

**PHYSICO CHEMICAL ANALYSIS ON DRINKING WATER IN ORHIONMWON  
LOCAL GOVERNMENT AREA**

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**A THESIS SUBMITTED TO THE DEPARTMENT OF SCIENCE LABORATORY  
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**OCTOBER, 2025**

## CERTIFICATION

This is to certify that the research work titled **PHYSICO CHEMICAL ANALYSIS ON DRINKING WATER IN ORHIONMWON LOCAL GOVERNMENT AREA** was carried out by **OMORODION MARIS** in the Department of Science Laboratory Technology, University of Benin, under my supervision in partial fulfillment of the requirements for the award of a Bachelor's Degree.

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**EXTERNAL EXAMINER**

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**DATE**

## **DEDICATION**

I dedicate this project work to God Almighty, whose guidance and strength have been my constant companion throughout my academic journey.

## ACKNOWLEDGEMENTS

I wish to express my profound gratitude to Almighty God, whose grace, wisdom, and strength sustained me throughout the course of this research. Without His divine guidance, this work would not have been possible.

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## LIST OF ABBREVIATIONS

- APHA: American Public Health Association
- BOD: Biochemical Oxygen Demand
- COD: Chemical Oxygen Demand
- DO: Dissolved Oxygen
- EC: Electrical Conductivity
- LGA: Local Government Area
- NA: Not Available
- NAFDAC: National Agency for Food and Drug Administration and Control
- NGV: No Guideline Value
- NIS: Nigerian Industrial Standard
- NSDWQ: Nigerian Standard for Drinking Water Quality
- SON: Standards Organisation of Nigeria
- TDS: Total Dissolved Solids
- TSS: Total Suspended Solids
- USEPA: United States Environmental Protection Agency
- WHO: World Health Organization

## ABSTRACT

In Orhionmwon Local Government Area, many residents depend on untreated surface and groundwater sources such as wells, boreholes, and rivers for drinking and domestic use. The quality of these sources had not been scientifically assessed, raising concerns about their suitability for human consumption. The area faces growing contamination from agricultural runoff, poor waste disposal. These factors can introduce harmful substances like nitrates, phosphates, and heavy metals into drinking water sources. Consuming contaminated drinking water can cause diseases such as cholera, typhoid, and diarrhea, and long-term exposure to toxic metals like lead or chromium can result in neurological and kidney damage. Hence, there was a need to determine if water from these sources posed such health risks. This study assessed the physicochemical quality of drinking water from selected sources in Orhionmwon Local Government Area, Edo State, Nigeria. Water samples were collected from five sites comprising two boreholes, two hand-dug wells, and one river. A total of twenty-three physicochemical parameters were analysed, including pH, turbidity, electrical conductivity, total dissolved solids (TDS), total suspended solids (TSS), nitrate, sulphate, phosphate, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total hardness, alkalinity, and several heavy metals (Fe, Cu, Zn, Ni, Pb, Mn, Cr, etc.). Analytical methods were based on APHA standard procedures and results were compared with Nigerian Industrial Standard (NIS 977:2017) and WHO permissible limits. The findings revealed that pH values across all water sources were below the acceptable range (6.5–8.5), indicating acidic water with potential for corrosiveness and metal leaching. River water showed elevated turbidity, BOD (3.8 mg/L), and COD (38.0 mg/L), suggesting organic pollution. Lead and chromium levels in the river exceeded regulatory limits, posing potential health risks. Borehole water generally exhibited the best quality, while the river was the most contaminated source. Most other parameters, including nitrate, sulphate, chloride, and iron, were within permissible limits. These results indicate that while some water sources are suitable for consumption, others, particularly the river, require urgent intervention and treatment. The study recommends regular monitoring, pH correction, community sensitization, and infrastructure improvement to ensure the provision of safe drinking water in Orhionmwon.

## CHAPTER ONE

### INTRODUCTION

#### 1.1 BACKGROUND OF STUDY

Water is indispensable for sustaining life, economic growth, and ecosystem balance. Globally, billions of people depend on water for drinking, cooking, sanitation, and industrial use. However, the quality of drinking water remains a significant concern, especially in developing countries where access to safe and treated water is limited (WHO, 2022). The physicochemical characteristics of water, such as pH, turbidity, temperature, electrical conductivity (EC), total dissolved solids (TDS), hardness, and concentrations of ions and metals, determine its suitability for consumption and its potential impact on human health (Chukwu *et al.*, 2024).

Drinking contaminated water is associated with a wide range of waterborne diseases including cholera, typhoid fever, hepatitis A, and diarrheal illnesses. According to the World Health Organization (WHO), more than 2 billion people globally still use drinking water sources contaminated with faeces (WHO, 2022). These risks are compounded in rural areas, where there is often inadequate infrastructure to monitor and treat water before consumption.

The Orhionmwon Local Government Area (LGA) of Edo State, Nigeria, comprises numerous rural and semi-urban communities that rely heavily on groundwater and surface water sources, including wells, boreholes, rivers, streams, and rainwater. These sources are often untreated and vulnerable to contamination from various anthropogenic and natural activities. Agricultural runoff, poor waste disposal practices, and proximity to industrial or oil-producing zones all contribute to the degradation of water quality in this region.

Moreover, with population growth and increased economic activity in Orhionmwon, there is

a growing demand for water resources, potentially stressing existing supplies and compounding contamination risks. The assessment of physicochemical properties of water in this environment is therefore necessary to determine its safety and sustainability.

#### **1.4 AIM AND OBJECTIVE**

The primary aim of this study is to assess the physicochemical quality of drinking water in the Orhionmwon environment. The specific objectives are to:

- Determine heavy metals in the water
- Compare these values with WHO and NSDWQ permissible limits.
- Identify sources and patterns of potential contamination.
- Make recommendations for improving water quality management in the study area.

### **1.3 RESEARCH QUESTIONS**

To guide this study on the physicochemical analysis of water from different sources in Orhionmwon Local Government Area, Edo State, Nigeria, the following research questions have been formulated:

- 1 What are the physicochemical characteristics (such as temperature, pH, turbidity, total dissolved solids, electrical conductivity, dissolved oxygen, and major ion concentrations) of water obtained from boreholes, wells, rivers, and sachet water in the study area?
- 2 How do the physicochemical parameters of these water sources compare with the World Health Organization (WHO) and Nigerian Industrial Standards (NIS) permissible limits for potable water?
- 3 What are the possible environmental and anthropogenic factors contributing to variations in the physicochemical quality of water sources within Orhionmwon LGA?
- 4 What potential public health risks are associated with the consumption and use of water from these different sources based on their physicochemical properties?
- 5 What recommendations can be made for improving water quality management and ensuring safe water supply for the residents of Orhionmwon Local Government Area?

### **1.5 SCOPE OF STUDY**

The research will focus on the analysis of selected water sources in Orhionmwon LGA, such as boreholes, hand-dug wells, streams, and sachet water. Only physicochemical parameters will be considered in this phase of study. Microbial and biological parameters, though important, are outside the current scope but are recommended for future research.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 WATER QUALITY ASSESSMENT

Over the years, it has become vital to explore the conceptual, empirical, and theoretical frameworks surrounding drinking water quality assessment. To achieve this, we need to first review previous studies on physicochemical analysis, water quality standards, and the health implications of unsafe drinking water, with an emphasis on Nigerian and African contexts. With an aim to provide a solid background for the present study by identifying key gaps and relevant indicators.

Water quality refers to the chemical, physical, and biological characteristics of water in relation to its suitability for a specific purpose, particularly for human consumption (WHO, 2022). For water to be considered potable, it must be free from harmful microorganisms, toxic substances, offensive taste or odour, and undesirable levels of dissolved solids and metals (Afolabi *et al.*, 2021).

Physicochemical parameters such as pH, turbidity, temperature, electrical conductivity (EC), total dissolved solids (TDS), and concentrations of major ions (e.g., chloride, nitrate, phosphate, calcium, magnesium) and trace metals (e.g., iron, lead, copper) are commonly measured to determine water quality. These parameters serve as indicators of contamination and help trace the sources and behavior of pollutants in the environment (Taiwo *et al.*, 2023).

#### 2.2 IMPORTANCE OF PHYSICOCHEMICAL WATER ANALYSIS

Physicochemical analysis is a vital component of water quality assessment. It provides critical information about the origin, movement, and interaction of water with geological and anthropogenic inputs. For example, high turbidity may indicate erosion or organic

contamination, while elevated nitrates and phosphates may signal agricultural runoff or sewage pollution (Edokpayi et al., 2020).

Furthermore, parameters like electrical conductivity and total dissolved solids reflect the mineral content and ionic composition of water, affecting taste, corrosivity, and usability. Physicochemical analysis is especially important in areas without centralized water treatment systems, where untreated or poorly treated sources are used directly for drinking and cooking.

## **2.3 SOURCES OF DRINKING WATER**

Access to safe and adequate drinking water is a fundamental human necessity and a major public health concern, particularly in developing regions. Drinking water can originate from a variety of natural and artificial sources, including surface water (rivers, lakes, and streams), groundwater (wells, boreholes, aquifers), harvested rainwater, and municipal water supply systems (WHO, 2022).

### **2.3.1 Groundwater Sources: Wells, Boreholes, and Aquifers**

In rural and semi-urban settings such as Orhionmwon LGA, groundwater is the most common source of drinking water. It is typically accessed through hand-dug wells, boreholes, or deep aquifer systems. These sources are generally more protected from immediate surface contamination compared to surface water; however, they are still vulnerable to leaching of agricultural chemicals, seepage from pit latrines, and heavy metal infiltration, especially in areas with poor geological protection or lack of sanitary infrastructure (Edokpayi *et al.*, 2020).

- Hand-dug wells are shallow and highly susceptible to contamination from surface runoff and human activities.

- Boreholes, which tap deeper aquifers, often yield better quality water, but issues such as iron, manganese, and hardness contamination may still occur if not properly treated.
- Aquifers serve as deep natural reservoirs of water but may carry geogenic contaminants such as arsenic, lead, or fluoride depending on the underlying rock formations.

## **2.4 OVERVIEW OF PHYSICOCHEMICAL PARAMETERS OF DRINKING WATER**

The physicochemical parameters of drinking water play a critical role in determining its suitability for human consumption, agricultural use, and other domestic purposes. These parameters influence taste, odour, appearance, and, more importantly, the health safety of water. Below is a detailed overview of each parameter used in assessing drinking water quality.

### **2.4.1 pH**

The pH of water indicates its acidity or alkalinity and is measured on a scale from 0 to 14. A pH between 6.5 and 8.5 is generally considered acceptable for drinking water (WHO, 2022). Water with a low pH is corrosive and can leach toxic metals like lead or copper from pipes, while high pH can cause scaling and an unpleasant taste (APHA, 2020).

### **2.4.2 Electrical Conductivity (EC)**

EC measures the ability of water to conduct electricity, which is directly related to the concentration of dissolved salts or ions. It is expressed in  $\mu\text{S}/\text{cm}$ . Higher values indicate greater ion content and may reflect contamination from agricultural runoff, sewage, or industrial waste (Edokpayi *et al.*, 2020).

### **2.4.3 Total Dissolved Solids (TDS)**

TDS represents the total concentration of dissolved substances in water, including minerals, salts, and organic matter. TDS values above 500 mg/L may alter taste and affect water palatability (WHO, 2022). Excessive TDS can also lead to kidney and digestive issues.

### **3.2.1 Total Suspended Solids (TSS)**

TSS includes particulate matter that remains suspended in water and contributes to turbidity. High TSS levels can reduce light penetration, promote microbial growth, and interfere with disinfection processes (APHA, 2020).

### **3.2.2 Dissolved Oxygen (DO)**

DO is essential for aquatic life and is a key indicator of water purity. High DO levels indicate good quality, while low levels may reflect pollution or organic matter decomposition. For potable water, DO should generally be above 5 mg/L (USEPA, 2020).

### **3.2.3 Biological Oxygen Demand (BOD)**

BOD measures the amount of oxygen required by microorganisms to decompose organic material in water. High BOD indicates the presence of biodegradable organic pollution, which may lead to oxygen depletion (WHO, 2022).

### **3.2.4 Chemical Oxygen Demand (COD)**

COD estimates the oxygen needed to chemically oxidize organic and inorganic substances in water. It provides a broader measure of pollution than BOD. High COD values indicate heavy contamination, typically from sewage or industrial discharge (APHA, 2020).

### **3.2.5 Sulphate (SO<sub>4</sub><sup>2-</sup>)**

Sulphates occur naturally in water due to the dissolution of minerals and anthropogenic sources like fertilizer runoff. At levels above 250 mg/L, they may impart a bitter taste and have a laxative effect, especially on children and the elderly (WHO, 2022).

### **3.2.6 Phosphate (PO<sub>4</sub><sup>3-</sup>)**

Phosphates in drinking water typically originate from detergents, agricultural runoff, and sewage. Though not harmful at low levels, high phosphate concentrations can promote eutrophication and microbial growth, affecting water quality (Afolabi *et al.*, 2021).

### **3.2.7 Nitrate (NO<sub>3</sub><sup>-</sup>)**

Nitrate is a common pollutant in agricultural areas. Excessive intake (above 50 mg/L) can cause methemoglobinemia ("blue baby syndrome") in infants and reproductive complications in adults (WHO, 2022).

### **3.2.8 Calcium (Ca<sup>2+</sup>) and Magnesium (Mg<sup>2+</sup>)**

These are essential minerals contributing to water hardness. While not directly harmful, their presence affects taste and can cause scale buildup in pipes. Hard water is not a health risk but can reduce the effectiveness of soap and detergents (Umoren, *et al.*, 2024).

### **3.2.9 Total Hardness**

Total hardness is the sum of calcium and magnesium concentrations. While water with 80–100 mg/L as CaCO<sub>3</sub> is generally acceptable, very hard water can cause scaling, while very soft water can be corrosive to plumbing (SON, 2020).

## **Alkalinity**

Alkalinity measures the buffering capacity of water—its ability to neutralize acids. It is mainly due to the presence of bicarbonates, carbonates, and hydroxides. Acceptable levels range between 20–200 mg/L. Excessive alkalinity can affect taste and digestion (Umoren, *et al.*, 2024).

### **3.2.10 Chloride (Cl)**

Chloride naturally occurs in water but high levels (above 250 mg/L) may result from sewage, industrial effluents, or saline intrusion. It gives a salty taste and contributes to high conductivity (WHO, 2022).

### **3.2.11 Iron (Fe)**

Iron is often present in groundwater due to the dissolution of ferrous minerals. Although essential to health, concentrations above 0.3 mg/L can cause staining, unpleasant taste, and microbial growth (APHA, 2020).

### **3.2.12 Copper (Cu)**

Copper in small amounts is essential, but excessive concentrations (above 2.0 mg/L) can lead to liver and gastrointestinal problems. It may enter water from corroded plumbing (USEPA, 2020).

### **3.2.13 Zinc (Zn)**

Zinc is not harmful in low amounts but can give water an undesirable taste at concentrations above 3.0 mg/L. It can leach from galvanized pipes or industrial pollution (Onuoha, 2023).

