

**PHYSICOCHEMICAL AND MICROBIAL STUDIES OF
BOREHOLE WATER COLLECTED
IN EKOSODIN VILLAGE, EDO STATE.**

BY

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UNIVERSITY OF BENIN
BENIN CITY**

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**A PROJECT WORK WRITTEN AND SUBMITTED TO THE
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PHYSICAL SCIENCES, UNIVERSITY OF BENIN, BENIN
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CERTIFICATION

This is to certify that this project work was carried out by Miss OKECHUKWU FRANCES CHIAGOZIE with the matriculation number PSC2105276 under the supervision of PROF. D.E. OGBEIFUN in the Department of Chemistry, faculty of physical sciences, university of Benin, Benin City, Edo state.

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DEDICATION

This project research is wholly dedicated to God Almighty whose protection, grace, inspiration and Providence always remained with me throughout the course of my Academics. May his name always be honored for ever and ever. Amen

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ABSTRACT

This study evaluated the physicochemical and microbiological quality of borehole water from five student-dominated areas in Ekosodin Village, Benin City, to assess compliance with World Health Organization (WHO) and Nigerian Industrial Standard (NIS) guidelines. Standard analytical methods were employed to determine key physicochemical parameters, major ions, heavy metals, and microbial indicators

Most physicochemical parameters, including turbidity (0.98 - 4.38 NTU), TDS (10.32 - 92.27 mg/L), Conductivity (16.13 - 144.10 μ S/cm), hardness (0.15 - 2.90 mg/L), sulphates (3.0 - 4.61 mg/L), nitrates (2.87- 8.94 mg/L), and nitrites(0.01- 0.02 mg/L), were within permissible limits of 5NTU, 500mg/L, 1000 μ S/cm, 500mg/L, 250mg/L, <50mg/L and 3mg/l respectively. However, pH values at Edo Street (5.77) were below the recommended range of 6.5-8.5, and water temperatures exceeded the 25 °C guideline in most locations. Concentrations of cadmium (up to 0.03 mg/L) and lead (up to 0.03 mg/L) exceeded permissible limits (0.003 mg/L and 0.01 mg/L, respectively), suggesting potential toxicological risks. Microbiological assessment indicated elevated heterotrophic bacterial counts (3.00– 76 CFU/mL) and fecal contamination, making the water unsuitable for direct consumption.

The findings from this study underscore the need for regular water quality monitoring, appropriate treatment measures, and improved borehole management to safeguard student health in Ekosodin Village.

CHAPTER ONE

1.1 INTRODUCTION

1.1.1 BACKGROUND OF STUDY

Water, the most essential resource for life, is closely connected to human health, societal stability, and environmental sustainability. In many parts of the developing world, especially in sub-Saharan Africa, groundwater has become the primary source of drinking water, particularly in areas lacking municipal water infrastructure. Ekosodin, a peri-urban settlement on the outskirts of the University of Benin in Edo State, Nigeria, illustrates this reality. With a rapidly growing population composed mainly of off-campus students and low-income households, the need for clean, safe groundwater has risen sharply. However, this increasing dependence is increasingly at risk due to contamination from natural and human-made sources. As urban sprawl, poor sanitation, and unregulated construction expand in this vulnerable area, the quality of groundwater, often accessed through boreholes and hand-dug wells, has come under scrutiny. This study therefore conducts a thorough physicochemical and microbial analysis of groundwater in Ekosodin, not only to evaluate its safety but also to contribute to the growing body of vital knowledge that addresses the underexplored environmental health challenges in communities dominated by students.

The intersection of rapid urbanization, unregulated human activities, and inadequate waste management systems has led to serious groundwater quality problems in Nigeria. Many studies have shown how sanitation practices and the improper disposal of domestic waste damage groundwater sources (Sojobi, 2016; Egbueri, 2019; Awomeso *et al.*, 2020; Atemoagbo, 2024; Fatokun *et al.*, 2024). In Ekosodin, a typical peri-urban area with many hostels and limited drainage, fecal contamination from poorly built or leaking septic tanks has been a consistent issue. The presence of microbes in groundwater, proven by regular detection of *Escherichia coli*, *Salmonella*, and *Enterobacter spp.*, clearly shows ongoing environmental and health dangers. These germs are not just signs of poor water

quality but also cause diseases like cholera, typhoid fever, and various gastrointestinal infections (Atemoagbo, 2024). Making things worse is the increasing discovery of bacteria resistant to antibiotics in groundwater, a troubling trend that could lead to drug-resistant outbreaks in low-resource settings (Fatokun *et al.*, 2024).

Chemical pollution, although less visible than microbial contamination, poses an equally significant threat to groundwater quality in Ekosodin. The excessive use of fertilizers, herbicides, and other agrochemicals in nearby farms, along with natural weathering of mineral-rich bedrock, introduces harmful levels of nitrates, phosphates, heavy metals, and dissolved solids into underground aquifers (Egbueri, 2019; Ganiyu *et al.*, 2021; Akoji, 2019). Elevated concentrations of heavy metals such as lead, cadmium, manganese, and iron, often linked to natural sources and surface runoff, have been reported in other parts of Edo State and Nigeria overall (Awomeso *et al.*, 2020; Egbueri *et al.*, 2024). These toxic elements are especially concerning due to their long-term health effects, particularly among vulnerable groups like children, pregnant women, and immunocompromised individuals (Ganiyu *et al.*, 2021). Additionally, changes in key physicochemical parameters such as pH, turbidity, electrical conductivity (EC), and total dissolved solids (TDS) can affect water potability, corrosiveness, and its suitability for household and agricultural use (Qureshi *et al.*, 2021; Egbueri and Agbasi, 2022; Masood *et al.*, 2023).

Understanding the dynamics of groundwater quality requires not only an examination of isolated parameters but a holistic, systemic analysis. Parameters such as pH and total hardness (TH) influence the solubility and mobility of toxic metals in groundwater, while high EC and TDS levels often point to saline intrusion or anthropogenic inputs from sewage and solid waste leachates (Rezaei *et al.*, 2020; Vig *et al.*, 2022). Nitrate and phosphate concentrations, especially when exceeding WHO guidelines, signal fecal contamination or agricultural runoff, both of which are prevalent in environments like Ekosodin (Qureshi *et al.*, 2021; Rao *et al.*, 2023). Turbidity, while typically regarded as a secondary aesthetic parameter, also plays a vital role in microbial persistence, as suspended solids can shield bacteria and viruses from disinfection (Masood *et al.*, 2023).

Consequently, a multidimensional approach to groundwater quality assessment is indispensable; one that integrates physicochemical profiling with microbial diagnostics.

The persistence of fecal indicator organisms such as *E. coli* and total coliforms in groundwater is an established marker of compromised sanitation and the potential presence of other pathogens, including enteric viruses and protozoa like *Cryptosporidium* and *Giardia* (Pedley and Howard, 1997; Natishah *et al.*, 2025; Abanyie *et al.*, 2023). These microbes pose a direct risk to public health, particularly in student-dominated settlements where water handling and storage practices may be inadequate. In such environments, outbreaks of gastrointestinal illnesses can spread rapidly due to shared facilities and high population density. Moreover, the identification of verotoxigenic *E. coli* (VTEC) strains, *Salmonella*, and *Shigella* in groundwater samples (though less frequent) is particularly concerning because of their potential to cause severe disease (Chique *et al.*, 2020). Compounding this microbial challenge is the growing presence of antibiotic-resistant bacteria (ARB), which reflect both overuse of antibiotics and environmental dissemination of resistant genes through wastewater and contaminated soil (Andrade *et al.*, 2019). The convergence of ARB with groundwater contamination can be said to be a looming public health crisis that requires urgent scientific investigation and policy intervention.

