 2 in May and the highest value of 0.07 at stations 3 and 2 in June. At stations 1, 2, and 3, the chromium values of the surface water from the Orhionmwon River varied between 0.04-0.06, 0.02-0.07, and 0.04-0.07, respectively. For each of the three locations, the average mean chromium readings were 0.05, 0.04, and 0.05 in the same order. One-way analysis of variance (ANOVA) of the three stations' total dissolved solids measurements revealed no significant difference ($p>0.05$).

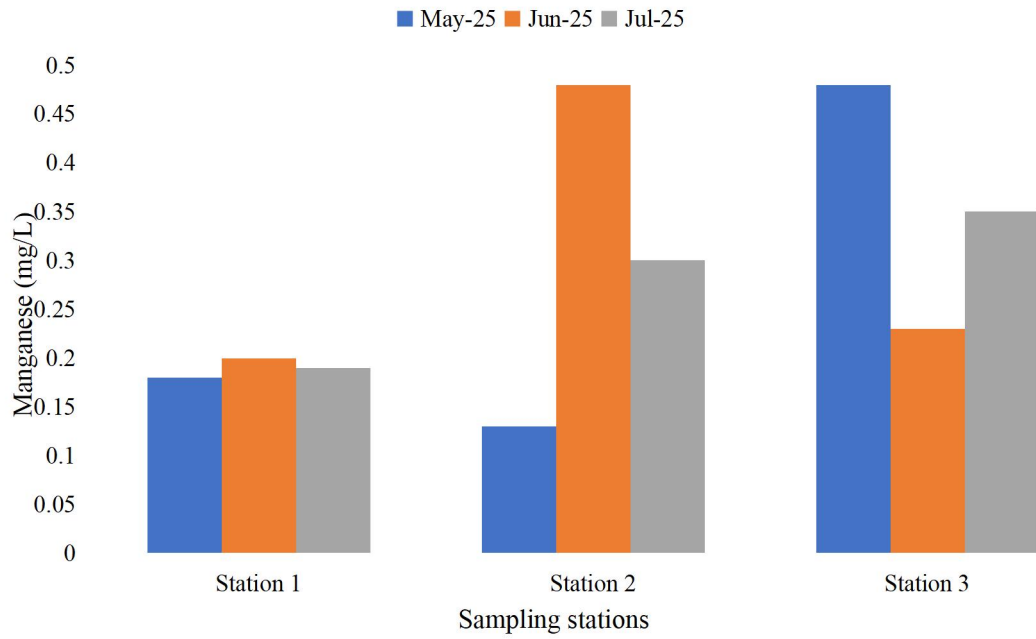


Figure 4.25: Geographical and temporal variation of Manganese (mg/L) in surface water from Orhionmwon River.

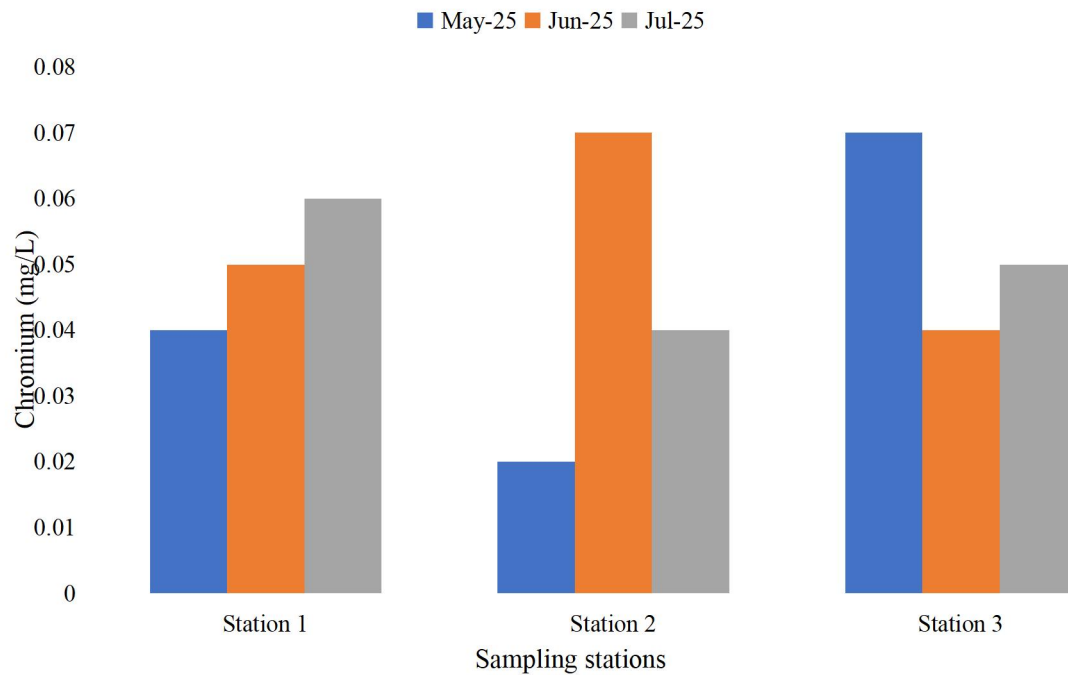


Figure 4.26: Geographical and temporal variation of Chromium (mg/L) in surface water from Orhionmwon River.

4.1.27 Total hydrocarbon content (THC) (mg/L)

Figure 4.27 shows the geographical and temporal variations for total hydrocarbon content at three sampled stations in Orhionmwon River. All of the stations showed somewhat similar tendencies. The variance revealed that station 2 had the highest THC value of 5.42 in June and the lowest THC value of 2.80 in July. At stations 1, 2, and 3, the THC content of the surface water from the Orhionmwon River varied from 3.85–4.12, 2.80–5.42, and 4.02–4.15, respectively. In the same order, the three stations' average mean THC readings were 3.96, 3.81, and 4.10. One-way analysis of variance (ANOVA) of the three stations' total hydrocarbon content measurements revealed no significant difference ($p>0.05$).