### **3.2.14 Nickel (Ni)**

Nickel may contaminate drinking water from industrial discharge or corrosion of stainless-steel pipes. Long-term exposure is associated with dermatological and carcinogenic risks (WHO, 2022).

### **3.2.15 Lead (Pb)**

Lead is highly toxic even at low concentrations. It may enter drinking water through corrosion of old lead pipes. It can impair cognitive development in children and cause miscarriage or kidney damage in adults (USEPA, 2020).

### **3.2.16 Manganese (Mn)**

Manganese is naturally occurring and may appear in groundwater. Though essential in trace amounts, levels above 0.4 mg/L can affect neurological development in infants and cause black staining of fixtures (WHO, 2022).

## **3.3 REVIEW OF EMPIRICAL STUDIES**

Several recent studies across Nigeria and other parts of Africa have investigated the physicochemical quality of drinking water, with special emphasis on rural and peri-urban communities where reliance on untreated surface and groundwater sources is common.

Edokpayi *et al.* (2020) conducted an in-depth assessment of groundwater quality in the Vhembe District of South Africa and reported elevated concentrations of nitrates, chlorides, and total dissolved solids (TDS). The authors attributed these high values to agricultural activities, sewage infiltration, and poorly managed sanitation systems, stressing that long-term consumption of such water could predispose local populations to methemoglobinemia and other waterborne diseases.



In Nigeria, Afolabi *et al.* (2021) investigated the quality of boreholes in Ibandan. Their results revealed frequent exceedances of WHO permissible limits for nitrates and lead. The study highlighted the dual sources of contamination: leaching from agricultural fertilizers and corroding household plumbing systems. The findings further underscored the vulnerability of shallow wells to environmental pollution, calling for the adoption of safer and deeper boreholes with appropriate treatment measures.

A recent study by Igiebor *et al.* (2021) in Orhionmwon Local Government Area of Edo State focused on borehole water quality. The researchers found elevated levels of turbidity, TDS, and iron. These abnormalities were linked to inadequate water treatment facilities, anthropogenic activities, and the geological composition of the aquifer. The study emphasized that prolonged ingestion of such water could result in gastrointestinal disorders and staining of household fixtures, while also posing challenges for industrial use of the water.

Further evidence from the Niger Delta region was provided by Iqbal *et al.* (2023), who reported excessive fluoride and nitrate concentrations in rural boreholes across Enugu State. The authors explained that while fluoride is beneficial in small quantities, its presence at elevated levels increases the risk of dental and skeletal fluorosis, particularly among children. They concluded that unchecked exposure to these contaminants represents a major public health concern.

In Osun State, Olayiwola *et al.* (2020) conducted an analysis of both streams and shallow wells and observed low pH levels, in addition to iron concentrations above WHO guidelines. The acidic nature of the water was linked to increased solubility of heavy metals, thereby compounding the risk of exposure. The authors further noted that such water sources are often used directly for domestic purposes without prior treatment, heightening the likelihood of long-term health effects.

More recently, Igbinvbo *et al.* (2023) assessed sachet water samples and identified the presence of heavy metals, including cadmium and lead, in a subset of the brands analyzed. These findings raised concerns over the regulation and monitoring of commercially packaged water, which is often assumed to be safe by consumers. The authors called for strengthened enforcement of national standards for packaged water production to prevent chronic exposure to toxic metals.

In Kwara State, Usman *et al.* (2024) reported significant microbial and physicochemical contamination in both borehole and well water samples. Parameters such as turbidity, EC, and nitrate were consistently above permissible limits. The study linked these outcomes to rapid urbanization, poor waste management practices, and the indiscriminate siting of wells near pit latrines. The researchers recommended community-level interventions, including proper siting of wells, periodic monitoring, and sensitization of households on safe water practices.

Another investigation by Odiana *et al.* (2024) in Edo State demonstrated that borehole water sources often contain elevated TDS and iron concentrations, largely influenced by underground geological structures and improper waste disposal practices. The study drew attention to the cumulative health risks associated with such exposures and proposed a framework for community-based monitoring and treatment strategies to improve water safety.

### **3.4 HEALTH IMPLICATIONS OF POOR PHYSICOCHEMICAL WATER QUALITY**

Contaminated water with improper physicochemical properties can have serious health effects, especially on vulnerable populations such as children and pregnant women. For instance, abnormal pH levels, either too low (acidic) or too high (alkaline), can corrode pipes, increase the solubility of toxic metals like lead and copper, and irritate the gastrointestinal tract. In children, this can result in increased absorption of heavy metals, while in pregnant women, it

may cause nausea and digestive discomfort (WHO, 2022).

High total dissolved solids (TDS) levels may alter the taste of water and lead to mineral imbalances. Prolonged consumption of water with high TDS can cause gastrointestinal irritation in children and may contribute to kidney stress or dehydration in pregnant women (Edokpayi *et al.*, 2020). Similarly, elevated electrical conductivity (EC), often indicative of high ion concentrations, has been associated with hypertension and kidney dysfunction. This poses a serious risk for pregnant women, who are already more susceptible to changes in blood pressure and electrolyte balance (Popoola *et al.*, 2019).

Alkalinity, which reflects water's buffering capacity, is essential for neutralizing acids, but excessive alkalinity can cause bitter taste and gastrointestinal issues. Pregnant women consuming highly alkaline water may experience indigestion and heartburn, while children may be at risk of altered stomach pH affecting nutrient absorption (Nlemolisa *et al.*, 2025). Excessive chloride content in water can result in a salty taste and is linked to elevated blood pressure. This is particularly concerning for hypertensive pregnant women and infants with undeveloped kidneys (Onuoha, 2023).

Iron, though an essential micronutrient, when present in excess in drinking water, can lead to organ damage over time, stain clothes and plumbing fixtures, and impart an unpleasant metallic taste. In children, iron overload can impair liver function, while in pregnant women it may lead to nausea or constipation (Olayiwola *et al.*, 2020). Sulphate, when consumed in high quantities, has a laxative effect that may cause dehydration and gastrointestinal distress. This is especially problematic in infants and pregnant women, who are more susceptible to fluid loss (Taiwo *et al.*, 2023).

Nitrate contamination in water is a critical health issue. Once ingested, nitrates are converted to nitrites, which impair the oxygen-carrying capacity of hemoglobin. In infants, this leads to

methemoglobinemia or —blue baby syndrome, a potentially fatal condition. Pregnant women exposed to high nitrate levels may experience reduced oxygen delivery to the fetus, increasing the risk of miscarriage or developmental delays (Afolabi *et al.*, 2021).

In summary, the health impacts of unsafe physicochemical water parameters are well-documented and underscore the need for rigorous assessment and remediation efforts in communities like Orhionmwon, where residents may unknowingly rely on contaminated water sources.

## CHAPTER THREE

### METHODOLOGY

#### 3.1 DESCRIPTION OF THE STUDY AREA

Orhionmwon Local Government Area is one of the 18 LGAs in Edo State, located in the southern part of Nigeria. It lies between latitudes  $5^{\circ}30'N$  and  $6^{\circ}N$  and longitudes  $5^{\circ}30'E$  and  $6^{\circ}E$ . The region is largely rural, with scattered communities relying on various water sources such as boreholes, hand-dug wells, streams, and rainwater harvesting systems.

Most residents depend on untreated groundwater sources, increasing the risk of contamination due to inadequate sanitation and agricultural practices. The area's geology includes sandy loam and lateritic soils, which can influence the mineral composition of groundwater. Orhionmwon Local Government Area is located in the southern part of Edo State, Nigeria. It shares boundaries with Uhunmwonde LGA to the north, Ikpoba-Okha to the west, and Delta State to the south and east. The LGA is characterized by a humid tropical climate, with distinct wet and dry seasons. Economic activities in the area include farming, trading, hunting, and fishing.

The region is also susceptible to environmental degradation due to agricultural expansion, deforestation, and oil-related activities. The water sources in this area are largely unregulated, making them vulnerable to contamination from fertilizers, waste discharge, erosion, and natural geochemical leaching (Ogbe *et al.*, 2025). These factors make Orhionmwon an important case study for assessing the physicochemical quality of drinking water.



**Fig 3.1: Map of study area SHOWING Evbuarhue Community in Orhionmwon Local Government Area**

### **3.8 RESEARCH DESIGN**

The study adopted a descriptive cross-sectional design, combining field sample collection and laboratory analysis to evaluate the physicochemical properties of drinking water sources in the community.

#### **3.8.1 Sampling Locations and Sample Size**

Water samples were collected from:

- Ikpe River: 1 surface water
- Boreholes: 2 different functional boreholes across the LGA
- Hand-dug wells: 2 separate wells in different residential zones

This provided a total of 5 sampling points, ensuring representation from each water source commonly consumed in the LGA.

### **3.9 SAMPLE COLLECTION PROCEDURES**

Sampling followed **APHA (2017)** guidelines:

- **Borehole and Well Water:** Taps were allowed to run for 3–5 minutes and well buckets rinsed thoroughly before collecting samples to avoid debris and contamination.
- **Stream:** Samples were collected 30 cm below the surface to avoid surface contaminants.
- Containers were rinsed three times with the water to be sampled before final collection.

- All samples were stored at 4°C and analyzed within 24–48 hours to prevent parameter alteration.

### **3.10 ANALYTICAL METHODS**

The analysis of the collected water samples was conducted using standard procedures as described in APHA (2023), and other established analytical guidelines. The parameters analyzed include pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Sulphate ( $\text{SO}_4^{2-}$ ), Phosphate ( $\text{PO}_4^{3-}$ ), Nitrate ( $\text{NO}_3^-$ ), Calcium ( $\text{Ca}^{2+}$ ), Magnesium ( $\text{Mg}^{2+}$ ), Total Hardness, Alkalinity, Chloride (Cl), Iron (Fe), Copper (Cu), Zinc (Zn), Nickel (Ni), Lead (Pb), and Manganese (Mn). The specific analytical methods used for each parameter are described below:

#### **3.4.1 Determination of pH (Potentiometric Method – APHA 4500-H<sup>+</sup> B)**

Calibrate the pH meter using standard buffers pH 4.0, 7.0 and 10.0. Rinse the electrode with distilled water and gently blot dry. Pour 50 mL of the water sample into a beaker, immerse the electrode ensuring good contact, allow the reading to stabilize and record the pH value.

#### **3.4.2 Electrical Conductivity (EC) – APHA 2510 B**

Standardize the conductivity meter using 0.01 M KCl solution. Rinse the probe, immerse into 50 mL of the sample in a beaker, wait for stabilized reading and record conductivity in  $\mu\text{S}/\text{cm}$ .

#### **3.4.3 Total Dissolved Solids (TDS) – APHA 2540 C**

Pre-dry an evaporating dish at 103–105°C, cool in desiccator and weigh ( $W_1$ ). Filter 100 mL sample through Whatman No. 42 filter paper. Transfer filtrate into the weighed dish, evaporate to dryness in oven at 103–105°C. Cool in desiccator and weigh ( $W_2$ ).

$$\text{TDS (mg/L)} = (W_2 - W_1) \times 1000 / \text{Volume of sample (mL)}$$

#### **3.4.4 Total Suspended Solids (TSS) – APHA 2540 D**

Dry a pre-weighed filter paper at 103–105°C, cool and weigh ( $W_1$ ). Filter 100 mL of well-mixed water sample. Dry the filter with residue at 103–105°C for 1 hour. Cool and reweigh ( $W_2$ ).

$$\text{TSS (mg/L)} = (W_2 - W_1) \times 1000 / 100$$

#### **3.4.5 Dissolved Oxygen (DO) – Winkler Method (APHA 4500-O B)**

Fill the DO bottle (300 mL) without air bubbles. Add 2 mL manganous sulfate solution and 2 mL alkaline iodide-azide solution. Stopper and invert several times to form brown precipitate. Allow to settle. Add 2 mL concentrated  $\text{H}_2\text{SO}_4$  to dissolve precipitate. Take 200 mL aliquot into conical flask. Titrate immediately with 0.025 N sodium thiosulfate until pale yellow. Add 2–3 drops starch indicator and continue titration until blue color disappears.

$$\text{DO (mg/L)} = \text{mL of titrant} \times \text{Normality} \times 8$$

#### **3.4.6 Biological Oxygen Demand ( $\text{BOD}_5$ ) – APHA 5210 B**

Measure initial DO as above. Fill BOD bottles with sample (with dilution water if required). Add 1 mL each of phosphate buffer,  $\text{MgSO}_4$ ,  $\text{CaCl}_2$  and  $\text{FeCl}_3$  nutrient solution. Add sufficient seed inoculum if low bacteria. Stopper and incubate at 20°C in the dark for 5 days. After incubation, measure final DO.

$$\text{BOD}_5 \text{ (mg/L)} = (\text{DO}_1 - \text{DO}_5) \times \text{Dilution Factor}$$

#### **3.4.7 Chemical Oxygen Demand (COD) – Closed Reflux Method (APHA 5220 C)**

Pipette 2.5 mL water sample into COD digestion tube. Add 1.5 mL potassium dichromate reagent and 3.5 mL sulfuric acid-silver sulfate mixture slowly. Cap and digest at 150°C for 2 hours. Cool, add 2–3 drops ferroin indicator, titrate with 0.1 N ferrous ammonium sulfate until color changes from blue-green to reddish-brown.

$$\text{COD (mg/L)} = (\text{B} - \text{S}) \times \text{N} \times 8000 / \text{mL Sample}$$

(B = blank; S = sample titrant volume)

#### **3.4.8 Sulphate – Turbidimetric Method (APHA 4500-SO<sub>4</sub><sup>2-</sup> E)**

Pipette 50 mL sample into flask, add 5 mL buffer solution. While stirring, add BaCl<sub>2</sub> crystals (≈0.3 g). Mix for 1 minute. Read absorbance at 420 nm after 5 minutes. Determine concentration from calibration curve.

#### **3.4.9 Phosphate – Ascorbic Acid Method (APHA 4500-P E)**

Take 50 mL of filtered sample. Add 8 mL ammonium molybdate-ascorbic acid reagent. Mix and allow 10 minutes for color development. Read absorbance at 880 nm and calculate from calibration curve.

#### **3.4.10 Nitrate – UV Spectrophotometry (APHA 4500-NO<sub>3</sub><sup>-</sup> B)**

Filter sample and measure absorbance at 220 nm. Measure a second reading at 275 nm to correct for organic interference. Calculate nitrate from standard calibration curve.

#### **3.4.11 Calcium – EDTA Titration (APHA 3500-Ca B)**

Pipette 50 mL sample into conical flask. Add 2 mL 1 N NaOH to adjust pH to 12. Add pinch of murexide indicator; solution turns pink. Titrate with 0.01 M EDTA until color changes from pink to purple.

Calcium (mg/L) = mL EDTA × M × 400.8 / mL Sample

#### **3.4.12 Magnesium – EDTA Method (APHA 3500-Mg B)**

Take 50 mL sample, add ammonia buffer to pH 10. Add Eriochrome Black T indicator (wine red color forms). Titrate with 0.01 M EDTA to clear blue endpoint.