Despite the urgent need for reliable data, groundwater monitoring in Nigeria remains infrequent and poorly institutionalized. While both WHO and the Nigerian Industrial Standard (NIS) provide robust frameworks for water quality classification, defining safe thresholds for key physicochemical and microbial parameters. Their application in peri-urban contexts like Ekosodin is often hampered by logistical, infrastructural, and financial constraints (Jha *et al.*, 2020; Masood *et al.*, 2023; Sajib *et al.*, 2023). Water Quality Indices (WQIs), which aggregate multiple parameters into a single interpretive score, offer a promising method for communicating risk and guiding intervention. However, the effectiveness of WQIs is contingent on the quality and frequency of data collection, as well as on the capacity of local institutions to act on such assessments

(Singhal *et al.*, 2020; Adimalla, 2021; Mumtaz *et al.*, 2024). Moreover, newer technologies such as GIS mapping, fuzzy logic, and wireless sensors are being employed globally to assess spatial and temporal dynamics in water quality, though their uptake in Nigeria remains limited (Venkatesh *et al.*, 2024; Pham and Nguyen, 2024).

A growing body of empirical research across Nigeria attests to the widespread contamination of groundwater, especially in urban and semi-urban locations. Studies in Edo, Delta, and other states reveal that while some physicochemical parameters may comply with WHO and NIS standards, microbial contamination often remains high, rendering water unsafe for direct consumption (Egbueri, 2019; Olasoji *et al.*, 2019; Mustapha *et al.*, 2024; Adeleke and Faraday, 2024). Contaminants such as lead, cadmium, and arsenic have been detected in concentrations that exceed permissible limits, especially in regions proximate to markets, dumpsites, or mining areas (Abata & Ekwere, 2024; Omeka *et al.*, 2024). Similarly, water samples with acidic pH values (frequently observed in South-Southern Nigeria) may enhance metal solubility and further compromise safety (Adeleke and Faraday, 2024; Aluma *et al.*, 2024). Microbial loads in groundwater remain troublingly high, with coliforms, *Klebsiella*, *Shigella*, and *Staphylococcus* frequently surpassing WHO thresholds (Eyankware *et al.*, 2015; Oyedele *et al.*, 2019).

In light of these findings, the present study positions itself at the intersection of environmental science, public health, and urban studies. By focusing on Ekosodin village, it brings critical attention to the lived realities of students and low-income residents in rapidly urbanizing Nigerian communities, people whose everyday water choices are shaped not by safety or regulation but by availability and affordability. This study is not merely an audit of water quality parameters; it is a diagnostic engagement with a neglected crisis, one that interrogates the adequacy of current monitoring regimes, the pervasiveness of pollution pathways, and the real-world consequences of infrastructural neglect. It seeks to provide both scientific clarity and practical relevance, offering a comprehensive baseline for future interventions, policy recommendations, and

community education. Through its integration of physicochemical analysis, microbial testing, and comparative assessment against both WHO and NIS standards, this research aspires to illuminate not just the current state of groundwater in Ekosodin but the urgent need for a reimagined approach to environmental stewardship in Nigeria.

1.1.2 Statement of Problem

Water is an essential resource for life. Its importance ranges from small-scale domestic usage to a wide range of industrial purposes. However, access to portable water remains a significant challenge both globally and nationally, especially in developing countries like Nigeria. Despite being regarded a fundamental human right (UN, 2010), most urban and peri-urban areas still find it very difficult to have access to portable water. Residents in Peri-urban areas, such as Ekosodin, a densely populated student community, which depend largely on boreholes as their primary source for daily drinking and domestic use still find it difficult to have access to portable water. (Nwankwoala and Eze, 2024; Imarhiagbe *et al.*, 2023).

Despite the essential need for groundwater in this area, increasing human activities such as indiscriminate waste disposal, use of pesticides and herbicides, open defecation, leaking septic tanks, and the proximity of septic tanks to boreholes pose a significant risk to groundwater quality. These activities introduce contaminants like nitrates, coliforms, heavy metals, and other physicochemical parameters, which compromise the safety of this vital water source, especially in poorly regulated boreholes. Studies show that approximately 32.7% of residents, particularly students of the University of Benin, consume water directly from the source without treatment (Imarhiagbe *et al.*, 2023), thereby exposing them to several health challenges, which can deteriorate their academic performance and increase their financial burden due to higher medical expenses.

1.1.3 Justification of study

This study is justified by the increasing dependence of students in Ekosodin on groundwater for daily use, despite limited recent data on its safety and quality. The widespread reliance on groundwater, combined with rising population and pollution, now poses significant health risks for users (Eboagu *et al.*, 2023). As a result, waterborne diseases continue to be a leading cause of illness and death, especially among vulnerable populations (Ugochukwu *et al.*, 2020). Therefore, addressing these health hazards and strengthening community resilience requires targeted solutions based on thorough and reliable local data (Ameh *et al.*, 2025).

Although some research has acknowledged water contamination issues in Ekosodin, there has been no recent in-depth investigation that combines both physicochemical and microbial assessments in student hostels. This absence of data creates uncertainty about the health risks students face from waterborne pollutants such as nitrates, heavy metals, and pathogenic bacteria (Adeyemi and Osinfade, 2021). To resolve this, the present study conducts a detailed evaluation of water quality in student residences, offering direct comparisons with WHO and NIS standards. The findings will help guide health-focused interventions and long-term water safety strategies.

1.1.4 Scope of study

This study is focused on evaluating the quality of groundwater consumed by students residing in selected private hostels within Ekosodin Village, Edo State, Nigeria. The research specifically targets five student hostels located along major student-dense areas such as Edo Street, Newton Street, JB Street, Market Road, and Boundary Road. These locations were selected using a systematic random sampling approach to ensure representative data across the community.

This research is strictly limited to groundwater sources (boreholes) used by students in the selected areas. It excludes non-student residences, bottled or sachet water sources, and public water distribution systems beyond the hostel premises. Additionally, this study

does not explore socio-economic factors influencing water access, except where they are directly related to water quality outcomes.

The study assesses a wide range of parameters, including physicochemical indicators such as pH, temperature, turbidity, total dissolved solids (TDS), electrical conductivity, total hardness, nitrates, nitrites, sulphates, and heavy metals like lead, cadmium, and zinc. Microbiological analysis will focus on the presence of total coliforms and *Escherichia coli* (*E. coli*) and total Heterotrophic Bacteria (THBC).

To assess compliance, the results will be benchmarked against World Health Organization (WHO) and Nigeria Industrial Standard (NIS) drinking water standards. Based on the findings, this research will offer recommendations to enhance water safety and health outcomes among students in the Ekosodin community.

1.1.5 Limitations of the Study

This research is focused on groundwater samples collected from five student hostels in Ekosodin, which may not fully represent the wider community, especially non-student residences. Additionally, the study did not consider seasonal variation, as sampling occurred during only one period, limiting understanding of potential differences between the dry and rainy seasons. Time and resource constraints affected both the range of parameters tested and the number of samples analysed.

Some advanced tests could not be performed due to the lack of necessary laboratory equipment and materials. Furthermore, reliance on portable instruments for field measurements may have introduced minor inaccuracies. Although proper procedures were followed, the chance of small human errors during sample handling and analysis cannot be eliminated.

Nevertheless, these limitations do not compromise the value of the findings but rather indicate areas for further, more extensive investigation.

1.1.6 Aim

This research is designed to systematically analyze the physicochemical and microbiological parameters of groundwater from student hostels in Ekosodin Village.

Objectives of the study are:

1. To collect water samples from the student hostels.
2. To evaluate the physicochemical properties of the water samples, including pH, turbidity, Total Dissolved Solids, Electrical Conductivity, Total Hardness, nitrates, nitrites, sulphates, and heavy metals.
3. To determine the presence of microbiological indicators, particularly coliforms, *E. coli*, and other heterotrophic bacteria in water samples collected from selected student hostels in Ekosodin.
4. To evaluate the conformity of the water's physicochemical and microbiological characteristics with the prescribed drinking water standards from WHO and NIS.
5. To offer recommendations aimed at enhancing water safety and assisting relevant regulatory bodies and local stakeholders in Ekosodin Village.