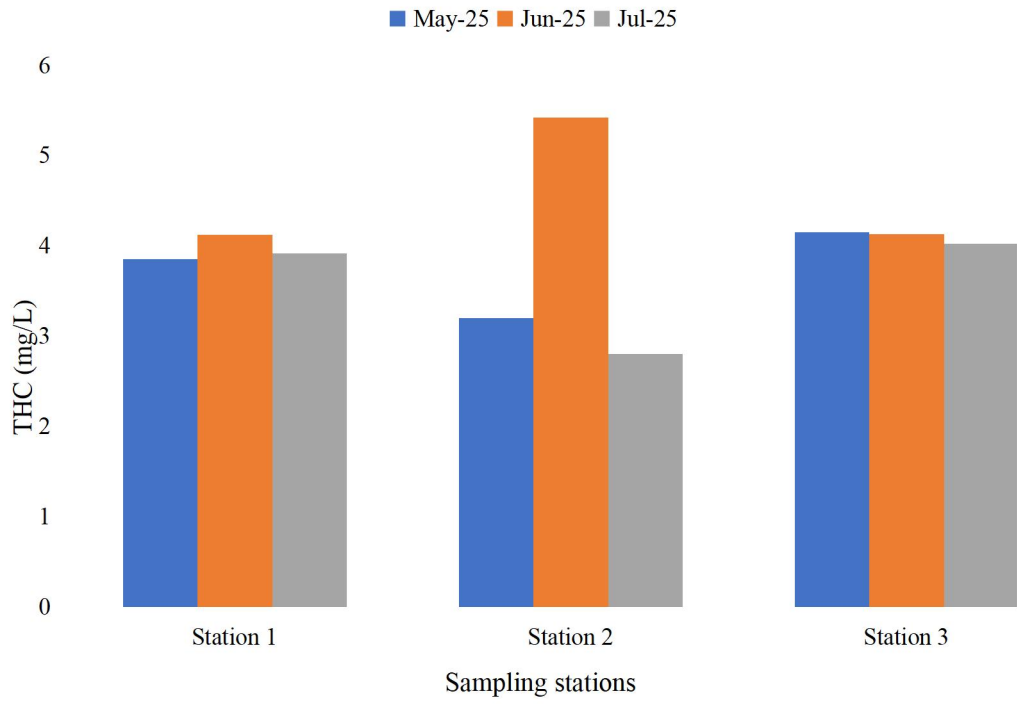


Figure 4.27: Geographical and temporal variation of THC (mg/L) in surface water from Orhionmwon River.

4.2 WATER QUALITY INDEX (WQI) OF SURFACE WATER FROM ORHIONMWON RIVER

Table 4.2 displays the summative water quality index (WQI) recorded in the study stations. At stations 1, 2, and 3, the cumulative water quality index values were 555.18, 514.94, and 529.81, respectively. With a mean score of 555.18, station 1 had the greatest water quality index, while station 2 had the lowest at 514.94. Station 1 (WQI=555.18) is categorized as Grade E and is not fit for consumption. The higher levels of lead (Pb), chromium (Cr), manganese (Mn), iron (Fe), dissolved oxygen (DO), biochemical oxygen demand (BOD), and turbidity at station 1 are responsible for this. Station 2 (WQI=514.94) is categorized as Grade E, meaning it is not fit for human consumption. The increased concentrations of lead (Pb), manganese (Mn), iron (Fe), dissolved oxygen (DO), biochemical oxygen demand (BOD), and turbidity at station 2 are the cause of this. Station 3 (WQI=529.81) is categorized as Grade E and is not fit for consumption. Lead (Pb), chromium (Cr), manganese (Mn), iron (Fe), dissolved oxygen (DO), biochemical oxygen demand (BOD), and turbidity were all elevated at station 3.

4.3 COMPREHENSIVE POLLUTION INDEX

Table 4.3 displays the study's summative comprehensive pollution index (CPI). At stations 1, 2, and 3, the cumulative comprehensive pollution index values were 0.88, 0.92, and 0.97, respectively. Station 1 had the lowest mean value of 0.88 for the comprehensive pollution index, while station 3 had the highest mean value of 0.97. Station 1 (CPI=0.88) has a low level of pollution, with physicochemical parameters like pH being the medium pollutant and heavy metals like chromium (Cr) and total hydrocarbon content (THC) being the slight pollutants, lead (Pb) being the serious pollutant, and iron (Fe) and manganese (Mn) being the heavy pollutants. Physicochemical parameters like pH are classified as medium pollutants in Station 2 (CPI=0.92), heavy metals like chromium (Cr) and total hydrocarbon content (THC) as slight pollutants, lead (Pb) and manganese (Mn) as serious pollutants, and iron (Fe) as heavy pollutants. Physicochemical parameters like pH are classified as medium pollutants in Station 3 (CPI=0.97), heavy metals like chromium (Cr) and total hydrocarbon content (THC) as slight pollutants, lead (Pb) and manganese (Mn) as serious pollutants, and iron (Fe) as heavy pollutants.

4.4 NON-CARCINOGENIC RISK ASSESSMENT

Table 4.4 shows the assessment of the non-carcinogenic risk connected to oral exposure to the Orhionmwon River. The acceptable regulatory limit value for a contaminant's target hazard quotient (THQ) is 1.0 (THQ = 1), per the USEPA (2021) guidelines for non-carcinogenic risk. In this investigation, THQ > 1 for oral exposure to THC and THQ < 1 for the corresponding heavy metals in water. When the hazard index (HI) is less than 1.0, an exposed population is deemed safe in terms of health risk; when HI is greater than 1.0, there may be cause for concern regarding possible non-cancer health impacts (Saha and Paul 2018). HI values for oral exposure in this investigation were higher than the threshold value of 1 (HI > 1). This suggests that communities located within the Orhionmwon river watershed are at risk for non-carcinogenic disorders linked to heavy metal poisoning due to their home use of surface water. It also suggests that the Orhionmwon River's current water quality in the sites under investigation is unfit for residential or recreational use.

4.5 CARCINOGENIC RISK ASSESSMENT

Table 4.5 displays the estimated carcinogenic risk of oral exposure to the Orhionmwon River's surface water. The order of carcinogenic risk was Cr > Pb. While the carcinogenic risk values for chromium (Cr) above the allowed range, the estimated oral carcinogenic risk (CR_{oral}) values for lead (Pb) for stations 1, 2, and 3 were below the USEPA (2012) acceptable range for carcinogenic risk ($1 \times 10^{-6} - 1 \times 10^{-4}$). The surface water was categorized as Grade VI (High risk) by the integrated carcinogenic risk (ICR) values, necessitating prompt attention and appropriate action.