Mg (mg/L) = (Total hardness – Calcium hardness)

### **3.4.13 Total Hardness – EDTA Titration (APHA 2340 C)**

Pipette 50 mL sample into flask, add ammonia buffer to pH 10. Add Eriochrome Black T indicator. Titrate with 0.01 M EDTA until wine-red to pure blue.

Hardness as CaCO<sub>3</sub> (mg/L) = mL EDTA × 1000 / mL sample

### **3.4.14 Alkalinity – Titration Method (APHA 2320 B)**

Take 50 mL sample. Add 2–3 drops phenolphthalein. Titrate with 0.02 N H<sub>2</sub>SO<sub>4</sub> to pH 8.3 (P-alkalinity). Add 2–3 drops methyl orange and continue titration to pH 4.5 (T-alkalinity).

Alkalinity expressed as CaCO<sub>3</sub> calculated per APHA formulas.

### **3.4.15 Chloride – Argentometric Titration (Mohr’s Method, APHA 4500-Cl<sup>-</sup> B)**

Measure 50 mL sample into flask. Add 1 mL 2% K<sub>2</sub>CrO<sub>4</sub> indicator (yellow color).

Titrate with 0.05 N AgNO<sub>3</sub> until a permanent brick-red precipitate forms.

Chloride (mg/L) = mL AgNO<sub>3</sub> × N × 35.45 × 1000 / 50

### **3.4.16 Iron – Phenanthroline Spectrophotometry (APHA 3500-Fe B)**

Take 50 mL sample. Add 2 mL hydroxylamine hydrochloride to reduce Fe<sup>3+</sup> to Fe<sup>2+</sup>. Add 10 mL ammonium acetate buffer and 2 mL 1,10-phenanthroline reagent. Allow 10 minutes.

Measure absorbance at 510 nm using UV-VIS spectrophotometry.

### **3.4.17 Copper, Zinc, Nickel, Lead & Manganese – AAS Methods**

Filter or digest sample with concentrated nitric acid depending on parameter (APHA 3111 B / 3113 B). Aspirate into AAS at element-specific wavelengths, using appropriate calibration standards.

Express results in mg/L.

## **3.11 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)**

- All glassware was washed with dilute nitric acid and rinsed with distilled water before use.
- Blank samples and duplicate analyses were used to ensure accuracy.
- Calibration of instruments was done using standard solutions as per manufacturer's instructions.
- All reagents were analytical grade.

### **3.12 DATA ANALYSIS**

Data obtained from laboratory analysis were compiled using Microsoft Excel and analysed statistically using descriptive statistics such as mean, standard deviation, and range. The results were compared with NIS 977:2017 LIMIT drinking water standards to assess compliance and identify deviations. Graphical representations such as bar charts and tables were used to present findings.

### **3.13 STANDARDS FOR DRINKING WATER QUALITY**

To ensure safety and public health, international and national bodies have established maximum allowable limits for each parameter in drinking water. Below are selected standards from the Nigerian Industrial Standard for Drinking Water Quality (NIS 977:2017)

**Table 3 . 1: WHO and Nigerian Industrial Standard for Drinking Water Quality with Health/Quality Concern.**

<b>Parameters</b>	<b>NIS</b>	<b>WHO</b>	<b>Health/Quality Concern</b>
	<b>977:2017</b>		
	<b>LIMIT</b>		
<b>Temperature Ambient</b>		NGV	Microbial growth, affects dissolved oxygen, taste
<b>pH</b>	6.5-8.5	6.5-8.5	Corrosion (low pH), scaling (high pH), taste issues
<b>Turbidity</b>	5.0	5 NTU	Indicates contamination, affects clarity, pathogen carrier
<b>Conductivity</b>	1000	NGV	High salts/minerals, affects taste, equipment corrosion
<b>Total Dissolved Solids (TDS)</b>			
<b>Total</b>	500	1000 mg/L	Taste issues, scaling, health effects at high levels
<b>Suspended Solids (TSS)</b>			
<b>Total</b>	NA	NGV	Aesthetic issues, pathogen carrier, filtration problems
<b>Nitrate (NO3)</b>			
<b>Nitrate</b>	10	50 mg/L	Methemoglobinemia (blue baby syndrome), infant health risk
<b>Sulphate (SO4)</b>			
<b>Sulphate</b>	100	500 mg/L	Laxative effect, taste issues, corrosion
<b>Phosphate</b>	NA	NGV	Eutrophication, algal blooms, indirect health risks

**(PO4)**

**Dissolved**    NA    NGV    Low levels harm aquatic life, indicate pollution

**Oxygen**

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<b>Biochemical Oxygen Demand (BOD)</b>	NA	NGV	Indicates organic pollution, low oxygen for aquatic life
<b>Chemical Oxygen Demand (COD)</b>	NA	NGV	High organic/inorganic pollutants, water quality decline
<b>Total Alkalinity</b>	100	NGV	Buffering capacity issues, pH instability
<b>Hardness, CaCO<sub>3</sub></b>	100	NGV	Scaling, soap inefficiency, taste issues
<b>Chloride (Cl)</b>	100	250 mg/L	Salty taste, corrosion of pipes, health effects
<b>Calcium (Ca)</b>	75	NGV	Scaling, hardness increase, minimal direct health impact
<b>Magnesium (Mg)</b>	20	NGV	Laxative effect, taste issues at high levels
<b>Iron (Fe)</b>	0.3	2 mg/L	Taste, staining, bacterial growth promotion
<b>Copper (Cu)</b>	1.0	2 mg/L	Gastrointestinal distress, liver/kidney damage (long-term)
<b>Zinc (Zn)</b>	5.0	3 mg/L	Taste issues, potential toxicity at high levels

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<b>Nickel (Ni)</b>	0.01	0.07 mg/L	Allergic reactions, potential carcinogenicity
<b>Lead (Pb)</b>	0.01	0.01 mg/L	Neurotoxicity, developmental issues, kidney damage
<b>Manganese (Mn)</b>	0.1	0.08 mg/L	Neurological effects, taste/staining issues

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<b>Cadmium (Cd)</b>	0.003	0.003 mg/L	Kidney damage, bone toxicity, carcinogenic risk
<b>Chromium (Cr)</b>	0.01	0.05 mg/L	Skin irritation, potential carcinogenicity (Cr VI)
<b>Arsenic (As)</b>	0.01	0.01 mg/L	Skin lesions, cancer, cardiovascular issues
<b>Mercury (Hg)</b>	0.001	0.006 mg/L	Neurological damage, kidney toxicity, developmental harm

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**NA** = Not Applicable, **NGV**= No Guideline Value.

These limits are essential benchmarks for comparing field measurements to evaluate water quality.

## **CHAPTER FOUR**

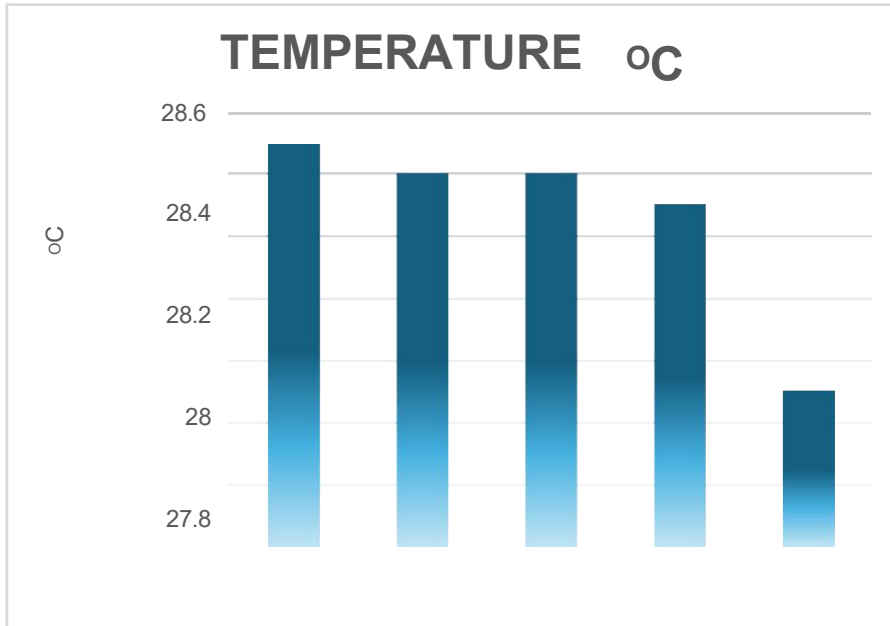
### **RESULTS**

#### **4.1 OVERVIEW OF RESULTS**

This chapter presents the results obtained from the physicochemical analysis of drinking water samples collected from various sources in Orhionmwon Local Government Area, Edo State. The sampled sources include two boreholes (BH1 and BH2), two hand-dug wells (WELL1 and WELL2), and one surface water source (RIVER). The results were compared against the Nigerian Industrial Standard for Drinking Water Quality (NIS 977:2017) to evaluate compliance and public health implications.

## 4.2 PHYSICOCHEMICAL PARAMETERS OF WATER SAMPLES

### 4.2.1 Temperature

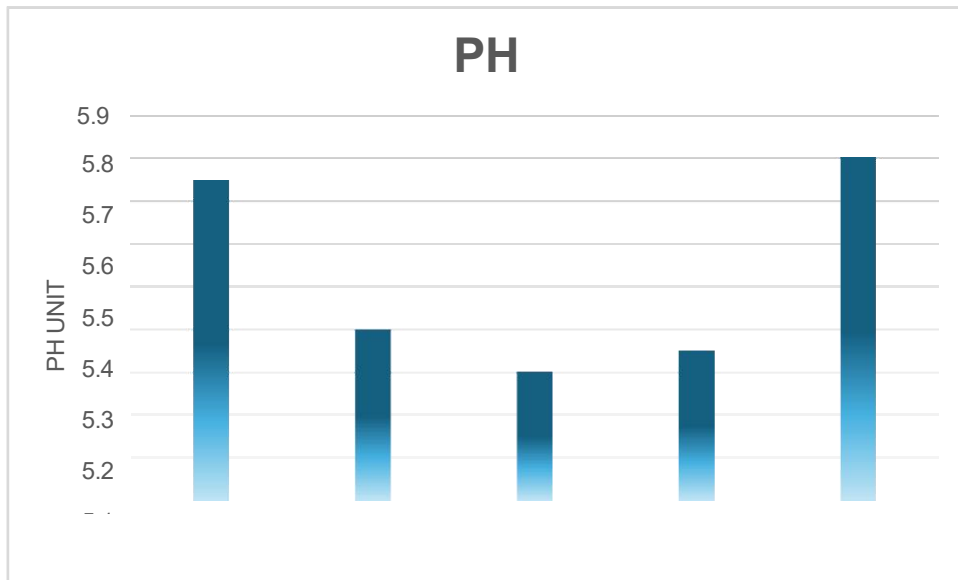


	BH 1	BH 2	WELL1	WELL2	RIVER
■ Temperature	28.5	28.4	28.4	28.3	27.7

Fig 4.1: Chart showing Levels of Temperature in BH1, BH2, WELL1, WELL2 and RIVER

Temperatures ranged from 27.7°C (river) to 28.5°C (BH1). All values were within acceptable limits, as water temperature is expected to align with ambient environmental conditions. However, elevated temperatures may indirectly affect DO and microbial activity.

## 4.2.2 pH



	BH 1	BH 2	WELL1	WELL2	RIVER
pH	5.75	5.4	5.3	5.35	5.8

Fig 4.2: Chart showing Levels of pH in BH1, BH2, WELL1, WELL2 and RIVER

The pH values ranged between 5.30 and 5.80 across all samples. All were below the NIS acceptable range (6.5–8.5), indicating acidic water, which can lead to pipe corrosion and metal leaching (APHA, 2023). Long-term consumption of such water may pose gastrointestinal risks.

### 4.2.3 Turbidity

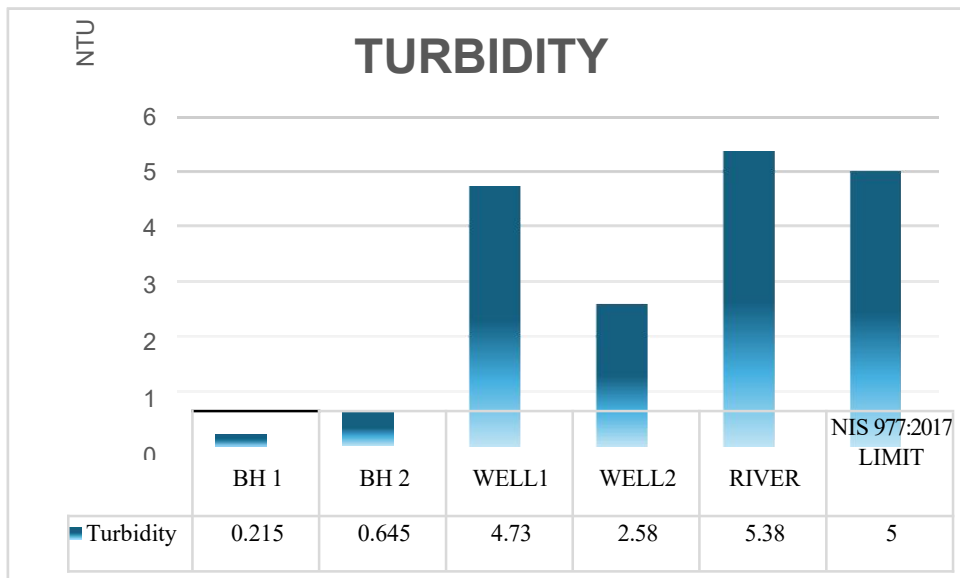
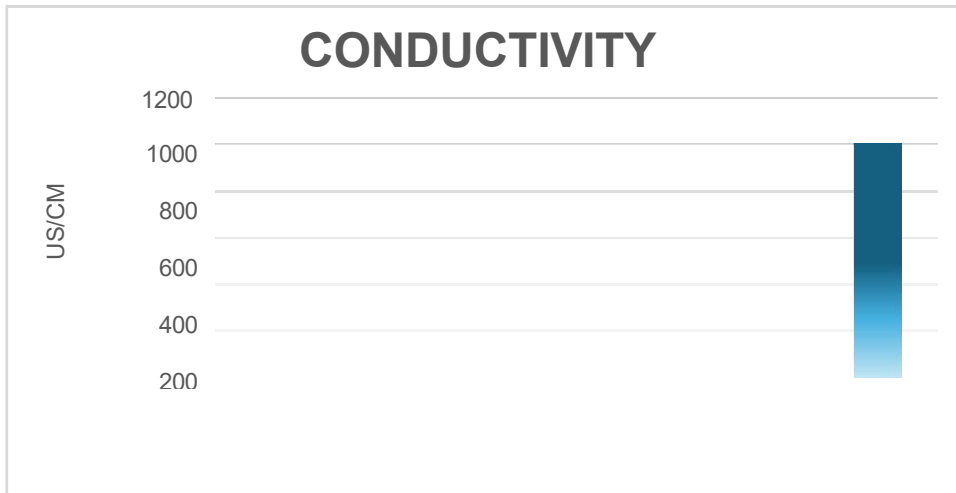


Fig 4.3: Chart showing Levels of Turbidity in BH1, BH2, WELL1, WELL2 and RIVER

Only the river (5.38 NTU) and WELL1 (4.73 NTU) exceeded or neared the 5 NTU threshold.