1.2 LITERATURE REVIEW

1.2.1 WATER: AVAILABILITY, IMPORTANCE, AND CLASSIFICATION:

Water is a clear, tasteless liquid that is essential to life and the growth of the global economy (Okeke *et al.*, 2022; Adesakin *et al.*, 2020). It has the chemical formula H_2O and is made up of one oxygen atom and two hydrogen atoms that are covalently bound together (Garba *et al.*, 2018). Roughly 71% of the planet's surface is made up of water and it is a valuable resource that makes the Earth habitable (Ogbeifun *et al.*, 2019; Garba *et al.*, 2018). Nevertheless, despite its abundance, estimates indicate that only 3% of the world's water is freshwater, and 97% is saltwater. Only 0.01% of this freshwater can be used by humans (Qureshi *et al.*, 2021).

The importance of water goes beyond its abundance, as it plays a vital role in sustaining life. It is very essential for all living organisms, ranging from the simplest microorganisms and plants to complex human beings (WHO, 2011). The human body itself is made up of about 70% water (Zeyneb, 2020). Unlike food, which can be absent for weeks, water is needed daily to replace fluids lost through breathing, sweating, and urination, ensuring normal body functions and survival (Ir *et al.*, 2020).

Beyond its role in human survival, water is equally critical for agriculture, industry, and environmental balance. It is indispensable for sufficient food production and for sustaining healthy ecosystems that support all forms of life (Zeyneb, 2020). Its diverse use in all sectors makes it a clear driver of economic development.

Water resources can be broadly classified according to their location. They are divided into two main types: surface water and groundwater (Okeke *et al.*, 2022; Nzelibe *et al.*, 2022). Groundwater, found beneath the Earth's surface, includes sources such as wells, springs, and boreholes, while surface water, located above ground, comprises streams, wetlands, and reservoirs (Nnaji *et al.*, 2016, as cited in Okeke *et al.*, 2022).

1.2.2 GROUNDWATER RESOURCES: ROLE, RELEVANCE, AND APPLICATIONS

Groundwater is the water stored beneath the Earth's surface in soil pores and rock fractures, commonly accessed through wells, boreholes, and springs (Ogbeifun *et al.*, 2019). When pumped to the surface using a network of pumps, it is referred to as borehole water (Obuekwe *et al.*, 2021). Globally, groundwater is the most extracted raw resource, with an annual withdrawal of about 982 km³. It serves as a source of drinking water for approximately 31.5% of the world's population, around 2.2 billion people (Andrade *et al.*, 2018).

Beyond its current use, groundwater plays a vital role in addressing global water challenges. As the world's largest distributed store of freshwater, it is well positioned to support societies in adapting to intermittent and prolonged water shortages caused by climate change (Pointet, 2022).

The increasing reliance on groundwater is partly due to the vulnerability of surface water sources. Surface water reservoirs are easily exposed to contaminants from various sources and are experiencing severe degradation worldwide (Magha *et al.*, 2021). Consequently, groundwater has become a preferred source globally.

In addition to domestic uses, groundwater is essential for agriculture and industry. It supports irrigated farming and indirectly contributes to food security, while also serving as a vital resource for various industrial purposes (Grönwall and Danert, 2020).

1.2.3 GROUNDWATER AS A KEY RESOURCE: GLOBAL TRENDS AND LOCAL REALITIES

Groundwater is the largest readily available source of drinking water worldwide. It supplies nearly 50% of global drinking water and serves as the sole source for the everyday needs of about 2.5 billion people (UNESCO, 2012; Zekster *et al.*, 2004, as cited in Grönwall and Danert, 2020). In countries like India and Bangladesh, groundwater is the main source of drinking water for 85% of the population, with tubewells being particularly significant in rural Bangladesh (Ali *et al.*, 2019; Hoque *et al.*, 2019, as cited in Grönwall and Danert, 2020). Similarly, in the United States, it serves as a source of drinking water to about 38% of the population (138.5 million people) (US EPA, 2015).

In sub-Saharan Africa, groundwater use is increasingly recognized as a key resource for meeting growing urban water demands. However, the use of boreholes as a primary drinking water source varies significantly across countries. Less than 5% of urban populations in Namibia, South Africa, and Botswana use boreholes, compared to over 25% in Nigeria, Liberia, Togo, Chad, and South Sudan (Foster *et al.*, 2018; Lapworth *et al.*, 2017; MacDonald *et al.*, 2012; Cobbing *et al.*, 2020, as cited in Danert and Healy, 2021a, 2021b).

In Nigeria, groundwater has become indispensable due to inadequate surface water systems and the pressures of urbanization. It is estimated to provide more than 60% of the nation's domestic water supply (Adewumi *et al.*, 2024).

At the community level, places like Ekosodin in Edo State demonstrate an even greater dependence on groundwater. With a population of about 45,000, approximately 90% of residents rely entirely on boreholes for their daily water needs, including drinking, cooking, and farming. This heavy reliance is primarily due to the absence of functional public water supply infrastructure (Nwankwoala and Eze, 2024; Imarhiagbe *et al.*, 2023).

1.2.4 SOURCES AND FACTORS INFLUENCING UNDERWATER CONTAMINATION.

Although groundwater often appears pure, it can contain significant amounts of dissolved chemicals that affect its quality (G. Beyene *et al.*, 2019). The quality of groundwater depends on both natural and human (anthropogenic) factors (Zhang *et al.*, 2020). Similar to surface water, groundwater is vulnerable to contamination due to the proximity of the water table to the soil surface and the presence of numerous surface pollution sources (Singh *et al.*, 2013, as cited in Irobehian *et al.*, 2023).

Groundwater quality can vary based on several factors, including location, season, soil and rock characteristics, and water flow paths. As water moves through mineral-rich sediments, naturally occurring metals such as iron and manganese may dissolve, sometimes reaching high concentrations (Akerele *et al.*, 2023).

Human activities have further intensified groundwater pollution risks. Rapid population growth, urbanization, industrialization, agricultural production, and economic expansion have all contributed to the release of contaminants of anthropogenic origin (Peiyue *et al.*, 2021). Wastewater from domestic, industrial, and public sources can seep into groundwater through damaged canals, poorly constructed boreholes, or directly through the soil (Soceanu *et al.*, 2021). Additionally, pollution can occur due to saltwater intrusion, septic tank leaks, landfill waste, farming activities, and chemical usage (Qureshi *et al.*, 2021).

Groundwater pollution occurs when these contaminants infiltrate and reach underground water sources. Once an aquifer becomes polluted, the contamination is difficult to detect and even harder to clean up. Unlike surface water, groundwater contamination is often invisible. Aquifers tend to remain polluted for long periods even after the pollution source has been removed (Obuekwe et al., 2021; Ojekunle et al., 2020).

Major sources of groundwater contamination can be broadly categorized as follows:

- **Inadequate Sanitation and Waste Disposal**

Poorly constructed or absent latrines, as well as improper disposal of domestic wastewater and solid waste, are primary contributors to groundwater pollution. These practices enable the seepage of pathogens (e.g., *E. coli*, *Enterobacter*, *Salmonella*) and nutrients such as nitrates and phosphates into groundwater. Such contamination is especially prevalent in densely populated or peri-urban areas (Sojobi, 2016; Egbueri, 2019; Atemoagbo, 2024; Awomeso et al., 2020; Fatokun *et al.*, 2024).

- **Agricultural Activities**

The intensive use of agrochemicals, including both inorganic and organic fertilizers, leads to elevated concentrations of nitrates, phosphates, and other chemical contaminants in groundwater. Runoff from farms and leaching through soils are the primary pathways for these pollutants (Egbueri, 2019; Awomeso *et al.*, 2020).

- **Industrial and Urban Runoff**

In peri-urban and urbanized areas, groundwater quality is degraded by the infiltration of industrial effluents and over-exploitation of groundwater resources. The absence of proper drainage systems further exacerbates this problem (Ojo *et al.*, 2024).

- **Natural (Geogenic) Sources**

The natural weathering of bedrock and the dissolution of minerals in clayey aquifers can release heavy metals such as lead, cadmium, iron, and manganese into groundwater. In some cases, these elements occur at concentrations exceeding safe drinking limits (Sojobi, 2016; Ganiyu *et al.*, 2021; Awomeso *et al.*, 2020; Akoji, 2019; Egbueri *et al.*, 2024).