CHAPTER FIVE

DISCUSSION

5.1 PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS CONTENT OF SURFACE WATER SAMPLES FROM ORHIONMWON RIVER

Temperature has an impact on oxygen solubility as well as the speed of chemical and biological processes in water. Elevated temperatures can cause stress to aquatic species and frequently decrease dissolved oxygen (Abali *et al.*, 2023). The stations 1, 2, and 3 recorded average mean temperatures of 30.10, 30.33, and 29.93 (°C), respectively. One-way analysis of variance (ANOVA) revealed no statistically significant difference ($p > 0.05$) between the temperature readings at various stations. The results show that the temperature values are within the ambient temperature range specified by NESREA (2011) and WHO (2011) standards. This means that the readings are consistent with natural tropical river temperatures, which are typically between 25 and 32°C. This suggests that there is no indication of thermal pollution or artificial heating in the Orhionmwon River. Similar results were reported by Abali *et al.* (2023), who found that the Idu Ogba River had mean temperatures between 25.70°C and 26.34°C, and by Enuneku *et al.* (2017), who found that the Obueyinomo River had mean temperatures between 25.38°C and 26.18°C, both of which were within acceptable bounds. Additionally, Edjere *et al.* (2023) discovered that Okpare River had somewhat higher temperatures (28.9–29°C), while the Ossiomo River recorded 29.1–30°C, according to Biose *et al.* (2024), suggesting that the thermal profiles of the majority of tropical Nigerian rivers are comparable. Climate, solar radiation intensity, and riparian vegetation cover may be responsible for the slight change in Orhionmwon River temperature. In addition to increasing biological activity and microbial breakdown rates, elevated temperatures may also reduce oxygen solubility, which could have an impact on aquatic metabolism.

The acidity or alkalinity of water is indicated by its pH, which also has a significant impact on chemical and biological interactions in the body of water (such as microbial activity and metal solubility). Aquatic life can flourish and metal mobilization from sediments can be prevented by keeping the pH close to neutral (Dewangan *et al.*, 2023). At sampling stations 1, 2, and 3, the average mean pH values were found to be 7.10, 6.99, and 6.83, respectively, indicating that the river was just slightly acidic to neutral, suitable for aquatic species and household use, and within the permitted range of 6.5-8.5 (NESREA, 2011 and WHO, 2011). The pH levels at the various stations did not differ statistically significantly ($p>0.05$). The pH values found in this study are lower than those found in the Ogbor Hill River by Okey-Wokeh *et al.* (2023), which ranged from 6.06 to 6.73. While Biose *et al.* (2024) found pH values between 5.8 and 6.5 in the Ossiomo River, both below standard limits, suggesting acidification by organic wastes, Abali *et al.* (2023) reported higher acidic conditions (mean pH 5.31) in the Idu Ogba River. The Inyishi River's pH ranged from 4.10 to 8.36, according to Ibe *et al.* (2019). The NESREA and WHO requirements (6.5-8.5) were not met by these values. The low pH value was attributed to the untreated alkaline effluent from the aluminum extrusion company, whereas the high pH value was attributed to the sulfuric acid component in the wastewater effluent. There were differences between the mean pH values at each site, indicating that the Orhionmwon River's pH remained constant throughout.

The concentration of dissolved ions (salts, minerals) is reflected in the water's electrical conductivity (EC). Greater mineralization or potential anthropogenic contamination are indicated by higher EC (Talab *et al.*, 2025). The electrical conductivity (EC) of the surface water at the three (3) different sampling locations along the Orhionmwon River ranged from 20.33 to 21.00 to 18.67 ($\mu\text{S}/\text{cm}$), all significantly below the WHO (2011) and NESREA (2011) limit of 1000 $\mu\text{S}/\text{cm}$, indicating very low ionic strength and minimal dissolved mineral salts. Biose *et al.* (2024) and Enuneku *et al.* (2017) discovered similar low EC values

in the Ossiomo River (16–55 $\mu\text{S}/\text{cm}$) and the Obueyinomo River (10–80 $\mu\text{S}/\text{cm}$), however Okey-Wokeh *et al.* (2023) reported significantly higher EC (1392 $\mu\text{S}/\text{cm}$) in the Ogbor Hill River because of industrial influence. In the Okpare River, Edjere *et al.* (2023) similarly found moderate conductivity (29–56 $\mu\text{S}/\text{cm}$), confirming that EC values are generally lower in rural or less industrialized catchments. The EC levels at the various stations did not differ statistically significantly ($p>0.05$). The Orhionmwon River's low electrical conductivity reflects soft water qualities that are ideal for home usage, such as low dissolved ionic load and little anthropogenic contamination.

The total amount of dissolved inorganic and organic matter in water is known as total dissolved solids (TDS); elevated TDS can alter flavour and may be a sign of pollution (Enuneku *et al.*, 2017). The three monitoring stations' total dissolved solids concentrations were below the allowable 500 mg/L limit, at 10.00 mg/L, 10.33 mg/L, and 9.33 mg/L, respectively (NESREA, 2011 and WHO, 2015). Using one-way analysis of variance (ANOVA), the TDS readings at various stations did not differ statistically significantly ($p>0.05$). Good water quality and minimal mineralization are implied by these low values. Edjere *et al.* (2023) found 15.00–29.00 mg/L in Okpare River, Biose *et al.* (2024) found 8.00–27.00 mg/L in Ossiomo River, and Abali *et al.* (2023) reported higher TDS (94.48 mg/L) in Idu Ogba River—all within permissible limits. Similar to the Orhionmwon River, Enuneku *et al.* (2017) found 7.42–19.43 mg/L in the Obueyinomo River, and Oyetunji *et al.* (2023) found greater levels of 151.8–170.4 mg/L in the Eleyele River. The river is still comparatively clean, as seen by the continuously low TDS at each station, which means little dissolved salts, little fertilizer runoff, and little entry of domestic wastewater.