High turbidity may suggest suspended particles or microbial contamination and can interfere with disinfection.

#### 4.2.4 Electrical Conductivity (EC)



	BH 1	BH 2	WELL1	WELL2	RIVER	NIS 977:201 7 LIMIT
■ Conductivity	22	15	16	19	23	1000

C

Values ranged from 15 to 23  $\mu\text{S}/\text{cm}$ , far below the maximum limit of 1000  $\mu\text{S}/\text{cm}$ . This indicates low ionic concentration, suggesting minimal dissolved salts or minerals.

#### 4.2.5 Total Dissolved Solids (TDS)

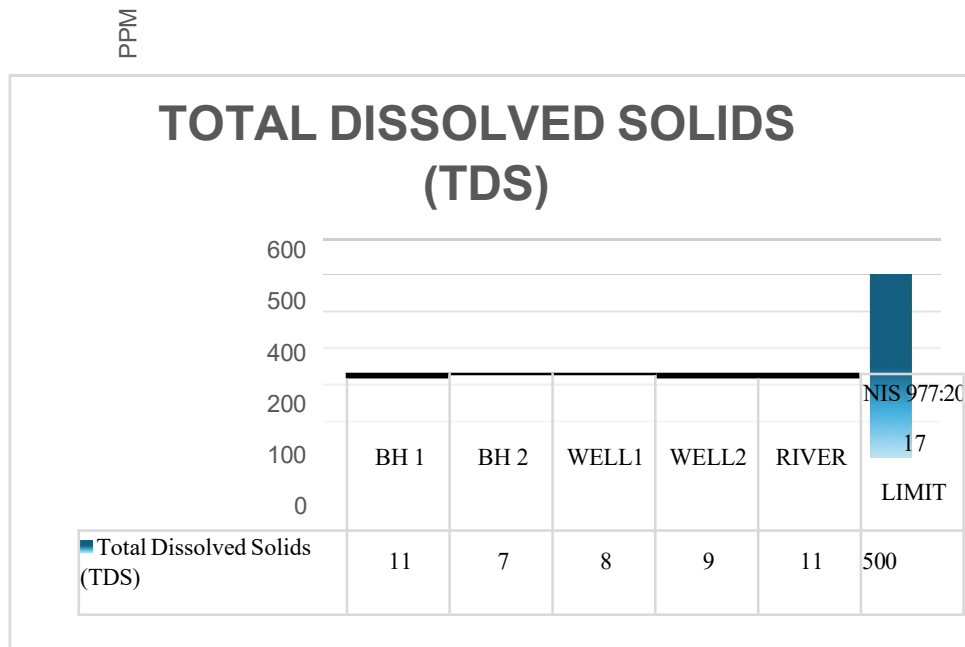


Fig 4.5: Chart showing Levels of Total Dissolved Solids in BH1, BH2, WELL1, WELL2 and RIVER

TDS levels (7–11 mg/L) were significantly below the 500 mg/L limit, indicating low mineralization. While safe, extremely low TDS can affect water palatability and may not provide essential minerals (WHO, 2022).

#### 4.2.6 Total Suspended Solids (TSS)

MG/L

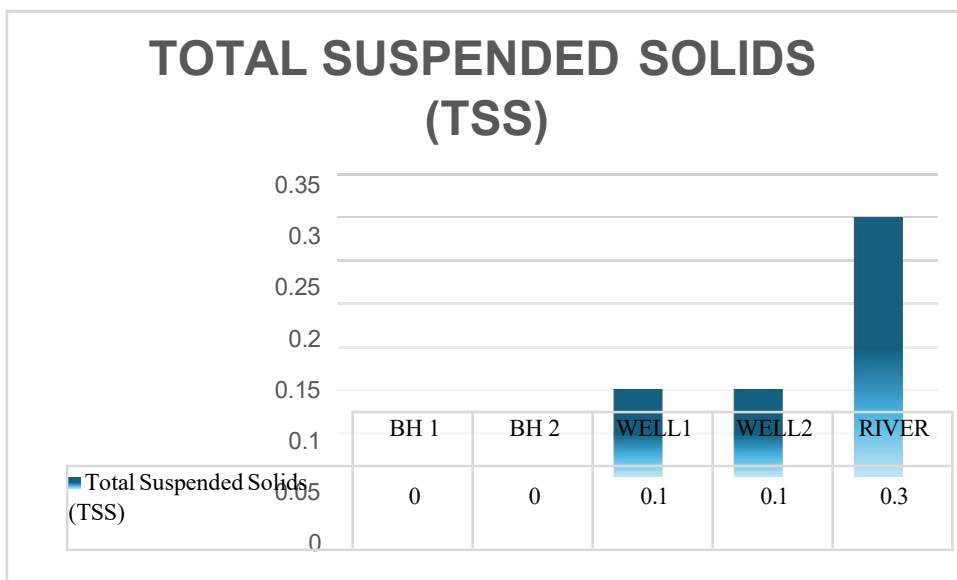


Fig 4.6: Chart showing Levels of Total Suspended Solids in BH1, BH2, WELL1, WELL2 and RIVER

Detected only in WELL1, WELL2, and RIVER (0.1–0.3 mg/L), these levels are low. However, the river source, with the highest TSS, may harbour microbial pollutants due to surface exposure.

#### 4.2.7 Nitrate (NO<sub>3</sub>)

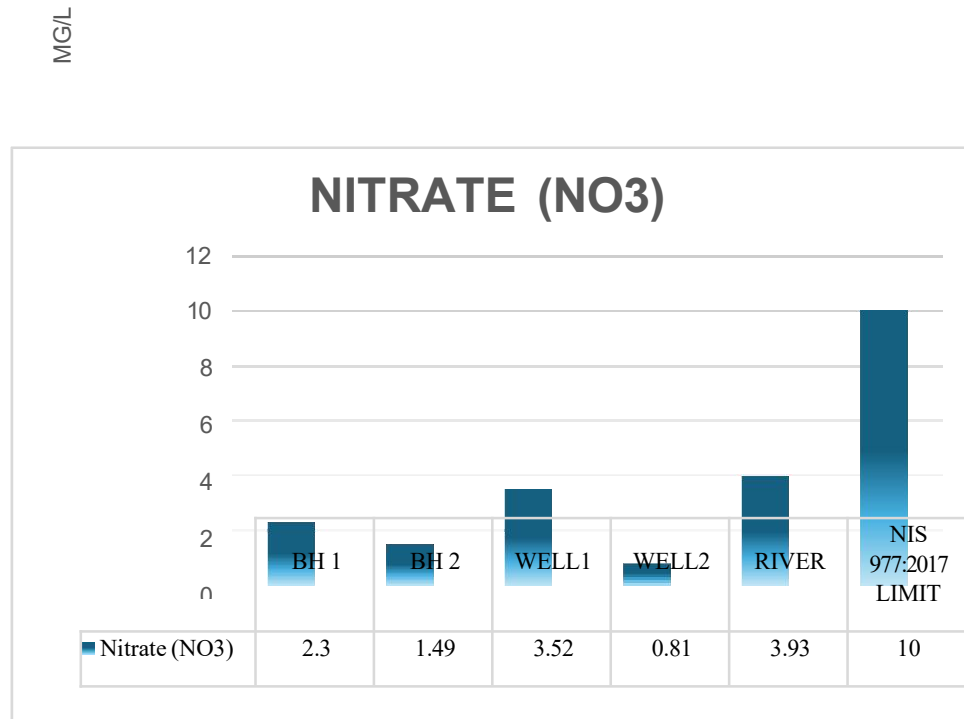


Fig 4.7: Chart showing Levels of Nitrate in BH1, BH2, WELL1, WELL2 and RIVER

All samples were below the 10 mg/L limit. The river had the highest concentration (3.93 mg/L), likely due to agricultural runoff or organic decay.

#### 4.2.8 Sulphate (SO<sub>4</sub><sup>2-</sup>)

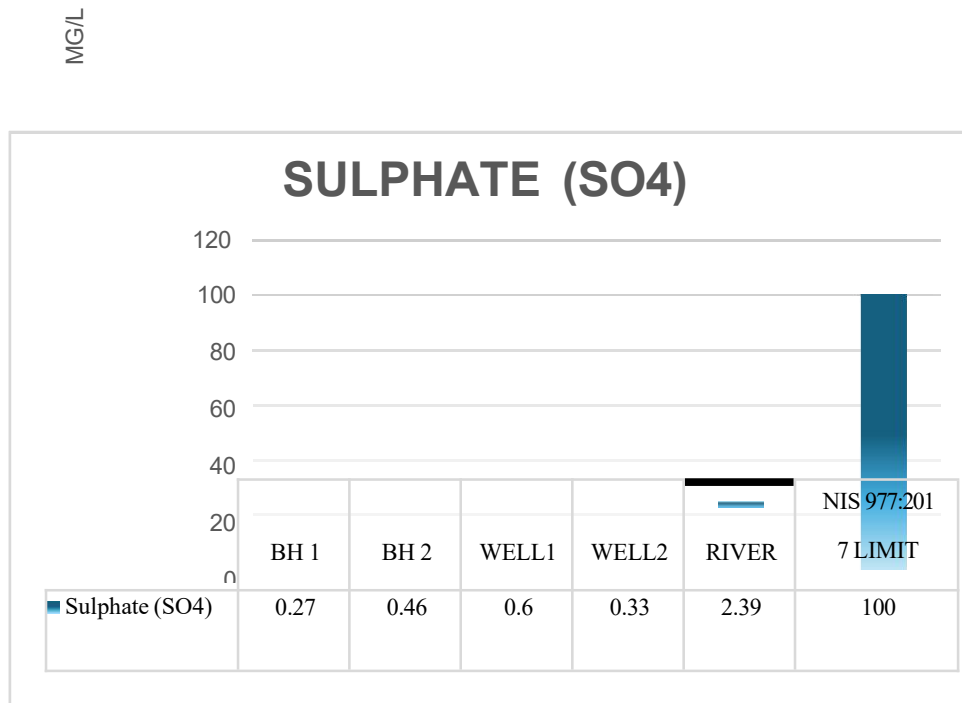
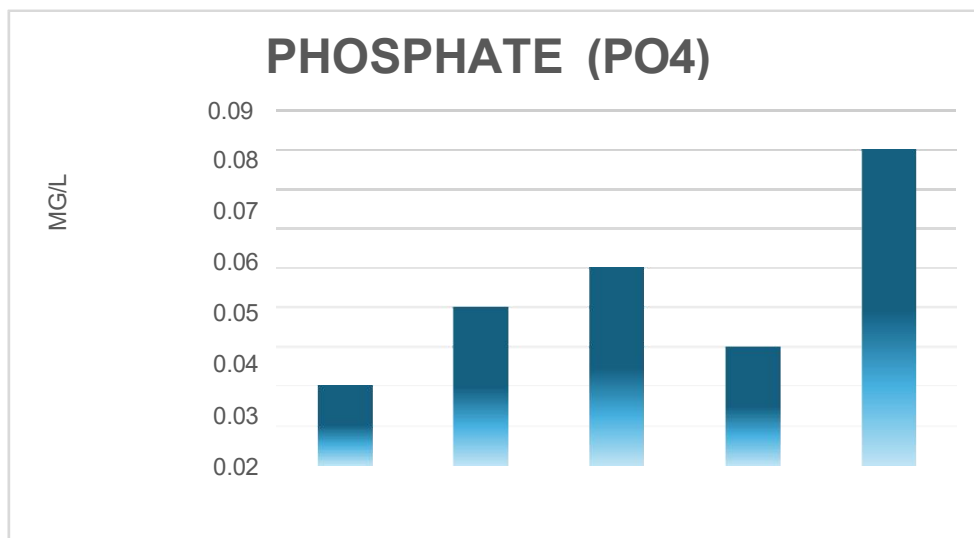


Fig 4.8: Chart showing Levels of Sulphate in BH1, BH2, WELL1, WELL2 and RIVER

Sulphate levels were low in all samples (0.27–2.39 mg/L), well below the 100 mg/L limit.

The river exhibited higher levels, which may be geogenic or from organic decay.

#### 4.2.9 Phosphate (PO<sub>4</sub><sup>3-</sup>)



	BH 1	BH 2	WELL1	WELL2	RIVER
■ Phosphate (PO4)	0.02	0.04	0.05	0.03	0.08

Fig 4.9: Chart showing Levels of Phosphate in BH1, BH2, WELL1, WELL2 and RIVER

Detected in all sources (0.02–0.08 mg/L), with the highest in the river. Though not regulated under NIS, elevated phosphate may enhance algal growth in surface waters.

#### 4.2.10 Dissolved Oxygen (DO)

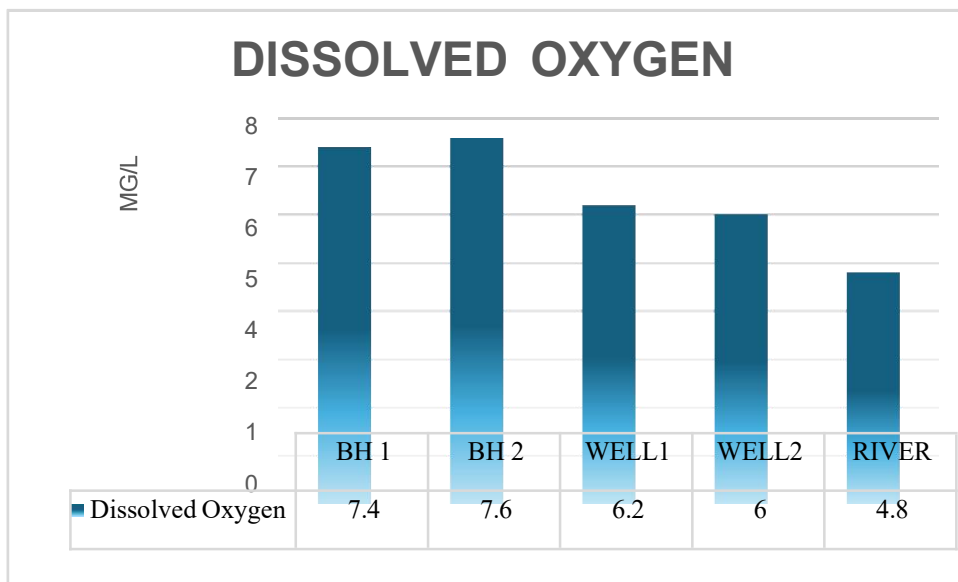


Fig 4.10: Chart showing Levels of Dissolved Oxygen in BH1, BH2, WELL1, WELL2 and RIVER

DO ranged from 4.8 mg/L (river) to 7.6 mg/L (BH2). Lower DO in the river indicates organic pollution or microbial activity, while higher values in boreholes suggest cleaner conditions.