1.2.5 GLOBAL WATER CRISIS: IMPACTS OF CONTAMINATION AND POOR SANITATION ON PUBLIC HEALTH:

Although water covers nearly two-thirds of Earth's surface, access to safe water remains a major challenge, particularly in developing regions. Globally, contaminated water and poor sanitation claim about 1.6 million lives each year, 90% of whom are children under five, with the majority of these deaths occurring in Africa, South America, India, and Southeast Asia (World Bank, 2021; WHO/UNICEF, 2012, as cited in Magha *et al.*, 2021). Waterborne illnesses caused by groundwater contamination alone account for over 1.2 million deaths annually, and this figure could exceed 135 million in the coming years if effective interventions are not implemented (Akerele *et al.*, 2023).

The burden is especially severe in developing countries. About 80% of diseases in these regions are waterborne due to the consumption of contaminated water (Khan *et al.*, 2013). Approximately 800 million people in Asia and Africa lack access to clean water for drinking and daily use, leaving them vulnerable to

harmful pathogens and toxic substances (Qureshi et al., 2021). The lack of adequate water quality monitoring and treatment leads to the widespread use of untreated water, contributing significantly to waterborne diseases (WHO & UNICEF, 2019).

The health effects of unsafe water are severe and wide-ranging. Poor water quality can lead to diseases such as diarrhea, helminth infections, schistosomiasis, trachoma, poliomyelitis, cholera, dysentery, and typhoid (Akerele et al., 2023; WHO & UNICEF, 2019). Excessive concentrations of nitrates and arsenic in water pose additional risks. For example, nitrate-rich drinking water used to prepare infant formula can cause infant methemoglobinemia, also known as “blue baby syndrome,” a condition that reduces the blood’s oxygen-carrying capacity (Peiyue et al., 2021; He et al., 2020).

Microbial contamination is a major contributor to waterborne illnesses. Pathogens such as *Salmonella spp.*, *Shigella spp.*, *Vibrio cholerae*, and *Escherichia coli*, often introduced into water bodies through fecal contamination, cause widespread waterborne diseases (Obuekwe et al., 2021). Many of these illnesses spread through the fecal-oral route, while others, such as schistosomiasis and trachoma, are transmitted through skin or eye contact (Strickland, 2000, as cited in Imarhiagbe et al., 2023).

Industrial pollution often causes several health risks. In industrial areas such as Ota and Shagamu, increasing levels of pollutants from various factories infiltrate soil and groundwater, degrading water quality and leading to several health challenges. Residents who use this untreated water often experience skin problems such as rashes, boils, and itching as well as severe joint pain in the hips and knees (Ojekunle et al., 2020).

Heavy metal contamination also poses significant health risks. Elevated blood lead (Pb) levels can cause brain damage, irritation, and plumbism, while long-term

exposure to cadmium (Cd) may lead to tubular proteinuria (Edori and Edori, 2012, as cited in Irobehian *et al.*, 2023).

The widespread consumption of untreated or contaminated water continues to impose a heavy burden of preventable diseases. These include diarrhoea, cholera, dysentery, typhoid, polio, and other severe infections (Wami *et al.*, 2022). Improving water quality monitoring, sanitation infrastructure, and pollution control measures remains crucial in reducing these public health challenges.

1.2.6 PHYSICOCHEMICAL PARAMETERS IN GROUNDWATER QUALITY ASSESSMENT

Assessing groundwater quality relies on measuring key physicochemical parameters, which provide essential information about water safety for drinking, irrigation, and other uses (G. Beyene *et al.* 2019). Some commonly used parameters include pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), major cations and anions, and Heavy metals. These indicators help determine if water meets health and safety standards.

1.2.6.1 Common Physicochemical Parameters and Their Significance

pH

pH is a fundamental indicator of water quality, indicating its acidity or alkalinity on a scale of 0 to 14. A pH of 7 indicates neutrality; values below and above this are considered acidic and alkaline, respectively (Ikuesan and Balogun, 2022). WHO (2006) recommends a pH range of 6.5–8.5 for drinking water. Deviations can affect taste, corrosion, and the solubility of metals (Qureshi *et al.*, 2021; Egbueri and Agbasi, 2022; Rezaei *et al.*, 2020; Rezaei and Hassani, 2018; Alogayell *et al.*, 2023; Vig *et al.*, 2022; Masood *et al.*, 2023). Although pH does not directly affect

human health, it influences other water properties and reactions, such as corrosion potential and the solubility of metals (Qureshi *et al.*, 2021; Egbueri and Agbasi, 2022).

TEMPERATURE:

Temperature is regarded as the degree of hotness or coldness of a substance. The temperature of water is not particularly the main issue when considering it as a physical parameter, but its effect on other properties (Ikeme *et al.*, 2014).

Increase in temperature affects various biological, chemical, and physical activities in water. It notably decreases the solubility of essential gases such as oxygen (O₂), carbon dioxide (CO₂) and nitrogen (N₂) (Yilmaz *et al.*, 2014). High water temperature also negatively impacts water quality by fostering the rapid growth of microorganisms, which can lead to issues with taste, odor, color, and increased corrosion (Ogbeifun *et al.*, 2019).

TURBIDITY:

Turbidity measures the clarity of water, indicating the presence of suspended particles, such as silt, clay, organic matter, and microorganisms. These suspended particles can harbor pathogens and reduce water clarity, rendering highly turbid water unsuitable for drinking (Qureshi *et al.*, 2021; Masood *et al.*, 2023).

ELECTRICAL CONDUCTIVITY:

Electrical Conductivity (EC) is a measure of water's ability to conduct electricity. EC increases with the concentration and types of dissolved salts or charged chemicals, reflecting the overall dissolved ionic content (Ogbeifun *et al.*, 2019; Talab *et al.*, 2025). Deviations in EC can impact water taste, contribute to pipe corrosion, and influence the solubility of metals (Qureshi *et al.*, 2021; Egbueri and

Agbasi, 2022; Rezaei *et al.*, 2020; Rezaei and Hassani, 2018; Alogayell *et al.*, 2023; Vig *et al.*, 2022; Masood *et al.*, 2023).

TOTAL DISSOLVED SOLIDS (TDS):

Total Dissolved Solids (TDS) quantifies the total amount of all dissolved inorganic and organic substances in water. These includes various cations and anions such as carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, and sodium (Uwidia *et al.*, 2013; Adesakin *et al.*, 2020). While high TDS can indicate hard water, it does not necessarily mean the water is contaminated or non-potable (Adesakin *et al.*, 2020). Conversely, low TDS does not guarantee that the water is uncontaminated, as it does not account for certain heavy metals like lead and chromium or pharmaceutical waste (Talab *et al.*, 2025). However, TDS levels above the WHO-recommended limits can significantly affect the taste of drinking water.

TOTAL HARDNESS:

The total hardness of water is primarily determined by the presence of calcium and magnesium ions (Ojekunle *et al.*, 2020). Generally, in terms of hardness, water is classified as soft (<75 mg/L CaCO₃), medium-hard (75-150 mg/L CaCO₃), hard (150-300 mg/L CaCO₃), and very hard (>300 mg/L CaCO₃) (G. Beyene *et al.*, 2019). Hardness levels above 200 mg/L can lead to scale formation, especially when water is heated, whereas soft water with hardness below 100 mg/L can be corrosive to pipes due to low buffering (G. Beyene *et al.*, 2019).

Hard water is not suitable for cooking, washing, bathing as well as other industrial and agricultural uses (Sawant *et al.*, 2012)

SPECIFIC ANIONS (NITRATES, NITRITES AND SULPHATES):

Sulphates, a form of salt, can give groundwater a salty taste when present in high levels. Such concentrations may lead to dehydration, vomiting, and gastrointestinal issues. According to WHO, the acceptable limit for sulfate is 250 mg/L.(Qureshi *et al.*, 2021).