Undissolved particles in water are measured by total suspended solids (TSS). In addition to interfering with photosynthesis and possibly carrying associated contaminants, high TSS lowers water clarity (Biose *et al.*, 2024). Low sediment or particulate matter load was

indicated by the total suspended solids values at stations 1, 2, and 3, which were 4.67, 4.33, and 4.50, respectively, substantially below the 500 mg/L permissible level set by NESREA and WHO. This is consistent with reports from Enuneku *et al.* (2017) of 4.93–9.73 mg/L and Biose *et al.* (2024) of 20–330 mg/L in the Ossiomo River and Obueyinomo River, respectively. According to Abali *et al.* (2023), the Idu Ogba River had 65.37 mg/L, indicating that the Orhionmwon River had less runoff and erosion. However, Edjere *et al.* (2023) found that the Okpare Community River had 100.00–600.00 mg/L, which is significantly higher than the permitted limit and indicates low water clarity that may be caused by pollution, sedimentation, or other environmental issues. There was no discernible variation ($p>0.05$) in the TSS concentration during the sampling months. Low catchment disturbance and vegetative stability of riverbanks may be the cause of the low TSS readings, which improve water clarity and indicate limited siltation. At stations 1, 2, and 3, total solids varied from 14.67 to 14.67 to 13.83 (mg/L), which is far below the 100 mg/L threshold recommended for safe consumption by NESREA (2011) and WHO (2011). One-way analysis of variance (ANOVA) revealed no statistically significant difference ($p>0.05$) in the results at various stations. The low TDS and TSS values are consistent with the low total solids, indicating the lack of major anthropogenic input. The Obueyinomo River has comparable low TS levels of 15.29–23.70 mg/L (Enuneku *et al.*, 2017). A clean river system with strong self-purification capacity is indicated by low TS.

The cloudiness of water brought on by suspended particles is reflected in turbidity. Increased silt, erosion, or contamination are frequently indicated by high turbidity, which also impacts aquatic photosynthesis and decreases light penetration (Talab *et al.*, 2025). Throughout the three monitoring sites in this study, the average turbidity was 6.09, 6.43, and 6.62 (NTU), which is marginally higher than the 5 NTU NESREA and WHO limit. Moderate suspended particles, most likely from surface runoff or the breakdown of organic materials, are indicated

by elevated turbidity levels. While Enuneku *et al.* (2017) found higher values of 8.67–16.33 NTU in the Obueyinomo River, Abali *et al.* (2023) reported 6.5 NTU in the Idu Ogba River. Edjere *et al.* (2023) found high values of 107–561 NTU in the Okpare River, while Okey-Wokeh *et al.* (2023) noted turbidity peaks of 26.7 NTU in the Ogbor Hill River. Additionally, Onoyima *et al.* (2025) recorded extreme values in the Ogun River ranging from 153.49 to 323.67 NTU, all of which exceeded the WHO (2011) and NESREA (2011) guidelines. The turbidity levels at several stations in the Orhionmwon River did not differ statistically significantly ($p>0.05$). The Orhionmwon River's comparatively low turbidity indicates good light penetration and mild disturbance, both of which are favourable for aquatic productivity.

Low buffering capacity was indicated by the three measured stations' alkalinity levels of 6.10 mg/L, 5.08 mg/L, and 6.10 mg/L, which were significantly below the 100–200 mg/L range set by NESREA (2011) and WHO (2011). One-way analysis of variance (ANOVA) study of the concentrations revealed no significant difference ($p>0.05$) between the sampling months. While Abali *et al.* (2023) observed 16.47 mg/L in the Idu Ogba River and Enuneku *et al.* (2017) discovered 9.87–16.13 mg/L in the Obueyinomo River, Biose *et al.* (2024) reported similar low alkalinity (2.50–8.25 mg/L) in the Ossiomo River. Such low alkalinity indicates that the water is susceptible to pH changes and can quickly turn acidic when pollutants are added.

The amount of dissolved oxygen in water, or DO, is essential for aquatic life. Low DO levels could be a sign of organic pollution or warm water that reduces the solubility of oxygen, both of which are harmful to aquatic life. For aquatic creatures, DO is essential. According to Okey-Wokeh *et al.* (2023), low DO readings typically signify organic contamination or oxygen depletion from breakdown processes. At stations 1, 2, and 3, the dissolved oxygen levels were 5.20 mg/L, 4.60 mg/L, and 4.73 mg/L, respectively. These values showed mild oxygen depletion because they were below the 6.0 mg/L allowable range suggested by

NESREA and WHO. Similar results were found in the Ossiomo River (3.00–4.94 mg/L) by Biose *et al.* (2024), the Obueyinomo River (2.04–4.27 mg/L) by Enuneku *et al.* (2017), and the Idu Ogba River (3.47 mg/L) by Abali *et al.* (2023). Low DO (1.148 mg/L) was also discovered in the Eleyele River by Oyentunji *et al.* (2023). One-way analysis of variance (ANOVA) revealed no statistically significant difference ($p>0.05$) in the results at various stations. The breakdown of organic matter or warm temperatures that lower oxygen solubility could be the cause of the decreased DO in the Orhionmwon River. Fish survival is impacted by low DO, which also suggests mild organic contamination.

The amount of oxygen needed by microbes to break down organic materials in water is measured by BOD. A high organic load or pollution from residential or agricultural sources is indicated by elevated BOD. The three sampling sites' biochemical oxygen demand (BOD) values ranged from 3.67 to 3.80 to 3.67 (mg/L), which marginally above the 3.0 mg/L limit set by NESREA (2011) and WHO (2011), indicating minor organic pollution. Biochemical oxygen demand (BOD) measurements at each station did not differ statistically significantly ($p>0.05$) according to one-way analysis of variance (ANOVA). Similar findings were reported by Enuneku *et al.* (2017), who reported BOD levels of 1.23–1.93 mg/L in the Obueyinomo River, and Edjere *et al.* (2023), who discovered BOD values of 1.20–3.40 mg/L in the Okpare River. Abali *et al.* (2023) discovered a higher BOD value of 10.61 mg/L in the Idu Ogba River, which they attributed to organic contamination from trash discharge. While Okey-Wokeh *et al.* (2023) noted seasonal peaks exceeding 10 mg/L, which are indicative of high biodegradable organic matter, particularly from abattoir discharges, Biose *et al.* (2024) recorded low BOD values of 0.46–2.54 mg/L. As a result, the Orhionmwon River exhibits a mild organic loading, most likely due to restricted domestic waste intake and natural vegetation breakdown.