#### 4.2.11 Biochemical Oxygen Demand (BOD)

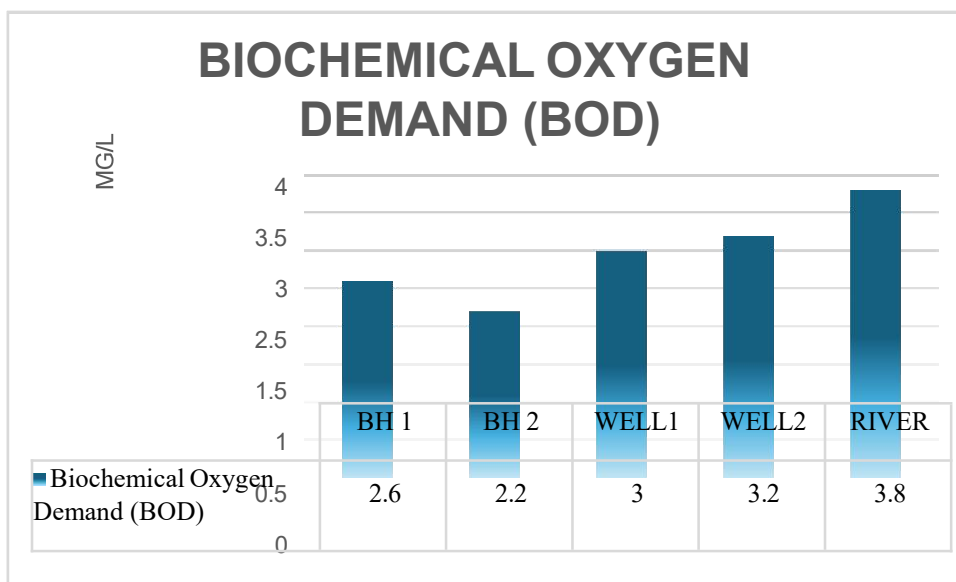
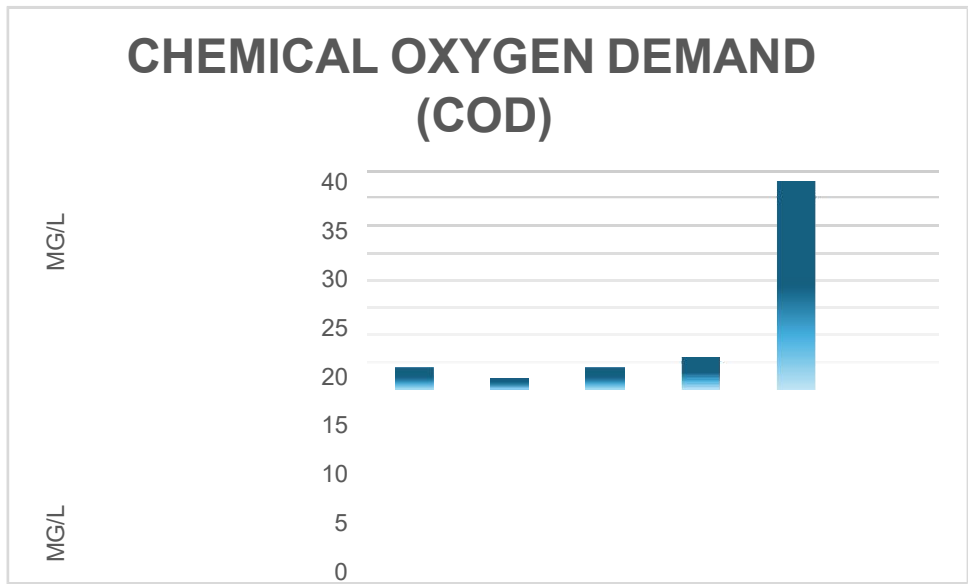


Fig 4.11: Chart showing Levels of Biochemical Oxygen Demand in BH1, BH2, WELL1, WELL2 and RIVER

BOD values (2.2–3.8 mg/L) were highest in the river, indicating active biological decomposition of organic matter. Borehole values were lower, indicating better water quality.

#### 4.2.12 Chemical Oxygen Demand (COD)



	BH 1	BH 2	WELL 1	WELL 2	RIVER	NIS 977:20 17 LIMIT
■ Chemical oxygen Demand (COD)	4	2	4	6	38	0

Fig 4.12: Chart showing Levels of Chemical Oxygen Demand in BH1, BH2, WELL1, WELL2 and RIVER

COD was highest in the river (38 mg/L), a strong indicator of organic and chemical pollution. Other sources had much lower values (2–6 mg/L), consistent with minimal contamination.

### 4.2.13 Total Alkalinity

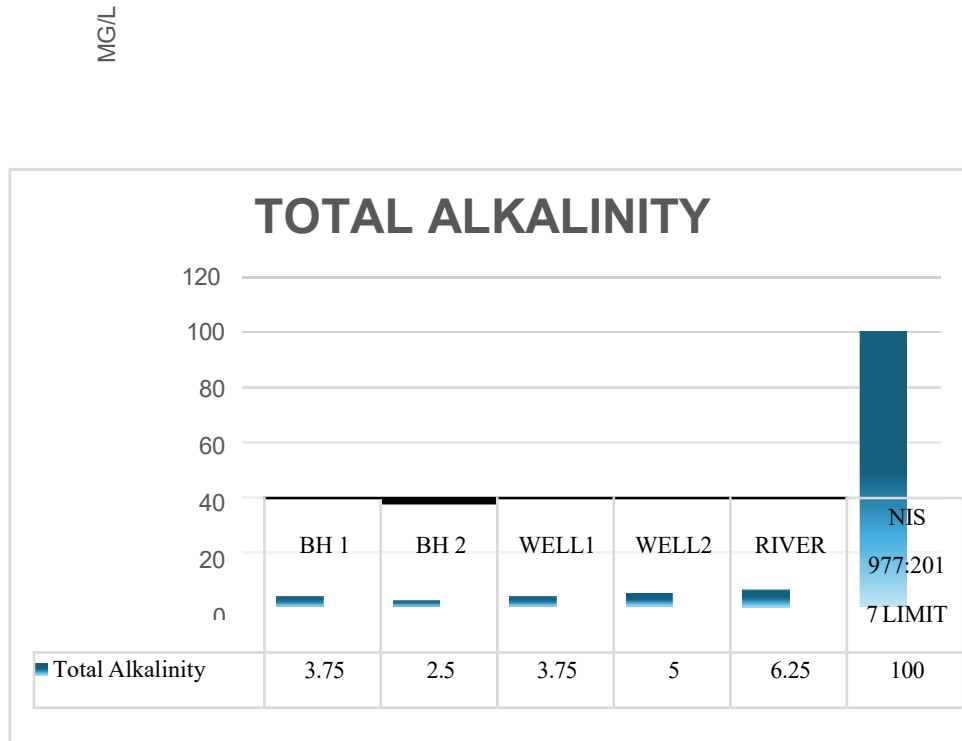
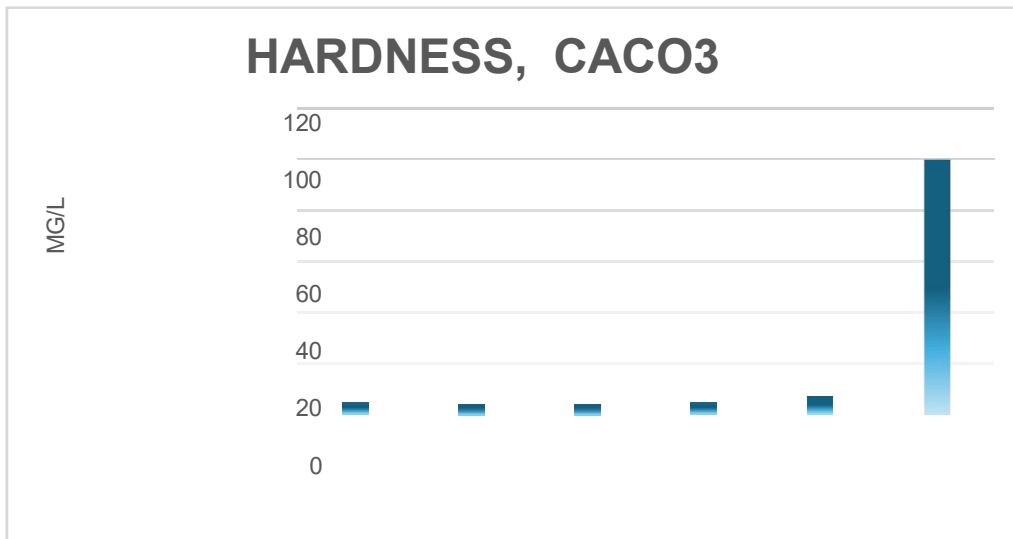


Fig 4.13: Chart showing Levels of Total Alkalinity in BH1, BH2, WELL1, WELL2 and RIVER

All samples showed low alkalinity (2.5–6.25 mg/L), well below the 100 mg/L limit. This low buffering capacity explains the low pH values, making the water more susceptible to acidification.

#### 4.2.14 Hardness

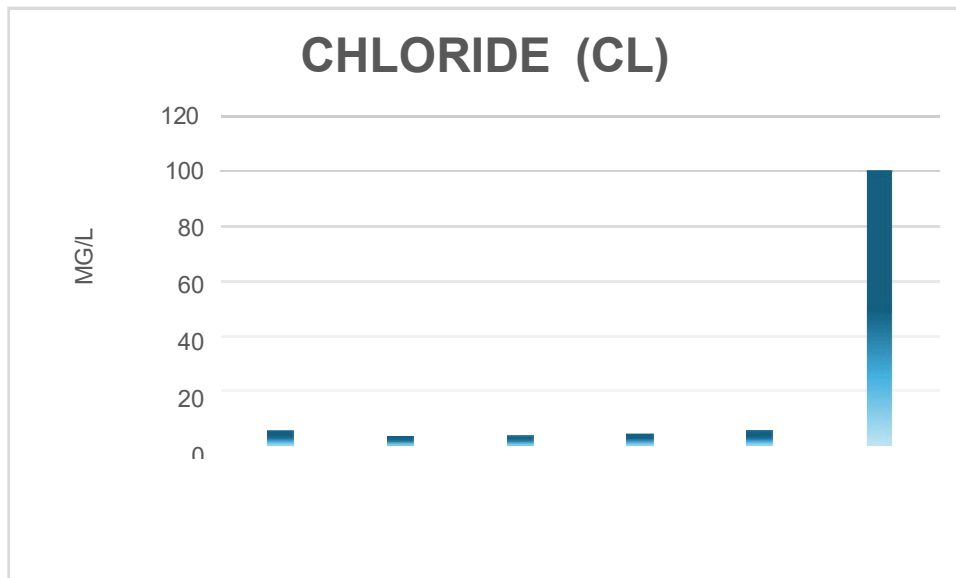


	BH 1	BH 2	WELL1	WELL2	RIVER	NIS 977:2017 LIMIT
■ Hardness, CaCO <sub>3</sub>	4.8	4	4	4.8	7.21	100

Fig 4.14: Chart showing Levels of Hardness in BH1, BH2, WELL1, WELL2 and RIVER

Hardness was generally low (4.0–7.21 mg/L), which is well within the acceptable 100 mg/L limit. This confirms the water is soft, reducing scaling potential but possibly affecting taste and soap lathering.

#### 4.2.15 Chloride (Cl)

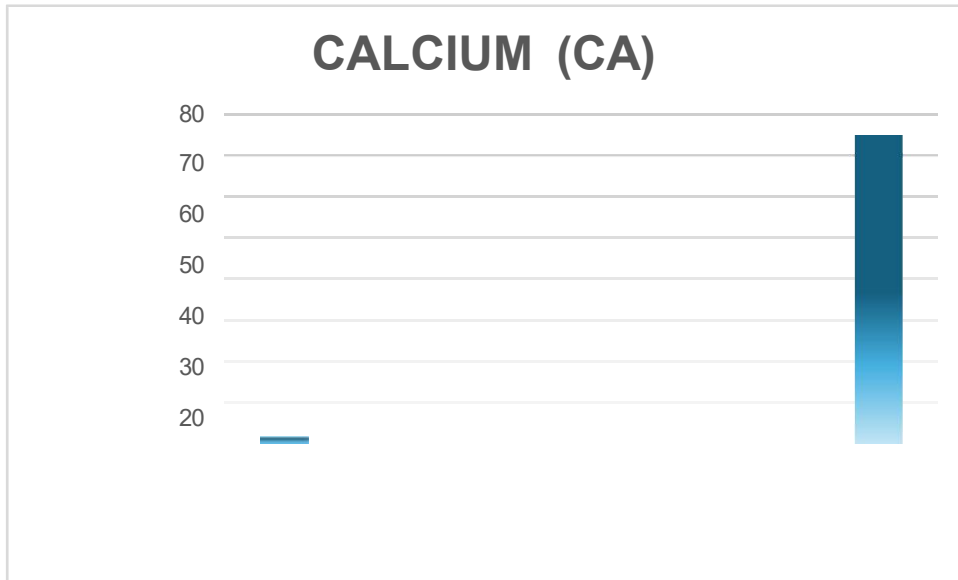


	BH 1	BH 2	WELL1	WELL2	RIVER	NIS 977:2017 LIMIT
Chloride (Cl)	5.4	3.3	3.6	4.5	5.7	100

Fig 4.15: Chart showing Levels of Chloride in BH1, BH2, WELL1, WELL2 and RIVER

Chloride concentrations (3.3–5.7 mg/L) were within safe limits ( $\leq 100$  mg/L), posing no taste or corrosive risks.

#### 4.2.16 Calcium (Ca<sup>2+</sup>)



	BH 1	BH 2	WELL1	WELL2	RIVER	NIS 977:2017 LIMIT
■ Calcium (Ca)	1.6	0.96	1.28	0.96	0.96	75

Fig 4.16: Chart showing Levels of Calcium in BH1, BH2, WELL1, WELL2 and RIVER

Calcium levels ranged from 0.96–1.6 mg/L, significantly lower than the 75 mg/L limit, confirming the soft nature of the water.