Nitrogen exists in the soil in the forms of nitrate, nitrite, and ammonium and can easily move into the groundwater by leaching effects(Soceanu *et al.*, 2021). Nitrate is a common form of nitrogen in natural waters, which can be biochemically reduced to nitrite, often under anaerobic conditions (Adubor *et al.*,2025).

Nitrite interferes with the oxygen carrying capacity of the blood of infants leading to methemoglobinemia or ‘blue baby syndrome’ (Shapiro *et al.*, 2005). Nitrates can also react with amines and amides in the body to form carcinogenic nitrosoamines (Eletta *et al.*, 2010).

Nitrate in groundwater is a key sign of human-related pollution, mainly from agricultural activities and soil nitrogen mineralization. Non-agricultural sources including septic systems, lawn fertilizers, nitrogen-rich effluents, also contribute to this contamination (Shakerkhatibi *et al.*,2019).

According to WHO, the recommended value of nitrates and nitrites is 50 mg/L and 0.2 mg/l respectively. Deviation can lead to issues such as diuresis, increased starch deposits, and splenic hemorrhaging (Reimann *et al.*, 2003; Eletta *et al.*, 2010)

HEAVY METALS (Pb, Cd, Zn):

Heavy metals (HMs), specifically defined by specific gravities greater than 5 and atomic densities larger than 4 g/cm³ (Barzegar *et al.*, 2015; Ganiyu *et al.*, 2017; Enuneku *et al.*, 2018; Kumar *et al.*, 2020). Heavy metals are well-known pollutants due to their persistence, toxicity, and tendency to accumulate in living organisms and the environment (Shakerkhatib *et al.*,2019). Some of these metals are vital for

metabolic processes in plants and animals at low concentrations. However, their presence in elevated concentrations profoundly affects water quality, becoming toxic and threatening human lives (Drasovean and Murariu, 2021). For example, too much lead can disrupt the nervous and reproductive system, causing high blood pressure and anaemia (Igboekwe *et al.*, 2013).

Their major sources include volcanic eruption, weathering of metal-bearing rocks, anthropogenic activities such as; industrialization, mining and agricultural practices (Ojekunle *et al.*, 2020).

1.2.7 MICROBIAL PARAMETERS IN GROUNDWATER QUALITY ASSESSMENT

Groundwater in developing countries frequently contains diverse microbial organisms, primarily due to inadequate sanitation and poor waste management. These include bacteria (especially fecal bacteria), viruses, and sometimes protozoa, all posing substantial public health risks (Adesakin *et al.*, 2020)). The World Health Organization (WHO) explicitly recommends zero fecal coliforms in 100 ml of drinking water (Ogbeifun *et al.*, 2019). Therefore, detecting coliforms in drinking water indicates Fecal contamination (Uhuo *et al.*, 2014), which introduces pathogens which make the water unsuitable for drinking. Pathogens such as; Salmonella, Shigella, Vibrio cholerae, and E. coli, in water sources, leads to diseases such as typhoid, cholera, and diarrhea (Adesakin *et al.*, 2020).

1.2.8 INTERNATIONAL AND NATIONAL REGULATORY STANDARDS FOR DRINKING WATER (WHO AND NIS)

Standards are risk management strategies developed at national and regional level from the scientific basis provided in the guidelines (WHO,2011) as cited in (G. Beyene *et al.*,2019).

The duty of ensuring safe drinking water requires cooperation between national authorities and international organizations. In Nigeria, the Nigeria Industrial Standard (NIS) outlines acceptable levels of physical, chemical, and microbiological substances in drinking water. On a global level, the World Health Organization (WHO) provides internationally recognized guidelines for drinking water quality, developed through thorough scientific evaluation. These guidelines establish safe limits for pollutants such as nitrates, toxic metals, and microbes, serving as a benchmark for national policies. Both NIS and WHO are essential in advancing water safety by offering standardized procedures for monitoring, treatment, and regulation.

Table 1.1: Key Standards for Safe Groundwater Quality

Parameters	NIS Limit (Nigeria)	WHO Guideline Value
pH	6.5-8.5	6.5-8.5
Temperature	Ambient	—
Turbidity	5 NTU	5 NTU
Electrical Conductivity (EC)	1000 μ S/cm	\sim <1000 μ S/cm
Total Dissolved Solids (TDS)	500 mg/L	<500 mg/L
Total Hardness	150 mg/L	500 mg/L

Lead (Pb)	0.01 mg/L	0.01 mg/L
Zinc (Zn)	3 mg/L	3 mg/L
Cadmium (Cd)	≤0.003 mg/L	0.003 mg/L
Nitrate (NO ₃ ⁻)	≤50 mg/L	50 mg/L
Nitrite (NO ₂ ⁻)	3 mg/L	3 mg/L
Sulphate (SO ₄ ²⁻)	250 mg/L	250 mg/L
E. coli	0 CFU/100 mL	0 CFU/100 mL
Total Coliforms	0 CFU/100 mL	0 CFU/100 mL

These standards set maximum allowable limits for key chemical and microbial parameters to ensure water is safe for human consumption. They are central to water quality monitoring and management.

1.2.9 PHYSICOCHEMICAL AND MICROBIAL QUALITY OF GROUNDWATER IN NIGERIA: A REVIEW OF REGIONAL CASE STUDIES

In Nigeria, groundwater remains a critical source of drinking water, particularly in rural and peri-urban areas where access to treated municipal water is limited. However, growing concerns about its safety continue to surface, with researchers drawing attention to both physicochemical and microbial contamination of this precious resource.

In a study carried out in Etsako East Local Government Area of Edo State, Irobehian *et al.* (2023) observed that groundwater samples from boreholes exhibited acidic pH levels alongside detectable concentrations of heavy metals like lead (Pb) and cadmium (Cd). Long-term exposure to such contaminants has been linked to serious health issues, including kidney damage, cardiovascular complications, and cancer. Their findings also revealed the presence of harmful microorganisms, rendering the water unsuitable for drinking without proper

treatment. Ogbeifun *et al.* (2019) conducted a similar study across three local government areas in Benin City, Oredo, Egor, and Ovia North-East. They reported that, although most physicochemical parameters fell within the World Health Organization (WHO) standards for potable water, the pH levels in some samples were lower than recommended. Despite this, the researchers concluded that borehole water in those regions was generally not dangerous for human consumption.

The issue of microbial contamination is far from isolated. Recent findings by Fakotun *et al.* (2024) in Ipetumodu, Osun State, exposed a troubling load of bacteria in groundwater samples, many of which were resistant to multiple antibiotics. The microbial levels exceeded both WHO and SON (Standards Organization of Nigeria) permissible limits, raising serious concerns about public health. Ekhosuehi *et al.* (2018) reported similar discoveries in Ekosodin, Edo State, where water sources contained multidrug-resistant bacteria. These pathogens not only compromise health but also make treatment more difficult due to their resistance patterns.

Adeleke *et al.* (2024) further reinforced this concern with findings from Ondo State, where coliform bacteria were present in all sampled groundwater sources. In many rural settings, residents depend on springs, hand-dug wells, and shallow ponds, sources highly vulnerable to contamination. Combined with inadequate sanitation facilities and persistent open defecation, the risk of disease outbreaks becomes significantly heightened. Amaibi *et al.* (2022) highlighted this connection in their report, emphasizing the urgency of improved sanitation to prevent such outbreaks. Another case study from Ughelli in Delta State by Eyankware *et al.* (2015) supports this narrative. While most chemical parameters in their samples were within safe limits, the presence of microbial contaminants in several wells called the water's safety into question. Adesakin *et al.* (2020), studying Samaru in Zaria, came to similar conclusions. They found both acidic water and microbial

contamination in groundwater sources serving the Ahmadu Bello University community and nearby Zaria Aviation School.

Interestingly, consistently low pH levels seem to be a recurring concern. For example, Ogbeifun *et al.* (2019) confirmed acidic pH levels in samples from Benin City. Similarly, Sojobi (2016) attributed acidic groundwater in Omu Aran, North Central Nigeria, to underlying geological factors. This study also noted elevated levels of nitrate and lead, suggesting a need for water pretreatment before consumption. The researcher further pointed out that poorly constructed boreholes and close proximity to waste discharge points increase the risk of organic contamination.