The total oxygen required to chemically oxidize both organic and inorganic materials is indicated by COD. According to Abali *et al.* (2023), a high COD indicates a substantial pollution load. Stations 1, 2, and 3 had average chemical oxygen demand (COD) values of 32.67, 23.33, and 45.33 (mg/L), respectively. One-way analysis of variance (ANOVA) revealed a statistically significant difference ($p < 0.05$) in the COD values at each location. The chemical oxygen demand levels in the Orhionmwon River are comparatively greater than the 30 mg/L safe consumption criterion established by the WHO (2011) and NESREA (2011), indicating a large presence of oxidizable material. While Biose *et al.* (2024) discovered lower COD values of 10–20 mg/L in the Ossiomo River, Abali *et al.* (2023) reported a higher COD value of 51 mg/L in the Idu Ogba River, confirming organic pollution. Surface runoff containing both organic and inorganic pollutants may be the cause of the Orhionmwon River's increased chemical oxygen demand (COD) values. Moderate pollution is indicated by elevated chemical oxygen demand (COD), which frequently coincides with decreased dissolved oxygen (DO) and increased biochemical oxygen demand (BOD).

The Orhionmwon River's chloride values at stations 1, 2, and 3 varied from 7.03 to 5.07 to 7.09 mg/L. The chloride levels are much below the 300 mg/L threshold, suggesting no sewage or saline incursion. There was no statistically significant difference ($p > 0.05$) in the chloride values between the stations, according to one-way analysis of variance (ANOVA). Biose *et al.* (2024) found low chloride levels in the Ossiomo River (3.45–10.64 mg/L) while Enuneku *et al.* (2017) found low levels in the Obueyinomo River (11.72–21.18 mg/L). Additionally, Abali *et al.* (2023) found that the average chloride value was 7.23 mg/L, which suggests that there was little chemical disinfection or contamination from chlorinated substances. This demonstrates that neither saline intrusion nor household wastewater have an impact on the Orhionmwon River.

Although nitrate is a necessary nutrient, too much of it can cause eutrophication and oxygen depletion (Okafor *et al.*, 2023). At stations 1, 2, and 3, the nitrate levels were determined to be 9.49 mg/L, 4.99 mg/L, and 8.35 mg/L, respectively. These results fell under the 50 mg/L limit set by WHO (2011) and NESREA (2011). Abali *et al.* (2023) found an average nitrate value of 6.29 mg/L, Enuneku *et al.* (2017) found nitrate values of 0.96–1.44 mg/L, Biose *et al.* (2024) found values between 0.12–1.74 mg/L, and Onoyima and Nwoye (2022) found nitrate values of 9.47–9.50 mg/L. In a similar vein, Oyetunji *et al.* (2023) discovered nitrate values ranging from 0.51 to 1.006 mg/L, while Adeleke *et al.* (2022) discovered average nitrate values of 1.66 and 1.69 mg/L in Ikpoba and Iguosa Rivers. One-way analysis of variance (ANOVA) revealed a statistically significant difference ($p < 0.05$) in the nitrate concentrations at various locations. The Orhionmwon River's high nitrate levels could be caused by rotting vegetation and agricultural runoff. Eutrophication may result from a prolonged rise.

Fertilizers and detergents are the sources of phosphate. Eutrophication and algal blooms are accelerated by elevated phosphate (Biose *et al.*, 2024). Low nutrient enrichment was indicated by the phosphate values at stations 1, 2, and 3, which were 0.72 mg/L, 0.22 mg/L, and 0.48 mg/L, respectively, below the 3.5 mg/L tolerable level set by NESREA (2011) and WHO (2011). There was no discernible variation ($p > 0.05$) in the phosphate concentrations between the sampling months. This is consistent with the findings of Enuneku *et al.* (2017), who found phosphate levels in the Obueyinomo River ranging from 0.48 to 0.56 mg/L, and Abali *et al.* (2023), who found an average phosphate level of 0.513 mg/L in the Idu Ogba River. Biose *et al.* (2024) in the Ossiomo River and Oyetunji *et al.* (2023) in the Eleyele River observed lower phosphate concentrations of 0.02–0.08 mg/L and 0.036–0.076 mg/L, respectively. The resemblance suggests that nearby areas use phosphate detergents and fertilizers sparingly.

Sulphate can be found in the environment or in industrial wastewater. Although it may alter taste and raise salinity, excessive sulfate is not very harmful (Edjere and Emeji, 2023). At Stations 1, 2, and 3, the sulphate values were determined to be 2.03 mg/L, 1.84 mg/L, and 1.66 mg/L, respectively. The allowable limit of 100 mg/L established by NESREA (2011) and WHO (2011) was met by these values. Similar findings were reported by Abali *et al.* (2023), who observed 9.4 mg/L in the Idu Ogba River, and Biose *et al.* (2024), who discovered sulphate concentrations ranging from 0.83–3.28 mg/L in the Ossiomo River. The three sampling stations did not differ statistically significantly ($p>0.05$). The Orhionmwon River's low sulphate concentration suggests that there is less sewage or industrial input, indicating that human activity has less of an impact on the water.

The amount of calcium and magnesium ions in water is measured by its hardness. Although it can lead to scaling, hard water has the ability to act as a buffer (Biose *et al.*, 2024). The Orhionmwon River's total hardness concentrations at Stations 1, 2, and 3 varied from 7.10 mg/L to 6.57 mg/L to 7.10 mg/L, respectively. The total hardness values at each station did not differ statistically significantly ($p>0.05$) according to one-way analysis of variance (ANOVA). According to NESREA (2011) and WHO (2011), these readings were far below the allowable limit of 150 mg/L. In the Ossiomo River, Biose *et al.* (2024) found hardness levels between 4.80 and 8.01 mg/L, but in the Obueyinomo River, Enuneku *et al.* (2017) found hardness values between 9.33 and 11.33 mg/L. In the Okpare River, Edjere *et al.* (2023) found somewhat greater hardness values of 7.96–16.70 mg/L. The Orhionmwon River's soft water, which is ideal for home use but has a limited ability to act as a buffer against acidification, is indicated by its low hardness.