#### 4.2.17 Magnesium (Mg<sup>2+</sup>)

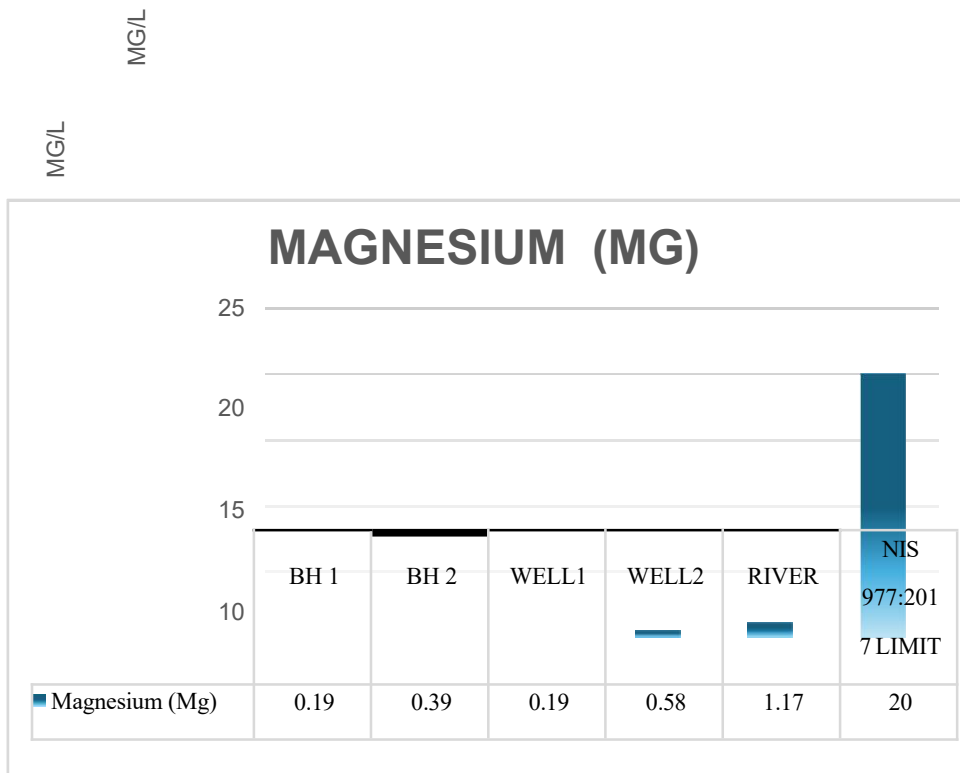
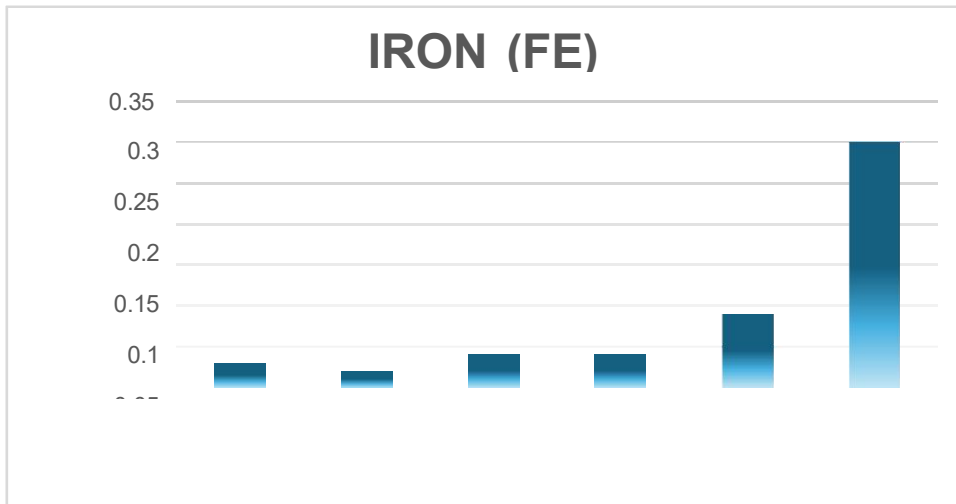


Fig 4.17: Chart showing Levels of Magnesium in BH1, BH2, WELL1, WELL2 and RIVER

Magnesium was below the 20 mg/L limit in all samples. The river showed the highest concentration (1.17 mg/L), still considered very safe.

#### 4.2.18 Iron (Fe)



	BH 1	BH 2	WELL1	WELL2	RIVER	NIS 977:2017 LIMIT
■ Iron (Fe)	0.03	0.02	0.04	0.04	0.09	0.3

Fig 4.18: Chart showing Levels of Iron in BH1, BH2, WELL1, WELL2 and RIVER

Iron concentrations (0.02–0.09 mg/L) were well below the permissible limit (0.3 mg/L).

River water had the highest value, possibly from natural leaching or suspended particles.

#### 4.2.19 Copper (Cu)

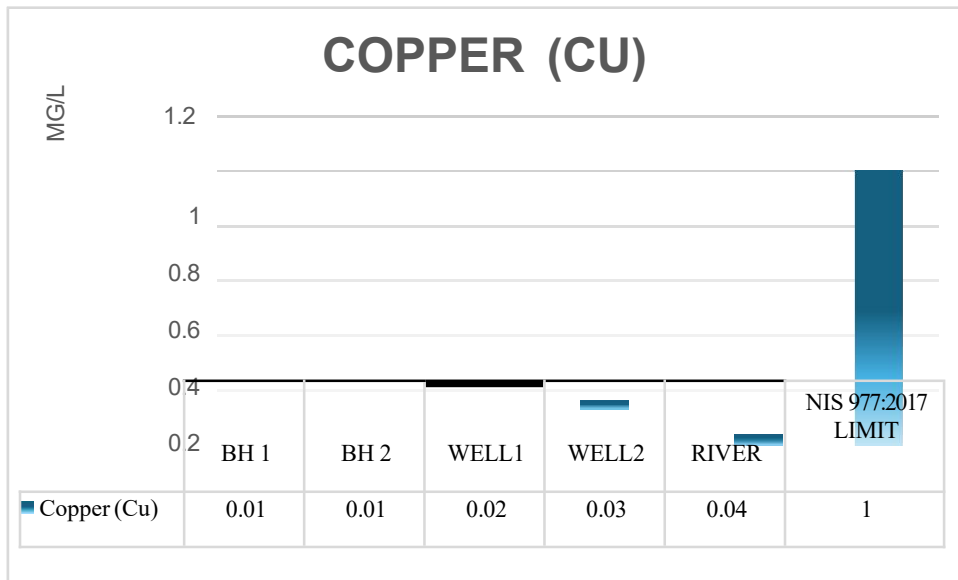


Fig 4.19: Chart showing Levels of Copper in BH1, BH2, WELL1, WELL2 and RIVER

Copper was present in trace amounts (0.01–0.04 mg/L), far below the 1.0 mg/L limit, indicating minimal metallic contamination.

#### 4.2.20 Zinc (Zn)

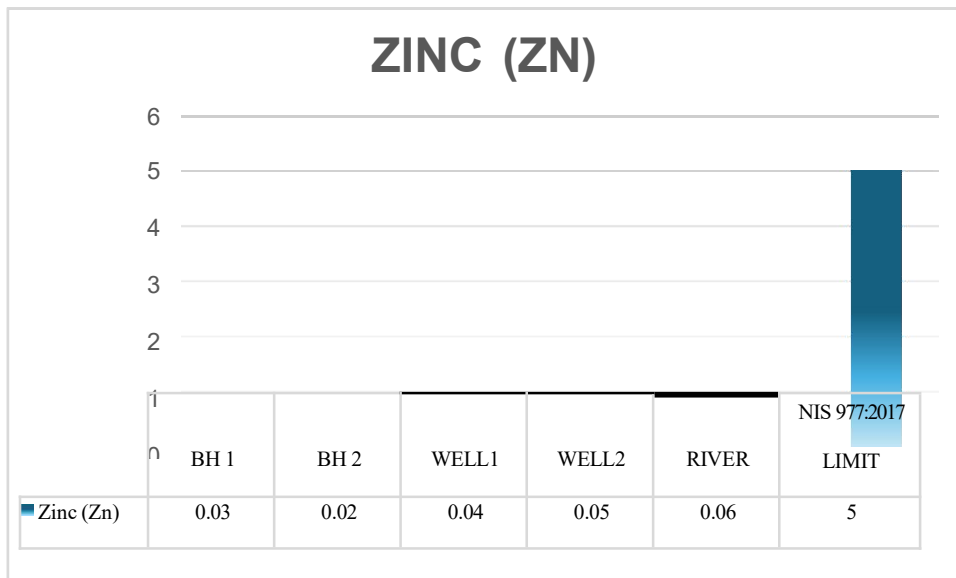


Fig 4.20: Chart showing Levels of Zinc in BH1, BH2, WELL1, WELL2 and RIVER

Zinc levels (0.02–0.06 mg/L) were within the safe range ( $\leq 5.0$  mg/L), with higher values in well and river water.

#### 4.2.21 Nickel (Ni)

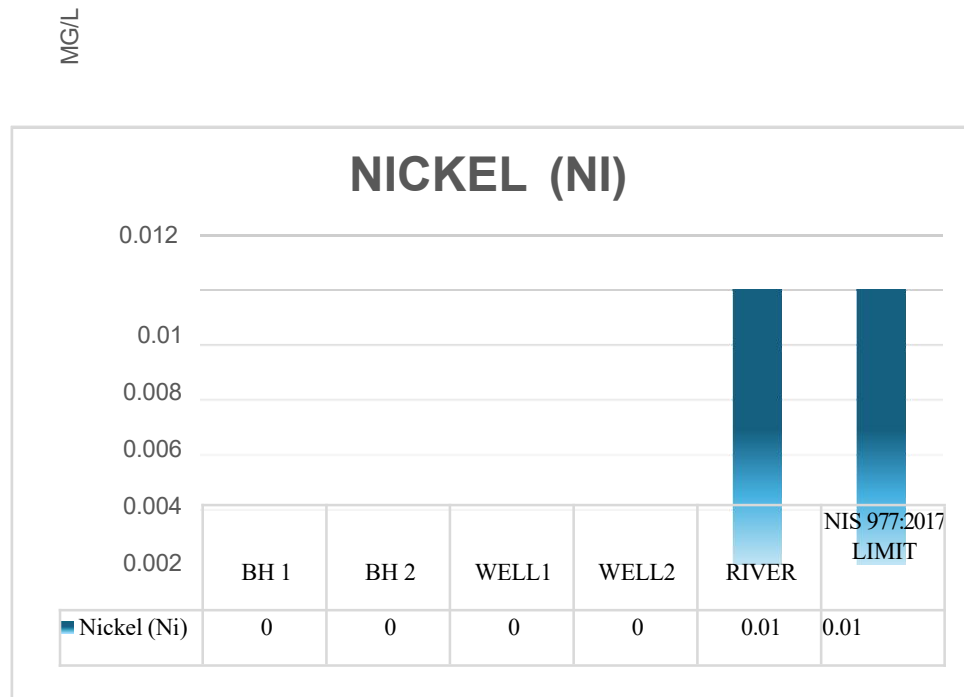


Fig 4.21: Chart showing Levels of Nickel in BH1, BH2, WELL1, WELL2 and RIVER

Nickel was undetectable (ND) in borehole and well samples but present in the river at 0.01 mg/L, which is exactly at the NIS maximum limit. Continuous exposure could pose health risks.

#### 4.2.22 Lead (Pb)

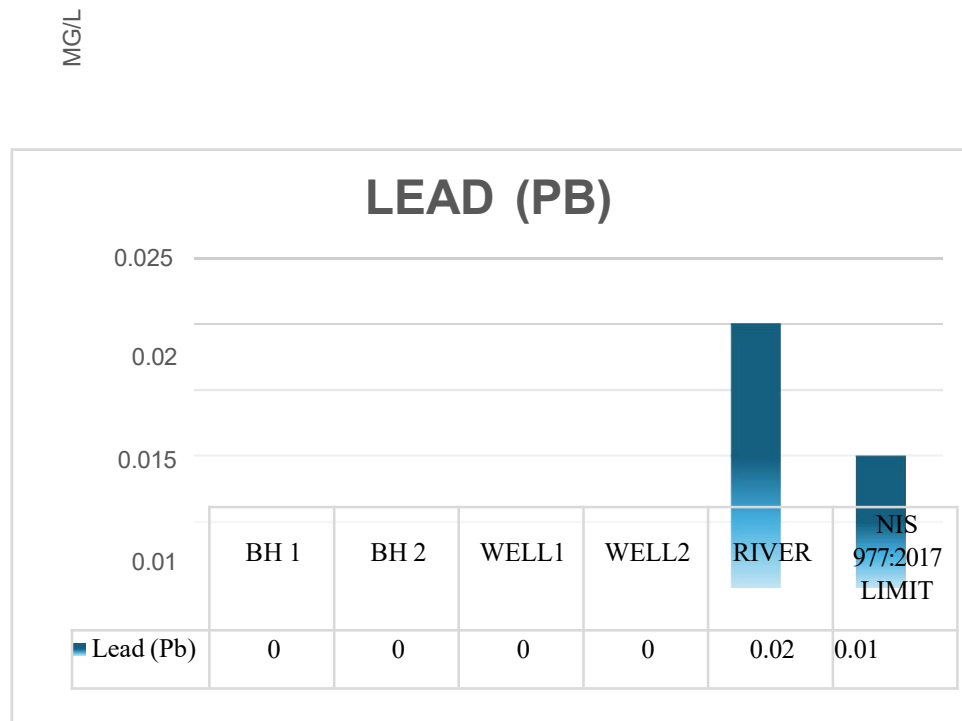


Fig 4.22: Chart showing Levels of Lead in BH1, BH2, WELL1, WELL2 and RIVER

Lead was not detected in any sample except in the river (0.02 mg/L), which exceeds the NIS limit of 0.01 mg/L, posing significant risks for children and pregnant women, including neurological damage (USEPA, 2020).

#### 4.2.23 Manganese (Mn)

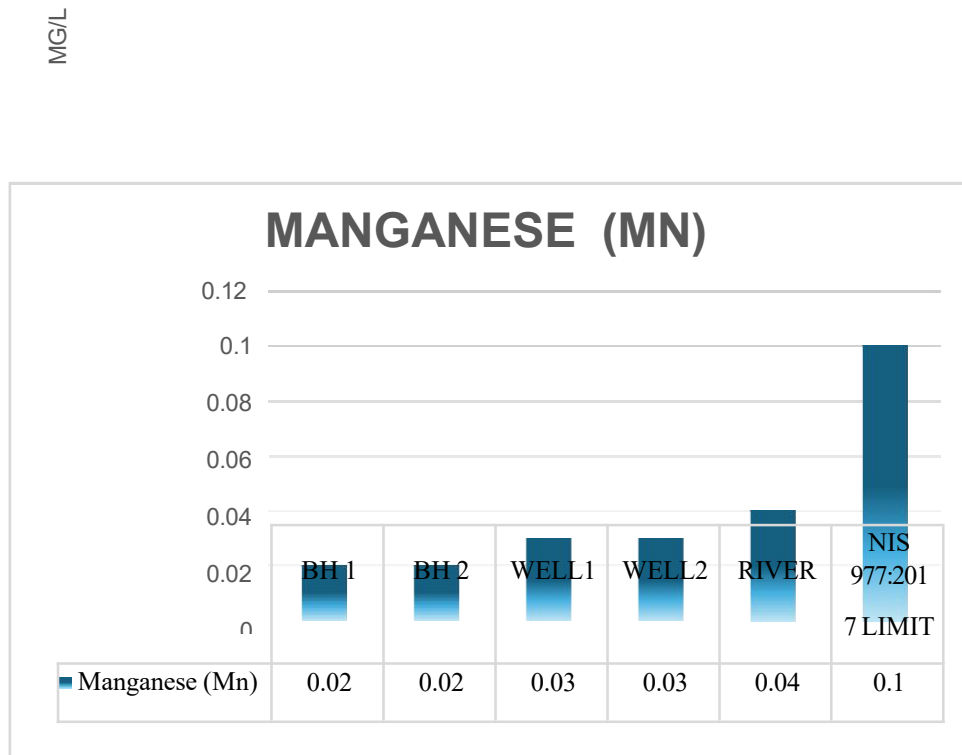


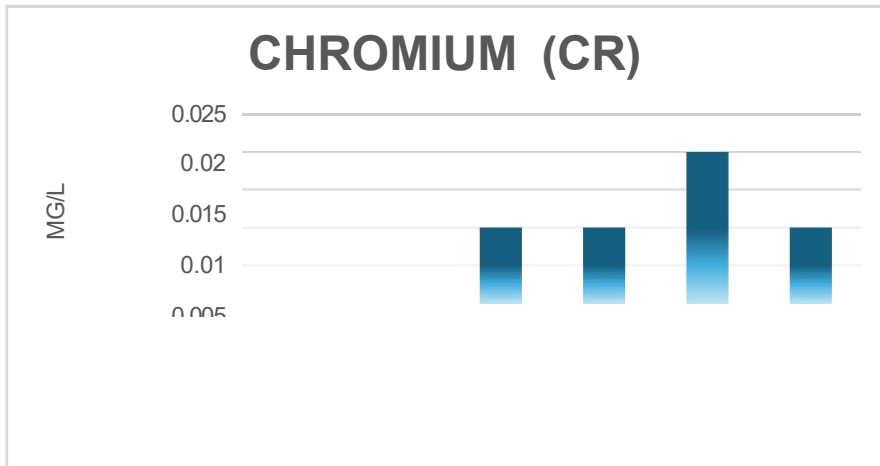
Fig 4.23: Chart showing Levels of Manganese in BH1, BH2, WELL1, WELL2 and RIVER

All samples had manganese below the 0.1 mg/L limit. The river had the highest value (0.04 mg/L), which is acceptable but may require monitoring over time.