Heavy metal pollution is another issue gaining attention, especially near industrial zones and mining areas. Irobehian *et al.* (2023) reported high concentrations of lead and cadmium in samples from Etsako East LGA, along with abnormal pH values. Likewise, Oni and Hassan (2013) found groundwater from Aba-Eku, a dumpsite in Ibadan, to contain unsafe levels of lead, cadmium, and iron, necessitating urgent environmental cleanup. Studies by Okeke *et al.* (2022) in Ebonyi State and Ojekunle *et al.* (2020) in Ogun State arrived at similar conclusions, linking contamination to industrial and mining activities.

In Ekosodin village, the lack of essential Water, Sanitation, and Hygiene (WASH) services adds another layer to the crisis. Rawlings *et al.* (2022) highlighted this deficiency, citing poor water treatment infrastructure and waste management. Supporting this, Imarhiagbe *et al.* (2023) surveyed households in Ekosodin and found that nearly 73% relied on boreholes for drinking water, yet only a small fraction boiled it before use. Alarming, 63% of the respondents had never tested their water, often out of ignorance. Waste disposal practices were also found wanting, about 83% of residents reported burning waste due to a lack of centralized collection. Health issues were prevalent too, with two-thirds of participants reporting episodes of vomiting, and one-third of them experiencing it frequently.

In conclusion, while groundwater remains indispensable for millions in Nigeria, its safety cannot be taken for granted. The studies highlighted above make it clear that both microbial and chemical contaminants are widespread, often worsened by poor sanitation, insufficient infrastructure, and human activity. Without meaningful interventions in water quality monitoring, sanitation improvement, and public awareness, the risks to public health are likely to increase.

CHAPTER TWO

MATERIALS AND METHODS

2.1 MATERIALS

2.1.1 REAGENTS

Hydrazine Sulphate

Hexamethylene Tetramine

Brucine Sulphate

Acetic acid

Anhydrous potassium nitrate

Concentrated Sulphuric acid

Sulphanilamide

N-(1-naphthyl) ethylenediamine dihydrochloride

Phosphoric acid

Sodium nitrite

Starch

Concentrated Hydrochloric Acid (6M)

Barium Chloride

Anhydrous Sodium Sulphate

2.1.2 APPARATUS

Mercury Thermometer

pH meter (HACH)

Conductivity Meter (DSS-307)

UV-Vis spectrophotometer (JENWAY 6320D)

Atomic Absorption Spectrophotometer (210 VGP)

Analytical balance

Wash bottle

Conical flasks (100ml)

Beakers (100ml)

Funnel

Tissue paper

Glass rod

Pipette (25ml)

Measuring Cylinder (100ml)

Volumetric flasks (100ml)

2.2 METHODOLOGY

2.2.1 SAMPLE COLLECTION AND PREPARATION

2.2.1.1 Sample site:

This study was conducted in Ekosodin, a village located in the Ovia North East Local Government Area of Edo State, Nigeria. Ovia North-East LGA covers an area of 2,301 square kilometers, with its headquarters in Okada town, situated along longitude $5^{\circ} 45'$ and $6^{\circ} 15'$ east, and latitude $5^{\circ} 15'$ and $6^{\circ} 45'$ north of Edo State's central region. Ekosodin is mainly inhabited by students who reside outside the University of Benin's residential hostels, with borehole water being the primary source for drinking and other domestic needs. Besides the students, most other residents of Ekosodin are either farmers or traders.



Figure 2.1: Map of Ekosodin in Ovia-North East LGA, Benin City, Edo State.

Source (A. Rawlings and S. Seghosime, 2022)

2.2.1.2 Sample Collection and Preservation

Water samples were collected from five hostels in student-populated regions of Ekosodin village: Edo Street, Newton Street, JB Street, Market Road, and Boundary Road. The grab sampling technique was employed to collect water samples. The sample collection was a single event. Proper preservation and handling of samples were ensured under standard laboratory protocols before analysis. Each borehole was allowed to run for two minutes to clear out any stagnant water before collecting the water samples into sterilized containers following standard sampling procedures (APHA, 2017). Samples for bacterial analysis and physicochemical tests were collected in pre-cleaned 30ml sampling bottles and 2-liter plastic containers, respectively. All samples were properly labeled and immediately transported to the laboratory in an ice-filled cooler to maintain a stable temperature of 4°C until analysis.



Figure 2.2: Sample collection

Table 2.1 Sample location and code and Description

Sample Location	Sample Code	Site Description
Edo Street (E)	E1	Sample 1
	E2	Sample 2
	E3	Sample 3
Market Road (M)	M1	Sample 1
	M2	Sample 2
	M3	Sample 3
Newton Road (N)	N1	Sample 1
	N2	Sample 2
	N3	Sample 3
J.B Road (J)	J1	Sample 1
	J2	Sample 2
	J3	Sample 3
Boundary Road (B)	B1	Sample 1
	B2	Sample 2
	B3	Sample 3

2.2.2 DETERMINATION OF PHYSICOCHEMICAL PARAMETERS

2.2.2.1 Temperature (°C)

A Celsius thermometer (mercury-in-glass centigrade thermometer, 0°C - 110°C) was used to determine the temperature. The thermometer was vertically immersed with the bulb containing the mercury in the water sample for about five (5) minutes. The readings were obtained after the mercury column attained equilibrium. (Aremu *et al.*, 2024).

2.2.2.2 Determination of pH

The sample's pH was measured using a pre-calibrated portable pH meter. The pH probe was inserted into the sample, allowed to stabilize, and the steady pH value was recorded. After each measurement, the pH probe was rinsed with distilled water and wiped with clean tissues before being placed into another sample to prevent contamination. Measurements were made in triplicate, and the average values were recorded. (Aremu *et al.*, 2024)

2.2.2.3 Determination of Electrical Conductivity

A multi-range conductivity meter was used to measure the electrical conductivity (EC) of the water samples. The electrode was properly rinsed with distilled water before taking the measurement. For every subsequent set of water determination, the electrode was rinsed at each interval. Data were obtained from the readings in $\mu\text{S cm}^{-1}$. (Nsi *et al.*, 2020)

2.2.2.4. Determination of total dissolved solids (TDS):

The TDS level of the samples was measured using the same device as the EC. A conversion factor (K) of 0.64 was applied. (Aweto *et al.*, 2018; as cited in Akpan *et al.*, 2020)

2.2.2.5 Determination of Turbidity

The turbidity of the water sample was measured using a UV-VIS spectrophotometer. A 400 NTU turbidity standard was prepared by dissolving 0.1 g of hydrazine sulfate and 1 g

of hexamethylene tetramine in 10 mL of water in separate beakers. Both solutions were mixed and allowed to stand for 24 hours. They were then diluted to 200 mL with distilled water. Next, different concentrations of working standards were prepared by pipetting calculated volumes of the 400 NTU standard into 100-mL volumetric flasks and filling to the mark with distilled water.

For the analysis, 100 mL of each sample and standard was measured into pre-cleaned beakers. The absorbance of both the working standards and the samples was read at a wavelength of 420 nm using the UV-VIS spectrophotometer. A calibration curve (see figure A1 in the appendix) was plotted using the absorbance values from the turbidity standards. The turbidity of the water samples was calculated from the calibration curve. (APHA, 2017; USEPA, 1983)

2.2.2.6 Determination of Total Hardness:

Calcium and magnesium ions were analyzed using the AAS (Ezechinyere *et al.*,2023). The total hardness was then calculated using the formula below from the measured values.

Total Hardness = $2.497[\text{Ca}(\text{mg/l})] + 4.118[\text{Mg}(\text{mg/l})]$ (Health Canada,2025).

2.2.2.7 Determination of Nitrates

The concentration of nitrate in water samples was determined using the Brucine Sulphate Method.