The average mean calcium levels for stations 1, 2, and 3 in the Orhionmwon River were 1.71 mg/L, 1.99 mg/L, and 1.71 mg/L, respectively. There was no statistically significant difference ($p>0.05$) between the sampling points. The NESREA (2011) and WHO (2011)

suggested limit of 180 mg/L was significantly below these values. According to Biose *et al.* (2024) and Enuneku *et al.* (2017), calcium concentrations in surface water collected from the Ossiomo River and Obueyinomo River ranged from 1.04–2.37 mg/L and 1.81–2.03 mg/L, respectively.

The low calcium concentration indicates that the water body has little mineralization and little calcareous rock disintegration.

The Orhionmwon River's magnesium concentrations were determined to be 0.69 mg/L, 0.52 mg/L, and 0.69 mg/L at Stations 1, 2, and 3, respectively. The WHO (2011) and NESREA (2011) acceptable limit of 40 mg/L was exceeded by these readings. While Enuneku *et al.* (2017) discovered values of 1.17–1.52 mg/L in the Obueyinomo River, Biose *et al.* (2024) reported magnesium levels in the Ossiomo River between 0.27–0.71 mg/L, indicating poor mineral hardness. Higher magnesium levels of 7.27–7.49 mg/L were reported by Oyetunji *et al.* (2023), however they were still below the permissible range. One-way analysis of variance (ANOVA) revealed no statistically significant variation ($p>0.05$) in the magnesium readings at various sites. The low magnesium level suggests little ionic contribution from the nearby geology and little mineral leaching.

At Stations 1, 2, and 3, the sodium concentrations were 1.16 mg/L, 0.71 mg/L, and 0.89 mg/L, respectively. The allowable level of 120 mg/L suggested by NESREA (2011) and WHO (2011) is much below these amounts. Sodium levels in the Ossiomo River ranged from 0.9 to 1.17 mg/L, indicating soft water conditions, according to a related study by Biose *et al.* (2024). There was no significant difference ($p>0.05$) between the three sampling stations, according to statistical analysis. The Orhionmwon River's low sodium content indicates little human input, such as fertilizer and detergent residues.

One nutrient that is frequently obtained from organic materials and fertilizers is potassium. Increased levels could be a sign of runoff from agriculture (Enuneku *et al.*, 2017). At Stations 1, 2, and 3 in the Orhionmwon River, the potassium values varied from 1.60 mg/L to 1.47 mg/L to 1.44 mg/L. These findings are significantly lower than the 50 mg/L allowable limit established by WHO (2011) and NESREA (2011). The Ossiomo River had lower potassium values of 0.47–0.83 mg/L, according to Biose *et al.* (2024). Potassium levels at each station did not differ statistically significantly ($p>0.05$) according to one-way analysis of variance (ANOVA). The low potassium content is a result of inadequate organic waste decomposition and low intake from residential or agricultural sources.

Iron is a common element found in water; at low amounts, it is necessary, but at high concentrations, it can indicate contamination, discolor water, cause taste problems, cause plumbing problems, and catalyze other chemical changes (Omonona *et al.*, 2019). At Stations 1, 2, and 3, the iron concentrations were 1.22 mg/L, 1.33 mg/L, and 1.18 mg/L, respectively. These values show iron pollution because they are higher than the permitted limit of 0.3 mg/L set by NESREA (2011) and WHO (2011). Okey-Wokeh *et al.* (2023) discovered a peak iron value of 2.68 mg/L in the Ogor Hill River, whereas Biose *et al.* (2024) reported iron values of 0.18–2.43 mg/L in the Ossiomo River. While Onoyima and Nwoye (2022) discovered even higher iron readings of 22.66–34.50 mg/L in River Kaduna, Omotoso *et al.* (2021) measured an average iron concentration of 4.801 mg/L in the Asa River. Additionally, Oyetunji *et al.* (2023) discovered that the Eleyele River had a peak iron value of 0.672. The stations did not differ statistically significantly ($p>0.05$). Leaching of iron-bearing rocks, runoff from lateritic soil, or corrosion of metallic objects could all contribute to the elevated iron levels. Overdosing on iron can be hazardous to aquatic life and cause colouring and taste changes.

Although copper is a necessary micronutrient, too much of it can harm the liver and create gastrointestinal problems. Frequently as a result of pipe deterioration (Abubakar *et al.*, 2015). At Stations 1, 2, and 3, the concentrations of copper were determined to be 0.12 mg/L, 0.12 mg/L, and 0.10 mg/L, respectively. The copper readings at each location did not differ statistically significantly ($p>0.05$) according to one-way analysis of variance (ANOVA). These readings fall under the 1.0 mg/L allowable range set by WHO (2011) and NESREA (2011). Okey-Wokeh *et al.* (2023) discovered copper values of 0.02-0.80 mg/L in the Ogbor Hill River, whereas Biose *et al.* (2024) reported copper values between 0.01-0.06 mg/L in the Ossiomo River. Additionally, Onoyima and Nwoye (2022) revealed that the River Kaduna had copper levels between 0.157 and 0.347 mg/L. Minimal metal contamination and no immediate health danger to humans or aquatic life are indicated by the permissible copper level.

Zinc is an essential element for life; high quantities are caused by waste or industrial discharges, although they are typically not harmful (Okafor *et al.*, 2023). The Orhionmwon River's zinc concentrations at Stations 1, 2, and 3 varied from 0.72 mg/L to 0.32 mg/L to 0.55 mg/L, respectively. According to NESREA (2011) and WHO (2011), these results fall under the allowable range of 3.0 mg/L. Similar zinc levels were found in the Ossiomo River by Biose *et al.* (2024) (0.00–0.04 mg/L), the Inyishi River by Ibe *et al.* (2019) (0.001–30.0 mg/L), and the Iguosa and Ikpoba Rivers by Adeleke *et al.* (2022) (8.57 mg/L for 7-Up effluents and 7.98 mg/L for Guinness effluents). Eleyele River mean values of 0.01–0.03 mg/L were similarly reported by Oyetunji *et al.* (2023). The three sampling stations did not differ significantly ($p>0.05$). There appears to be no significant anthropogenic zinc enrichment because the zinc contents are within natural background levels.