#### **4.2.24 Cadmium (Cd), Arsenic (As), Mercury (Hg)**

These were not detected (ND) in any sample, indicating absence or below detectable thresholds, which is favorable as they are highly toxic even at low concentrations.

#### 4.2.25 Chromium (Cr)



	BH 1	BH 2	WELL1	WELL2	RIVER	NIS 977:20 17 LIMIT
Chromium (Cr)	0	0	0.01	0.01	0.02	0.01

Fig 4.27: Chart showing Levels of Chromium in BH1, BH2, WELL1, WELL2 and RIVER

Chromium was found in WELL1, WELL2 (0.01 mg/L), and river (0.02 mg/L). The river value exceeds the NIS limit of 0.01 mg/L and poses carcinogenic risks with long-term exposure.

### 4.3 Comparison with NIS 977:2017 Standards

Most parameters analyzed in the boreholes and wells complied with the NIS standard, except for:

- **pH:** All samples were acidic and fell below the standard limit.
- **Turbidity:** River and WELL1 exceeded the 5.0 NTU limit.
- **Lead and Chromium:** Detected in the river above permissible limits.
- **Nickel:** River sample exactly at the maximum limit.

These deviations were more prevalent in surface water (river), which is more exposed to anthropogenic influences, runoff, and microbial activity.

**Table 4.1: Physiochemical Parameters In drinking water in Orhionmwon Local Government Area, Edo State**

Parameters	Units	BH 1	BH 2	WELL1	WELL2	RIVER	NIS 977:2017 LIMIT
Temperature	°c	28.5	28.4	28.4	28.3	27.7	Ambient
pH		5.75	5.40	5.30	5.35	5.80	6.5-8.5
Turbidity	NTU	0.215	0.645	4.73	2.58	5.38	5.0
Conductivity	uS/cm	22	15	16	19	23	1000
Total Dissolved Solids (TDS)	mg/l	11	7	8	9	11	500
Total Suspended Solids (TSS)	mg/l	0.0	0.0	0.1	0.1	0.3	NA
Nitrate (NO <sub>3</sub> )	mg/l	2.30	1.49	3.52	0.81	3.93	10
Sulphate (SO <sub>4</sub> )	mg/l	0.27	0.46	0.60	0.33	2.39	100
Phosphate (PO <sub>4</sub> )	mg/l	0.02	0.04	0.05	0.03	0.08	NA
Dissolved Oxygen	mg/l	7.4	7.6	6.2	6.0	4.8	NA
Biochemical Oxygen Demand (BOD)	mg/l	2.6	2.20	3.00	3.20	3.80	NA
Chemical oxygen Demand (COD)	mg/l	4.00	2.00	4.00	6.00	38.00	NA
Total Alkalinity	mg/l	3.75	2.50	3.75	5.00	6.25	100
Hardness, CaCO <sub>3</sub>	mg/l	4.80	4.00	4.00	4.80	7.21	100
Chloride (Cl)	mg/l	5.4	3.3	3.6	4.5	5.7	100
Calcium (Ca)	mg/l	1.60	0.96	1.28	0.96	0.96	75
Magnesium (Mg)	mg/l	0.19	0.39	0.19	0.58	1.17	20
Iron (Fe)	mg/l	0.03	0.02	0.04	0.04	0.09	0.3
Copper (Cu)	mg/l	0.01	0.01	0.02	0.03	0.04	1.0
Zinc (Zn)	mg/l	0.03	0.02	0.04	0.05	0.06	5.0
Nickel (Ni)	mg/l	ND	ND	ND	ND	0.01	0.01
Lead (Pb)	mg/l	ND	ND	ND	ND	0.02	0.01
Manganese (Mn)	mg/l	0.02	0.02	0.03	0.03	0.04	0.1
Cadmium (Cd)	mg/l	ND	ND	ND	ND	ND	0.003
Chromium (Cr)	mg/l	ND	ND	0.01	0.01	0.02	0.01
Arsenic (As)	mg/l	ND	ND	ND	ND	ND	0.01
Mercury (Hg)	mg/l	ND	ND	ND	ND	ND	0.001

NOTE: NA = Not Available

## CHAPTER FIVE

### DISCUSSION, CONCLUSION AND RECOMMENDATIONS

#### 5.1 DISCUSSION

The physicochemical characteristics of water samples from Orhionmwon reveal varying degrees of compliance with the Nigerian Industrial Standard (NIS 977:2017) and international water quality guidelines (WHO, 2022). Results indicate that while boreholes generally provide safer water, surface and well sources show multiple deviations that raise health concerns.

##### 5.2.1 pH

The acidic nature of all samples (pH 5.30–5.80) is consistent with findings by Olalekan *et al.* (2022) in southwestern Nigeria, where several groundwater sources recorded sub-standard pH. Similarly, Edokpayi *et al.* (2020) observed pH values below 6.5 in rural borehole sources in South Africa. This deviation from the recommended range of 6.5–8.5 (WHO, 2017; NIS 977:2017) indicates potential for corrosive action on plumbing systems and increased metal leaching such as lead and copper. For vulnerable populations, such as children, prolonged consumption of acidic water can irritate mucous membranes and increase toxic metal exposure.

##### 5.2.2 Turbidity

Turbidity levels in the river (5.38 NTU) and WELL1 (4.73 NTU) either exceed or approach the NIS limit of 5 NTU. This trend is in line with the study by Fahimah *et al.* (2023), which showed elevated turbidity in underground water due to poor sanitation around the source. High turbidity interferes with disinfection, increases microbial survival, and can lead to

waterborne diseases, especially among infants and immunocompromised individuals (WHO, 2022).

### **5.2.3 Conductivity and TDS**

Low EC (15–23  $\mu\text{S}/\text{cm}$ ) and TDS (7–11 mg/L) values indicate minimal ionic presence. These are far below permissible thresholds (1000  $\mu\text{S}/\text{cm}$  for EC, 500 mg/L for TDS) and conform with the findings of Umoren *et al.* (2024) in some Communities in Abeokuta, Ogun State. While low TDS may signify safe water, extremely low levels can affect taste and may deprive consumers of beneficial minerals like calcium and magnesium (WHO, 2022).

### **5.2.4 DO, BOD, and COD**

The elevated BOD (3.8 mg/L) and COD (38 mg/L) in the river suggest high organic pollution, confirming findings by Chukwu *et al.* (2024), where surface waters near agricultural zones showed similar levels. Although no specific NIS limits are provided for BOD and COD in drinking water, WHO (2022) recommends BOD below 2 mg/L for safe water. High values imply microbial activity, oxygen depletion, and an increased risk of enteric pathogens.

### **5.2.5 Nitrate, Sulphate, and Phosphate**

Nitrate values (up to 3.93 mg/L) remained within safe limits (<10 mg/L), confirming reports by Popoola *et al.*, (2019) in borehole waters in Lagos metropolis. However, even low nitrate levels can be dangerous for infants, leading to methemoglobinemia or —blue baby syndromel if concentrations increase (WHO, 2022). Sulphate and phosphate levels were also low, and similar values have been reported by Umoren *et al.* (2024) in non-industrial rural settings. Nevertheless, phosphate enrichment in the river could stimulate eutrophication, promoting algal blooms in the long term.

### 5.2.6 Alkalinity and Hardness

Low alkalinity (2.5–6.25 mg/L) and hardness (4–7.21 mg/L) suggest poor buffering capacity and softness of the water, which aligns with the findings of Olayiwola *et al.* (2020) in southwestern Nigeria. While soft water is generally acceptable, low alkalinity contributes to low pH, thus compounding the risk of metal dissolution and corrosion of water distribution systems.

### 5.2.7 Chloride, Calcium, Magnesium

All values were well within limits (Cl: <100 mg/L, Ca: <75 mg/L, Mg: <20 mg/L). These values confirm conformity with studies by Ogbe *et al.* (2025) and suggest minimal saltwater intrusion or mineral contamination, often observed in inland rural water sources.

### 5.2.8 Heavy Metals (Fe, Cu, Zn, Ni, Pb, Mn, Cr)

- Iron, Copper, and Zinc were detected in trace amounts, below NIS thresholds. These results are consistent with findings in borehole water in southwestern Nigeria reported by Akoteyon *et al.* (2024).
- Nickel (0.01 mg/L) and Chromium (0.02 mg/L) were detected in the river, with Cr exceeding the limit (0.01 mg/L). Cr (VI) is a known carcinogen, and chronic exposure may lead to kidney and liver damage.
- Lead (0.02 mg/L) was above the NIS limit (0.01 mg/L) in the river. This mirrors the warning by WHO (2022) that no level of lead is safe, particularly for children, pregnant women, and foetuses, due to the risk of neurological damage and developmental delays.
- Manganese (0.02–0.04 mg/L) was within permissible levels (0.1 mg/L), though WHO

(2022) recommends caution above 0.05 mg/L, particularly for infants due to possible neurotoxicity with long-term exposure.

### **5.2.9 Trace Toxins: Cd, As, Hg**

These were not detected (ND) in any sample, which is a positive outcome. Cd, As, and Hg are highly toxic even at trace levels, and their absence supports the non-industrial nature of the Orhionmwon environment, consistent with Yahaya *et al.* (2021) and APHA (2022) reports on rural African water systems.

### **5.2.10 Overall Trends**

The comparative analysis suggests:

- Borehole water was the safest, followed by well water, while surface water (river) presented the highest health risks.
- Results are largely consistent with rural water studies in sub-Saharan Africa but indicate site-specific issues such as acidic pH, elevated turbidity, and toxic metal presence in the river source.

## 5.2 CONCLUSION

This study was carried out to evaluate the physicochemical characteristics of drinking water from selected sources in Orhionmwon Local Government Area, Edo State. Five water sources, comprising two boreholes, two hand-dug wells, and one river, were sampled and analysed for twenty-five physicochemical parameters. The goal was to assess their compliance with the Nigerian Industrial Standard for Drinking Water Quality (NIS 977:2017) and identify potential health implications associated with their consumption.

The results revealed significant variations across the different water sources, with borehole water generally exhibiting better physicochemical quality compared to wells and river water. The pH values of all samples were acidic, ranging between 5.30 and 5.80, which is below the permissible range of 6.5–8.5 as set by both NIS and the World Health Organization (WHO). This persistent low pH across all sources suggests a systemic deficiency in buffering capacity, likely due to low alkalinity values observed in the samples. Acidic water is known to corrode plumbing systems and promote the leaching of toxic metals such as lead, iron, and copper into the water supply. While no immediate toxicity may result from such pH levels, chronic exposure poses long-term risks to gastrointestinal health and may increase the concentration of heavy metals in the water distribution system.

Turbidity levels in the river and WELL1 exceeded or neared the NIS guideline of 5 NTU, suggesting the presence of suspended particles that could harbour microbial organisms or chemical pollutants. This aligns with earlier studies in rural Nigerian communities, where high turbidity was linked to poor well construction and runoff contamination during rainfall. Although the borehole samples showed significantly lower turbidity, the presence of suspended solids in well and river water underscores the need for effective treatment before consumption.

Electrical conductivity and total dissolved solids (TDS) values across all samples were relatively low, indicating minimal ionic content. This reflects the non-industrial and low-salinity nature of the environment. However, while low TDS is generally viewed as favourable for drinking water, extremely low values may result in poor taste and lack of essential minerals that contribute to the dietary needs of the local population. In rural and peri-urban areas where dietary mineral intake is already limited, ultra-pure water lacking calcium and magnesium may not offer optimum health benefits.

The results for dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) provide insight into the organic and biological state of the water. Borehole samples recorded high DO levels and low BOD and COD, confirming minimal biological pollution. In contrast, the river source showed markedly high BOD and COD values, 3.80 mg/L and 38.00 mg/L respectively, indicating significant organic pollution, likely from agricultural runoff, domestic sewage, or decomposing vegetation. These values exceed the WHO recommendation for BOD in drinking water and highlight the urgent need for treatment interventions before river water can be deemed safe for public use.

Analysis of major nutrients such as nitrates, sulphates, and phosphates showed concentrations within acceptable limits. Nitrate levels were highest in the river (3.93 mg/L), although still below the 10 mg/L maximum threshold set by WHO and NIS. Elevated nitrates, especially when associated with microbial contamination, pose a serious threat to infants due to the risk of methemoglobinemia or "blue baby syndrome." Sulphate and phosphate values were relatively low, yet the presence of phosphate in the river sample at 0.08 mg/L could contribute to eutrophication and excessive algal growth if the river is exposed to persistent nutrient loading.

Hardness and alkalinity values were very low across all sources. Total hardness ranged from

4.00 to 7.21 mg/L, which classifies the water as soft. Soft water has advantages in terms of minimizing scaling in plumbing and appliances but is also more aggressive in terms of corrosion and less palatable. The low alkalinity values (as low as 2.50 mg/L) further highlight the lack of buffering capacity in the water, making the sources vulnerable to pH instability and acidification.

With respect to heavy metals, most parameters were within safe limits for borehole and well samples. However, the river sample exceeded the permissible limits for lead and chromium. Lead was recorded at 0.02 mg/L, which is twice the acceptable limit of 0.01 mg/L, while chromium was detected at 0.02 mg/L, also exceeding the standard limit. The presence of these toxic metals poses a major public health concern. Chronic exposure to lead has been linked to neurodevelopmental disorders in children, reduced IQ, behavioural problems, and kidney damage. Chromium, particularly in its hexavalent form, is a known carcinogen and can affect both renal and hepatic function. The presence of these metals in the river suggests anthropogenic influence, possibly from agricultural inputs, improper waste disposal, or natural geological leaching intensified by low pH conditions.