Brucine sulfate reagent was prepared by dissolving 0.2 g of brucine sulfate in 100 mL of concentrated sulfuric acid. Stock nitrate solution of 1000 ppm was prepared by dissolving 0.163g of potassium nitrate (KNO_3) in distilled water and making up the volume to 100ml mark in a volumetric flask.

From the stock solution, intermediate standards at 100 ppm and 10 ppm were prepared by diluting calculated volumes of the 1000 ppm and 100 ppm solutions, respectively.

Several working standards of calculated volumes were pipetted from the 10ppm intermediate stock solution into different 100ml standard flasks and were made up to mark.

For the analysis, 10 mL aliquots of each sample and working standard were transferred into separate, clean beakers. To each beaker, 2 mL of the prepared brucine sulfate reagent and 10 mL of concentrated sulfuric acid were carefully added. The mixtures were gently stirred to ensure homogeneity and allowed to stand undisturbed for 20 minutes at room temperature to enable complete color development.

The absorbance of each solution was measured at 470 nm using a UV-Visible spectrophotometer. A calibration curve (see figure A4 in the appendix) was generated from the absorbance values of the nitrate standards. The nitrate concentrations in the water samples were then calculated from the standard calibration curve. (APHA, 2017)



Figure 2.3: Prepared Nitrate Standards for calibration

2.2.2.8 Determination of sulphates:

The determination of sulphate concentration in water samples was carried out using the Turbidimetric method.

Preparation of Reagent and Standard

A conditioning reagent was prepared by initially dissolving 10g of starch in 100ml of boiled distilled water. Then, 5ml of this starch solution was mixed with a solution

containing 3ml of concentrated hydrochloric acid, 30ml of distilled water, and 7.5g of Barium Chloride.

A 1000 ppm stock sulfate solution was prepared by precisely weighing 0.1479 g of analytical-grade anhydrous sodium sulfate, dissolving it in a small amount of distilled water, and then diluting the solution to 100 mL in a standard measuring flask. From this stock solution, a 100ppm intermediate standard was made using the dilution formula.

A series of sulphate solution standards was prepared from the 100 ppm intermediate solution.

For the analysis, 10 mL aliquots of the water samples and each working standard were transferred into clean volumetric flasks, and 1 mL of the conditioning reagent was added to each. The mixtures were thoroughly shaken for 30 seconds to ensure homogeneity and then allowed to stand undisturbed for 10 minutes to enable complete turbidity development.

The absorbance of the standards and samples was measured at a wavelength of 420 nm using a UV-Vis spectrophotometer. A calibration curve (see figure A3 in the appendix) was created using the absorbance values obtained for the sulfate standards. The sulfate concentrations in the water samples were then determined from the standard calibration curve (APHA, 2012).



Figure 2.4: Preparation of sulphate standards for Calibration

2.2.2.9 Determination of Nitrites:

The determination of nitrite concentration in water samples was carried out using the Griess Reaction Method.

The color reagent was prepared by adding 10 mL of 85% phosphoric acid and 1 g of sulfanilamide to 80 mL of water. Once the sulfanilamide had fully dissolved, 0.1 g of N-(1-naphthyl)-ethylenediamine dihydrochloride was added and stirred until completely dissolved. The solution was then diluted to a final volume of 100 mL with distilled water.

A 1000 ppm stock solution was prepared by accurately dissolving 0.1499 g of sodium nitrite (NaNO_2) in distilled water and diluting to 100 mL in a volumetric flask.

Intermediate standards of 100 ppm and 10 ppm were prepared from the stock solution by diluting calculated volumes of the 1000 ppm and 100 ppm solutions, respectively.

Several working standards of calculated volumes were pipetted from the 10ppm intermediate stock solution into different 100ml standard flasks and were made up to mark.

For the analysis, 10 mL aliquots of each sample and working standards were transferred into clean conical flasks. To each, 1 mL of the prepared color reagent was added, and the mixture was thoroughly mixed. The solutions were then allowed to stand for at least 15 minutes to enable full color development.

The absorbance of standards and samples was measured at 540 nm using a UV-VIS spectrophotometer, with a blank as a reference. A calibration curve (see figure A2 in the appendix) was created using the absorbance values from the nitrite standards. The nitrite concentrations in the water samples were then determined from the standard calibration curve (USEPA, 1983; APHA, 2017).



Figure 2.5: Prepared Nitrite Standards for calibration

2.2.2.10: Determination of Trace Metals (Zn, Pb, Cd):

30ml each of the samples was measured into a sample can and was subsequently analyzed for heavy metals using atomic absorption spectroscopy (AAS). (Nsi et al.,2020)

2.2.2.11: Microbial Analysis

The pour plate technique (using heterotrophic plate count) was used to detect and count total coliforms and fecal coliforms present. A factor of 10^{-3} diluted each sample, and 1 ml of the diluent was plated on nutrient agar in triplicate. The analysis was performed in triplicate for each sample to ensure accuracy. The plates were inverted and incubated at 37 °C for 24–48 hours under aerobic conditions. The total viable count (TVC) was recorded in colony-forming units per milliliter (CFU/ml). (Egbueri,2019).

The number of colony-forming units per milliliter (cfu/ml) was calculated using the formula below:

Phenotypic Identification of Bacteria from Samples

Pure cultures of the bacterial isolates were obtained from the subculture of a single colony from the successful pour plate technique and were characterized using cultural, morphological and biochemical methods. Several tests, such as Gram reaction, catalase, urease, indole, oxidase, citrate utilization and respective reactions of bacteria on triple sugar iron agar, were carried out to identify bacterial isolates presumptively (Holt *et al.*, 1994).

CHAPTER THREE

3.0 RESULTS AND DISCUSSION

3.1.1 RESULTS FROM PHYSICOCHEMICAL AND MICROBIAL ANALYSIS

Table 3.1: Triplicate Result from physicochemical analysis

Parameters	Sample locations														
	E1	E2	E3	M1	M2	M3	N1	N2	N3	J1	J2	J3	B1	B2	B3
Ph	6.00	5.70	5.60	7.20	7.20	7.10	7.10	6.80	6.70	7.30	7.20	7.10	7.50	7.10	7.00
Temperature (°C)	27.90	28.00	27.80	26.00	26.30	25.90	26.90	26.50	26.80	26.30	26.00	26.50	26.70	26.50	26.70
Turbidity (NTU)	4.75	4.00	4.40	1.25	1.00	1.30	0.75	1.00	1.20	2.75	2.50	2.90	1.25	1.50	1.30
Conductivity (µS/cm)	145.2	144.4	142.7	83.00	81.00	92.90	18.00	18.10	18.80	16.10	16.00	16.30	120.0	117.0	120.2
TDS (mg/l)	92.93	92.42	91.33	53.12	51.84	59.46	38.53	11.58	12.03	10.30	10.24	10.43	76.8	74.88	76.93
Calcium (mg/l)	0.10	0.10	0.09	0.10	0.11	0.10	ND	ND	ND	0.40	0.38	0.41	ND	ND	ND
Magnesium (mg/l)	0.66	0.70	0.58	0.01	0.01	0.03	0.04	0.03	0.04	0.01	0.04	0.01	0.49	0.47	0.50
Hardness (mg/l)	2.97	3.13	2.61	0.29	0.316	0.37	0.16	0.12	0.16	1.04	1.11	1.06	2.02	1.94	2.06
Nitrite (mg/l)	0.02	0.01	0.03	0.01	0.01	0.02	0.01	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.02

Parameters	Sample locations														
	E1	E2	E3	M1	M2	M3	N1	N2	N3	J1	J2	J3	B1	B2	B3
Nitrate (mg/l)	8.94	8.91	8.96	3.17	3.19	3.18	2.88	2.85	2.89	3.50	3.51	3.49	7.67	7.65	7.69
Sulphate (mg/l)	4.61	4.59	4.63	3.04	3.01	3.02	3.61	3.62	3.63	4.19	4.22	4.17	3.33	3.30	3.31

Table 3.2: Result from physicochemical (Mean ± Standard Deviation)