A hazardous non-essential metal that can harm the kidneys and skeleton is cadmium. Typically from industrial trash and batteries (Ibe *et al.*, 2019). In every test station from

Orhionmwon River, cadmium was not found (0.00 mg/L). This is less than the 0.003 mg/L allowable limit established by WHO (2011) and NESREA (2011). Cadmium levels in the Ossiomo River were determined to be between 0.01 and 0.11 mg/L by Biose *et al.* (2024) and between 0.022 and 0.468 mg/L in the Ogun River by Onoyima *et al.* (2025). In the same way, Onoyima and Nwoye (2022) reported 0.04-0.10 mg/L in the River Kaduna, while Ibe *et al.* (2019) discovered 0.02-0.065 mg/L in the Inyishi River. The Orhionmwon River's lack of cadmium suggests that it is free of pollution from batteries and industrial effluents.

Lead is a very toxic heavy metal that has detrimental effects on human health, particularly on children's neurodevelopment. According to Abubakar *et al.* (2015), its presence in water over allowable limits indicates anthropogenic pollution, such as from garbage, batteries, and metallurgical activities. At Stations 1, 2, and 3, the lead concentrations in the Orhionmwon River were determined to be 0.07 mg/L, 0.06 mg/L, and 0.07 mg/L, respectively. These lead levels were higher than the WHO (2011) and NESREA (2011) acceptable limit of 0.01 mg/L, indicating lead contamination. Lead readings at each site did not differ statistically significantly ($p > 0.05$), according to a one-way analysis of variance (ANOVA). In a similar vein, Biose *et al.* (2024) discovered lower Pb levels (0.00–0.02 mg/L) in the Ossiomo River, which were connected to fuel combustion, waste from battery operations, and incorrect disposal of lead-containing items. Onoyima *et al.* (2025) found as much as 1.45 mg/L in the Ogun River, while Okey-Wokeh *et al.* (2023) reported 0.44 mg/L in the Ogbor Hill River. In the Eleyele River, Adeleke *et al.* (2023) found 0.023–0.026 mg/L. One-way analysis of variance (ANOVA) revealed no statistically significant variation ($p > 0.05$) in the lead values at various locations. The Orhionmwon River's elevated lead levels could be caused by household garbage, leaded fuel residues, and vehicle emissions. Chronic lead exposure can result in developmental abnormalities, renal damage, and neurological issues.

Although manganese is a micronutrient that is required in trace amounts, excessive concentrations can discolour water and have neurological consequences (Omotoso and Olorunfemi, 2021). At Stations 1, 2, and 3, the manganese values were determined to be 0.19 mg/L, 0.30 mg/L, and 0.35 mg/L, respectively. The NESREA (2011) and WHO (2011) acceptable limit of 0.08 mg/L was surpassed by these readings. Similar high manganese concentrations were reported by Okey-Wokeh *et al.* (2023), who discovered an average manganese value of 0.221 mg/L, and Biose *et al.* (2024), who found manganese values of 0.02–0.27 mg/L. Mn levels in the Inyishi River ranged from 0.45 to 0.68 mg/L, according to Ibe *et al.* (2019). One-way analysis of variance (ANOVA) revealed no statistically significant difference ($p < 0.05$) in the Mn concentrations at various sites. Both natural soil leaching and agricultural runoff can cause elevated manganese levels. Neurological and motor functioning may be affected by prolonged exposure.

One heavy metal that causes cancer is chromium, particularly in its hexavalent form (Cr VI). Elevated Cr in water offers long-term concerns to human health and may indicate urban runoff or industrial leaching (Okafor *et al.*, 2023). The Orhionmwon River's chromium contents at Stations 1, 2, and 3 varied from 0.05 to 0.04 to 0.05 (mg/L). Throughout the sampling months, there was no discernible variation in the concentrations ($p > 0.05$). These results were close to the 0.05 mg/L acceptable limit set by the WHO (2011) and NESREA (2011). While Oyetunji *et al.* (2023) discovered 0.041 mg/L in the Eleyele River, Biose *et al.* (2024) reported comparable values of 0.02–0.11 mg/L in the Ossiomo River. Ibe *et al.* (2019) found extremely low chromium levels of 0.008–0.06 mg/L in the Inyishi River, while Okey-Wokeh *et al.* (2023) found 0.05 mg/L in the Ogbor Hill River. The stations did not differ statistically significantly ($p > 0.05$). The quantities of chromium could be caused by corrosion from metallic objects or agricultural inputs. Long-term exposure to hexavalent chromium can have mutagenic and carcinogenic effects.

At Stations 1, 2, and 3 in the Orhionmwon River, the total hydrocarbon content values were 3.96 mg/L, 3.81 mg/L, and 4.10 mg/L, respectively. These values show negligible hydrocarbon contamination because they fall within the 10 mg/L NESREA (2011) permitted limit. One-way analysis of variance (ANOVA) revealed no significant difference ($p>0.05$) in the THC readings between the various sampling points. Egun and Oboh (2023) found similar results, reporting greater THC levels (>10 mg/L) in the Ossiomo River as a result of petroleum contamination. The Orhionmwon River's comparatively low THC levels indicate little hydrocarbon contamination, suggesting that petroleum activities have less of an impact on the region.

According to this study, increased levels of certain physicochemical and heavy metal characteristics were the primary cause of the Orhionmwon River's surface water quality frequently falling below the drinkable water threshold. ceremonies along the riverbanks throughout the sampling period included swimming, washing clothes and canoes, disposing of household waste, and engaging in religious ceremonies that involved tossing objects into the river. The reported fluctuations in water quality were caused by these human activities as well as natural runoff and soil leaching. The findings imply that the river's water quality is greatly impacted by both lithogenic and anthropogenic factors, which could endanger aquatic life and make the water unfit for human consumption. Therefore, in order to prevent future degradation of the river ecology, adherence to environmental standards and appropriate management of human activities are crucial.