Other trace metals such as iron, copper, zinc, manganese, and nickel were found in relatively safe concentrations across most sources. The river had slightly higher values, yet they remained within permissible limits. Cadmium, arsenic, and mercury were not detected in any of the samples, which is a positive indicator of water safety, given the extremely toxic nature of these elements even at very low concentrations. The absence of these contaminants likely reflects the rural, non-industrial characteristics of the study area.

Overall, the borehole water emerged as the safest among all the sources evaluated, with minimal deviations from standard values. The wells showed moderate quality, with occasional exceedances in turbidity and low pH, while the river water proved to be the most

contaminated, particularly in terms of turbidity, organic load, and heavy metals. The health implications of consuming untreated water from the river are particularly severe for vulnerable populations such as infants, pregnant women, and the elderly, who may experience cumulative effects of toxic exposure over time. Given the reliance of many Orhionmwon communities on these water sources, it is critical that measures are taken to improve water quality through treatment, monitoring, and community education.

### **5.3 RECOMMENDATIONS**

In light of the findings from this study, several recommendations are proposed to address the existing gaps in water quality and protect public health in Orhionmwon and similar environments.

First, it is imperative that the local government, through its water board and public health departments, prioritize water treatment interventions for communities that rely on surface water sources. The river sample in this study contained levels of lead and chromium that exceed safe limits and pose long-term health risks. Simple but effective treatment methods such as sand filtration, activated carbon filtration, and chemical precipitation can be introduced at the household or community level. Additionally, pH adjustment through the use of calcium carbonate or lime should be considered to neutralize the acidic nature of the water and minimize metal leaching.

Furthermore, a robust water quality monitoring framework should be instituted, involving regular sampling and analysis of all major drinking water sources, especially during the rainy season when runoff contamination is most prevalent. The Ministry of Environment and related agencies such as NAFDAC and the Standards Organisation of Nigeria (SON) must collaborate to enforce compliance with national water quality standards, particularly among sachet and bottled water producers operating in the area.

Community sensitization is also essential. Residents need to be educated on the risks of consuming untreated water and trained on basic household water treatment techniques such as boiling, solar disinfection (SODIS), and chlorination. Public health campaigns can also discourage open defecation and poor waste disposal practices near water sources, which contribute to nutrient and microbial contamination.

Infrastructural improvements must not be overlooked. Wells should be properly lined and covered to prevent contamination from runoff or animals. Borehole platforms must be constructed with proper drainage systems to prevent stagnation and microbial breeding. In addition, the establishment of communal water committees with technical training can ensure local ownership, sustainability, and accountability in the maintenance of water infrastructure.

Finally, this study recommends that future research efforts include microbial analysis and seasonal variation studies to provide a more comprehensive picture of water safety across different periods of the year. Such data would support more targeted interventions and enhance the resilience of water supply systems to environmental changes and human activities.

In conclusion, while access to water in Orhionmwon is relatively widespread, access to safe water remains a challenge. Addressing this requires an integrated approach that combines scientific monitoring, policy enforcement, infrastructure development, and community participation to ensure that every resident has access to clean, safe, and affordable drinking water.

## REFERENCES

- Afolabi, T. A., Ojekunle, O. Z., and Olutona, G. O. (2021). Physicochemical and bacteriological quality of borehole water in Ibadan, Nigeria. *Environmental Health Engineering and Management Journal*, 8(3), 203–212.
- Ajibade, T. F., Olalekan, R. M., and Adeola, A. A. (2023). Heavy metals and nitrate contamination in sachet and borehole water in Lagos State, Nigeria. *Heliyon*, 9(3), e13821.
- Akhtar, N., and Bakhsh, A. (2021). Various Natural and Anthropogenic Factors Responsible for Water Quality Degradation: A Review. *Water (MDPI)*, 13(19), 2660. <https://www.mdpi.com/2073-4441/13/19/2660>
- Akinde, S. B., Igiebor, F. A., and Obiora, I. H. (2021). Evaluation of borehole water quality in Orhionmwon Local Government Area, Edo State, Nigeria. *Journal of Water and Health*, 19(4), 562–574.
- Akoteyon, I., Tovide, O., Adepoju, F., Okoronkwo, U. E. (2024). Groundwater Quality And Risk Assessment Of Heavy Metal Pollution Using Water Quality Index As A Communication Tool: Evidence from Ejigbo, Lagos- Nigeria. 12. 1-8. 10.5281/zenodo.13983527.
- American Public Health Association (APHA). (2023). *Standard Methods for the Examination of Water and Wastewater* (24th ed.). Washington, DC: APHA, AWWA, WEF.
- American Public Health Association. (2017). *Standard Methods for the Examination of Water and Wastewater* (23rd ed.). American Public Health Association, American Water Works Association, and Water Environment Federation. (Standard reference for analytical methods.) <https://www.standardmethods.org/doi/book/10.2105/smww.2882>.
- APHA (2017). *Guidance on pH, TDS, EC, turbidity and other physicochemical parameters*. APHA: Retrieved from: <https://www.standardmethods.org/doi/book/10.2105/smww.2882>.
- Chukwu, C. I., Ibrahim, A., and Musa, J. (2024). Physicochemical and bacteriological assessment of groundwater quality in Plateau State, Nigeria. *Journal of Water and Health Research*, 12(1), 45–57.
- Chukwu, E. G., Moses, O. A., and Nkwor, F. C. (2024). Assessment of physicochemical and bacteriological parameters of drinking water in Pankshin LGA, Plateau State, Nigeria. *Asian Journal of Chemical Sciences*, 15(4), 25–34.
- Edeki, J. I., Oghenekaro, A. O., and Okoh, S. (2023). Assessment of physicochemical and bacteriological quality of drinking water in Sapele, Delta State, Nigeria. *Journal of Water and Health*, 21(2), 286–299.
- Edeki, S. O., Omoregie, O., and Aigberua, A. (2023). Assessment of physicochemical and

bacteriological quality of drinking water in Sapele, Delta State, Nigeria. *Nigerian Journal of Environmental Sciences*, 11(2), 89–102.

- Edokpayi, J. N., Rogawski, E. T., Kahler, D. M., Hill, C. L., Reynolds, C., Nyathi, E., and Samie, A. (2020). Challenges to sustainable safe drinking water: A case study of water quality and use across seasons in rural communities in Limpopo Province, South Africa. *Water*, 12(1), 150.
- Fahimah, N., Salami, I. R. S., Oginawati, K., and Thaher, Y.N. (2023). Variations of groundwater turbidity in the Bandung regency, Indonesia: From community-used water quality monitoring data. *HydroResearch*, Volume 6, Pages 216-227.
- Ibrahim, E. G., Ayinya G-I, M., Ankwai G., and Dapam I, L. (2020). Assessment of drinking water quality in selected locations in North-Central Nigeria. *IOSR Journal of Applied Chemistry*. Volume 13(1):12-21
- Igbinevbo, I. D., Akiri-Obaroakpo, T. M., and Ebun-Igbeare, O. E. (2023). Physicochemical and Heavy Metals Analysis of Different Brands of Sachet Water Sold in Benin City, Nigeria. *Journal of Applied Sciences and Environmental Management*, 27(3), 503–
- Igiebor, F. A., Eromosele, C. O., and Ogedengbe, K. (2021). Assessment of borehole water quality in selected communities of Edo State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 25(4), 561–568.
- Iqbal J, Su C, Wang M, Abbas H, Baloch MYJ, Ghani J, Ullah Z and Huq ME. (2023). Groundwater fluoride and nitrate contamination and associated human health risk assessment in South Punjab, Pakistan. *Environ Sci Pollut Res Int*. May;30(22):61606-61625
- National Center for Biotechnology Information (NCBI). (2022). *Guidelines for drinking-water quality* (WHO GDWQ — online book entry). In: WHO. <https://www.ncbi.nlm.nih.gov/books/NBK579461>
- Nlemolisa, O. R., Ogbulie, J. N., Orji, J. C., Nweke, C. O., Kemka, U. N., Gaius-Mbalisi, V. K., and Ihenetu, F. C. (2025). Groundwater contamination and health risks near waste dumps and mechanic workshops: A seasonal perspective. *Cleaner Water*, 4, 100090. <https://doi.org/10.1016/j.clwat.2025.100090>.
- Odiana, A. O., Okoh, C. E., and Igbinosa, I. H. (2024). Physicochemical quality and microbial safety of drinking water sources in Edo State, Nigeria. *Scientific African*, 16, e01422.
- Odiana, J. A., Ibadode, F. O., and Akpoveta, O. V. (2024). Domestic water quality and health implications in Southern Edo State, Nigeria. *Environmental Monitoring and Assessment*, 196(7), 1223–1238.
- Odiana, S. I., Aigbe, H. I., and Ekhaton, O. S. (2024). Evaluation of physicochemical parameters of domestic water sources in Southern Edo State, Nigeria. *Dutse Journal of Pure and Applied Sciences*, 10(1), 45–57.
- Odigie, E. O., Okoro, C. C., and Ugbebor, J. E. (2022). Water Quality Index and

bacteriological analysis of Ossiomo River, Edo State, Nigeria. *Journal of Applied Water Science*, 12(4), 331–340.

- Odigie, J. E., Osemwenkhae, J. E., and Igiebor, F. A. (2022). Water Quality Index and bacteriological analysis of Ossiomo River, Orhionmwon LGA, Edo State, Nigeria. *Dutse Journal of Pure and Applied Sciences*, 8(3), 112–121.
- Ogbe, A. O., Musa, U. A., and Ibrahim, H. (2025). Surface water quality in Nigeria: A comprehensive review of physicochemical characteristics (2015–2025). *Sahel Journal of Life Sciences*, 7(2), 101–119.
- Ogbe, J. E., Oladipo, T., and Ajayi, R. A. (2025). A decade review of surface water quality in Nigeria (2015–2025): Implications for human health and policy. *African Journal of Environmental Sustainability*, 15(2), 201–219.
- Ogundiran, A. O., and Fashola, M. O. (2021). Nitrate and chloride contamination of hand-dug wells in Ibadan, Nigeria: Hydrochemical and health risk assessment. *Journal of African Earth Sciences*, 177, 104107.
- Okoro, H.K., Adeyinka, A., Jondiko O.E., and Ximba B.J. (2012). Physico-chemical analysis of selected groundwater samples of Ilorin town in Kwara State, Nigeria, *Academic Journnals*, Vol.7(23), pp. 2063-2069.
- Olalekan, R. M., Omotoso, O. A., and Akanni, A. O. (2022). Heavy metal contamination and public health risk assessment of sachet water brands in Lagos State, Nigeria. *Environmental Nanotechnology, Monitoring and Management*, 18, 100702.
- Olayiwola, A. J., Ogundiran, M. B., and Akintayo, I. (2020). Physicochemical and heavy metal characteristics of groundwater in Osun State, Nigeria. *Environmental Systems Research*, 9(1), 25.
- Olayiwola, A. M., Adeyemi, S. O., and Adebisi, O. M. (2020). Seasonal variation of physicochemical and heavy metal parameters of surface and groundwater in Osun State, Nigeria. *Environmental Systems Research*, 9, 25.
- Onuoha, U., Nnaji, A. O., and Nwankwoala, H. O. (2023). Water quality assessment of rural boreholes in Enugu State, Nigeria: Implications for public health. *Groundwater for Sustainable Development*, 21, 100907.
- Opafola, O. T., Oladepob, T. K., Ajibade, F. O., Davida, A. O., (2020). Potability assessment of packaged sachet water sold within a tertiary institution in southwestern Nigeria. *Journal of King Saud University*, 32(3).
- Popoola, L. T., Yusuff, A. S., and Aderibigbe, T. A. (2019). Assessment of natural groundwater physico-chemical properties in major industrial and residential locations of Lagos metropolis. *Applied Water Science*, 9(191). <https://doi.org/10.1007/s13201-019-1073-y>.
- Standards Organisation of Nigeria (SON). (2015). *Nigerian Standard for Drinking Water Quality (NIS 554:2015)*. Abuja: SON.

- Standards Organisation of Nigeria. (2015). *Nigerian Standard for Drinking-Water Quality (NIS 554:2015)*. Lagos: SON. (PDF) <https://africacheck.org/wp-content/uploads/2018/06/Nigerian-Standard-for-Drinking-Water-Quality-NIS-554-2015.pdf>.
- Taiwo, A. M. Hassan, T., Adeoye I. A., Asekoya, G.A., Tayo, O.E. Ogunsola, D. O., Babawale, M.K., Isicgei, O. T., Olayinka, S. O. (2023). *Assessment of levels and health risk of Potentially Toxic Elements (PTEs) in selected sachet water packaged from groundwater resources in Ogun State, Nigeria*. Journal of Trace Elements and Minerals, Volume 5, id.100087.
- Ugwumba, E. O., and Okechukwu, E. I. (2021). Groundwater contamination from agricultural activities in Anambra State, Nigeria: A physicochemical assessment. *Applied Water Science*, 11(6), 123.
- Umoren, O., Salaudeen, G., Olowo, S.T., Mohammed, M.A., George, A., Ayanleke, T.A., Afolabi, T., Bamigbaye, O.P. (2024). Physicochemical Parameters of Selected Ground and Surface Water Sources in Ijeun-Titun and Kuto Communities, Abeokuta, Ogun State, Nigeria. *11*.
- UN Water. (2023). *United Nations World Water Development Report 2023: Partnerships and cooperation for water*. Paris: UNESCO.
- United Nations (UN). (2023). *The Sustainable Development Goals Report 2023*. New York: United Nations.
- United States Environmental Protection Agency (USEPA) (2020). *National Primary Drinking Water Regulations and Health Advisories*. Retrieved from: <https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations>.
- Usman, K. M., Popoola, O. D., and Adigun, M. A. (2024). Evaluation of Microbiological and Physicochemical Quality of Borehole Water in Mini-Campus, Federal Polytechnic, Offa, Kwara State, Nigeria. *Faculty of Natural and Applied Sciences Journal of Scientific Innovations*, **6(1)**, 19–26. Retrieved from <https://fnasjournals.com/index.php/FNAS-JSI/article/view/554>.
- WHO (2022). *Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda* WHO: Retrieved from: <https://www.who.int/publications/i/item/9789240045064>;
- WHO (2022). *Water safety plans — Guidelines for drinking-water quality* Retrieved from : <https://www.ncbi.nlm.nih.gov/books/NBK579462/>.
- World Health Organization (WHO). (2018). *Guidelines for drinking-water quality: Fourth edition incorporating the first addendum*. Geneva: WHO. Retrieved from <https://www.who.int/publications/i/item/9789241549950>

World Health Organization. (2022). *Guidelines for drinking-water quality: Fourth edition, incorporating the first and second addenda*. Geneva: World Health Organization. Retrieved from: <https://www.who.int/publications/i/item/9789240045064>

Yahaya, T. O., Oladele, E. O., Fatodu, I. A., Abdulazeez, A., and Yeldu, Y. I. (2021). Concentration and human health risk assessment of heavy metals in groundwater of Lagos, Southwest Nigeria. *arXiv:2101.04917*.