5.2 WATER QUALITY INDEX (WQI) OF SURFACE WATER FROM ORHIONMWON RIVER

The three Orhionmwon River sampling stations yielded water quality index (WQI) values of 555.18, 514.94, and 529.81, respectively. According to NESREA (2011) guidelines, these results are considerably higher than the typical threshold of $WQI>100$, designating the river

as Grade E (unsuitable for drinking). The high WQI values show significant contamination brought on by the combined effects of heavy metals and several physicochemical factors. The high levels of iron (Fe), lead (Pb), manganese (Mn), dissolved oxygen (DO), biochemical oxygen demand (BOD), turbidity, and chromium (Cr) found in the river all of which were over allowable limits are the primary cause of the higher WQI. Biose *et al.* (2024) and Egun and Oboh (2023) reported similar results, identifying heavy metals as the main cause of poor water quality in the Ossiomo River with WQI values of 251.63-765.24 and 251.57-765.37. The Orhionmwon River's elevated WQI values point to a decline in water quality brought on by human activities such as bathing, washing, agricultural runoff, and waste disposal along the riverbanks. Because of the accumulation of hazardous metals, the results show that Orhionmwon River is unfit for direct human use without proper treatment.

5.3 COMPREHENSIVE POLLUTION INDEX (CPI) OF ORHIONMWON RIVER.

Across the three test stations, the Orhionmwon River's comprehensive pollution index (CPI) varied from 0.88 to 0.92 to 0.97. The river is classified as significantly contaminated based on CPI < 0.2 (clean), 0.21–0.4 (sub clean), 0.41–1.0 (slight pollution), 1.01–2.0 (moderately polluted), and >2.01 (heavily polluted). This classification is consistent with the results of Egun and Oboh (2023), who found that the Ossiomo River had CPI values between 0.4 and 1.0, indicating mild to moderate pollution levels in the waterways surrounding Edo State. The combined effects of physicochemical and heavy metal concentrations in the river water are reflected in the reported CPI values. The pollution index was influenced by slightly higher concentrations of iron (Fe), lead (Pb), manganese (Mn), chromium (Cr), and total hydrocarbon content (THC), even though the majority of parameters were within allowable limits. Similar research by Biose *et al.* (2024) and Enuneku *et al.* (2017) has demonstrated that the interaction of anthropogenic discharges and lithogenic sources results in similar pollution levels in rivers in semi-rural settings. According to the CPI data, the Orhionmwon

River is not yet at a critical contamination level, but it is starting to show signs of environmental stress. To stop future deterioration and preserve the ecological balance of the river, home and agricultural waste discharges must be continuously monitored and controlled.

5.4 NON-CARCINOGENIC RISK ASSESSMENT OF HEAVY METALS THROUGH ORAL CONSUMPTION OF ORHIONMWON SURFACE WATER

The Orhionmwon River's non-carcinogenic risk assessment found that the three sampling sites respective hazard index (HI) values ranged from 114.51 to 110.05 to 118.43. Long-term exposure to the river water may have negative non-carcinogenic health impacts because these values are significantly higher than the safe limit of 1.0 advised by the US Environmental Protection Agency (USEPA, 2012). Elevated levels of total hydrocarbon content (THC) in the river were the primary cause of the high HI values. Similar findings were noted by Onoyima *et al.* (2025) in the Ogun River, where Pb and Cd contributed to non-carcinogenic risk levels exceeding safety criteria, and by Biose *et al.* (2024) in the Ossiomo River, who reported HI values more than 1 ($HI > 1$). According to the data from the Orhionmwon River, those who rely on the water for domestic purposes—especially oral ingestion—may be at risk for health problems such neurological, renal, and developmental diseases. The findings emphasize the necessity of raising awareness and enforcing waste management laws in order to reduce the buildup of metals in surface waters.

5.5 CARCINOGENIC RISK ASSESSMENT OF HEAVY METALS THROUGH ORAL CONSUMPTION OF ORHIONMWON SURFACE WATER

According to the carcinogenic risk assessment, the three sampling stations' incremental carcinogenic risk (ICR) values varied from 5.06×10^{-2} to 4.05×10^{-1} to 5.04×10^{-2} . These findings indicate a possible carcinogenic risk from long-term exposure to contaminated water because they are higher than the USEPA's (2012) allowed range of 1×10^{-1} to 1×10^{-2} . The presence of lead (Pb) and chromium (Cr), which were discovered in the river beyond

allowable limits, was the main cause of the high ICR levels. In their respective studies of the Ossiomo and Ogun Rivers, Biose *et al.* (2024) and Onoyima *et al.* (2025) found comparable carcinogenic risk values and attributed the elevated ICR to heavy metal contamination. Because of the mutagenic and carcinogenic qualities of Cr and Pb, the results of this study indicate that long-term usage or consumption of untreated Orhionmwon River water may raise the chance of acquiring cancer-related illnesses. This emphasizes the critical need for mitigating techniques, such as treating water before consumption and routinely monitoring heavy metal levels to protect the ecosystem and public health.

CONCLUSION

This study assessed the physicochemical properties and heavy metal concentrations of surface water from the Orhionmwon River and found that while most parameters such as temperature, pH, electrical conductivity, total solids, alkalinity, chloride, nitrate, phosphate, sulphate, sodium, potassium, calcium, magnesium, and hardness were within permissible limits, parameters like dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and metals such as iron (Fe), lead (Pb), manganese (Mn), and chromium (Cr) exceeded recommended standards. The increased Water Quality Index (WQI) values (514.94–555.18), which define the water as unfit for drinking, and the Comprehensive Pollution Index (CPI) values (0.88–0.97), which indicate mild pollution, were caused by the high quantities of these contaminants. Additionally, the health risk assessment revealed carcinogenic ($ICR = 4.05E-04$ – $5.06E-04$) and non-carcinogenic ($HI = 110.05$ – 118.43) values above tolerable levels, indicating possible negative health impacts from prolonged exposure. These findings imply that the river's quality is greatly impacted by both natural and human activity, making water unfit for direct human consumption without treatment. Therefore, to stop further deterioration of the Orhionmwon River ecosystem,

stringent enforcement of environmental regulations, appropriate waste management, and ongoing water quality monitoring are required.

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