Parameters	Units	Sample Mean and Standard Deviation					NIS (2015) Standard	WHO (2017) Standard
		E	M	N	J	B		
Ph	-	5.77±0.21	7.17±0.06	6.87±0.21	7.20±0.10	7.20±0.26	6.5-8.5	6.5-8.5
Temperature	°C	27.9±0.10	20.07±0.21	26.73±0.21	26.27±0.25	26.57±0.12	25	-
Turbidity	NTU	4.38±0.38	1.18±0.16	0.98±0.23	2.72±0.20	1.35±0.13	5	5
Conductivity	(µS/cm)	144.10±1.28	85.63±6.37	18.30±0.44	16.13±0.15	119.07±0.80	1000	<1000
TDS	mg/l	92.27±0.82	54.81±4.08	20.71±0.28	10.32±0.10	76.20±1.15	500	500
Calcium	mg/l	0.1±0.01	0.1±0.01	ND	0.4±0.02	ND	-	75
Magnesium	mg/l	0.65±0.06	0.02±0.01	0.04±0.01	0.02±0.02	0.49±0.02	-	50
Total Hardness	mg/l	2.90±0.27	0.33±0.04	0.15±0.02	1.07±0.04	2.01±0.06	150	500
Nitrate	mg/l	8.94±0.03	3.18±0.01	2.87±0.02	3.50±0.01	7.67±0.02	≤50	<50
Nitrite	mg/l	0.02±0.01	0.01±0.01	0.02±0.01	0.01±0.01	0.01±0.01	3	3
Sulphate	mg/l	4.61±0.02	3.02±0.02	3.62±0.01	4.19±0.03	3.31±0.02	250	250

Discussion for Physicochemical Analysis

The quality of water is determined by both its physicochemical and biological properties, which are influenced by both natural and anthropogenic factors. This study analyzed the physicochemical and microbial quality of borehole water samples collected from five different student-dominated areas in Ekosodin. Table 3.2 shows the statistical summary of all the analyzed physicochemical parameters and their comparisons with the WHO and NIS standards.

The pH values of the groundwater samples ranged from 5.77 ± 0.21 (Edo Street) to 7.20 ± 0.26 (J.B), indicating slightly acidic to neutral conditions. All samples complied with both the NIS (6.5-8.5) and WHO (6.5-8.5) standards, except that from Edo Street which fell below the permissible range. The relatively low pH observed at Edo Street may be attributed to the decomposition of organic matter infiltrating the subsurface (Amaibi *et al.*,2022). Acidic water is of concern because it can corrode pipes and plumbing materials, thereby leaching metals into the water and posing a long-term health risk to consumers.

The temperature is a measure of the degree of hotness or coldness of a substance and in water quality studies, it is critical because it influences most physicochemical and biological processes. In this study, the lowest temperature was recorded at Market Road ($20.07\pm 0.21^{\circ}\text{C}$) while the highest was observed at Edo Street ($27.9\pm 0.10^{\circ}\text{C}$). Except for Market Road, all the measured values exceeded the WHO (25°C) and NIS (25°C) guideline limits for drinking water. Elevated temperatures can accelerate chemical reactions and microbial activity in water, potentially affecting its taste, dissolved oxygen content and overall quality.

Turbidity is an indicator of water clarity and reflects the presence of suspended particles such as silt, clay, organic matter and microorganisms. In this study, turbidity values ranged from 0.98 ± 0.23 NTU (Newton Street) to 4.38 ± 0.38 NTU (Edo Street). The result shows that all samples were within the permissible limits set by both WHO (≤ 5 NTU)

and NIS (≤ 5 NTU) for drinking water. This indicates that the groundwater is generally clear and free from excessive particulate matter that could compromise the visual quality or interfere with the disinfection efficiency.

Conductivity is a measure of the ability of water to conduct an electric current, which reflects the presence of dissolved ionic species such as chlorides, sulphates, carbonates, calcium, and Magnesium. In this study, conductivity values ranged from 16.13 ± 0.15 $\mu\text{S}/\text{cm}$ (J.B) to 144.10 ± 1.28 $\mu\text{S}/\text{cm}$ (Edo Street). All value were well within the permissible limits set by both WHO (≤ 1000 $\mu\text{S}/\text{cm}$) and NIS (≤ 1000 $\mu\text{S}/\text{cm}$). This indicates that the groundwater samples are of low mineral content and pose no risk of excessive salinity or scaling.

Total Dissolved Solids (TDS) represent the total concentration of dissolved organic and inorganic substances in water, including minerals, salts, and trace metals. TDS values in this study ranged from 10.32 ± 0.10 mg/L (J.B) to 92.27 ± 0.82 mg/L (Edo Street). These values are far below the permissible limits of both WHO (≤ 1000 mg/L) and NIS (≤ 500 mg/L) standards. This indicates that the groundwater samples contain relatively low levels of dissolved substances, making them suitable for drinking and other domestic uses without risk of scaling or unpleasant taste.

Total hardness in water is primarily attributed to the presence of both calcium and magnesium ions in water. The values for the total hardness of the samples in this study ranged from 0.15 ± 0.02 mg/L (Newton Street) to 2.90 ± 0.27 mg/L (Edo Street). Calcium concentrations varied from 0.10 ± 0.01 mg/L (Edo Street and Market Road) to 0.40 ± 0.02 mg/L (J.B), while magnesium concentrations ranged from 0.02 ± 0.01 mg/L (Market Road and J.B) to 0.65 ± 0.06 mg/L (Edo Street). All measured values fall well below the permissible limits set by WHO (≤ 500 mg/L as CaCO_3) and NIS (≤ 150 mg/L as CaCO_3), confirming that groundwater is soft and contains safe levels of calcium and magnesium. This indicates that the water poses no risk of scaling in pipes or adverse health effects, and is suitable for both drinking and domestic purposes.

Sulphates, nitrates and nitrites were also accounted for in this study. These ions can be introduced into water either through mineral dissolution or anthropogenic activities such as agricultural runoff and wastewater infiltration. Sulphate concentrations ranged from 3.02±0.02 mg/L (Market Road) to 4.61±0.02 mg/L (Edo Street), nitrite concentrations ranged from 0.01 ± 0.01 mg/L to 0.02 ± 0.01 mg/L across all samples while nitrate concentration ranged from 2.87±0.02 mg/L (Newton Street) to 8.94±0.03 mg/L (Edo Street). All values obtained were within the permissible limits of both WHO (sulphate ≤500 mg/L; nitrite 3 mg/L; nitrate <50 mg/L) and NIS (sulphate ≤100 mg/L; nitrite 3 mg/L; nitrate <50mg/L) standards, indicating no associated health risks from these parameters in the groundwater samples.

Table 3.3: Triplicate Result from heavy metal analysis

Parameters	Sample locations														
	E1	E2	E3	M1	M2	M3	N1	N2	N3	J1	J2	J3	B1	B2	B3
Cadmium (mg/l)	0.02	0.03	0.05	ND	ND	ND	0.02	0.01	0.03	0.01	0.03	0.02	0.01	0.02	0.01
Lead (mg/l)	0.03	0.05	0.02	0.01	0.01	0.03	0.02	0.04	0.03	0.02	0.03	0.02	0.03	0.03	0.02
Zinc (mg/l)	0.03	0.03	0.02	0.02	0.03	0.02	0.01	0.03	0.01	0.09	0.10	0.07	0.01	0.03	0.02

Table 3.4: Result from Heavy metal analysis (Mean ± Standard Deviation)

Parameters	Units	Sample Mean and Standard Deviation					NIS	WHO
		E	M	N	J	B	(2015) Standard	(2017) Standard
Cadmium	mg/l	0.03±0.02	ND	0.02±0.01	0.02±0.01	0.01±0.01	≤0.003	0.003
Lead	mg/l	0.03±0.02	0.02±0.01	0.03±0.01	0.02±0.01	0.03±0.01	0.01	0.01
Zinc	mg/l	0.03±0.01	0.02±0.01	0.02±0.01	0.09±0.02	0.02±0.01	3.00	3.00

Discussion for Heavy metal Analysis

Heavy metals are well-known pollutants due to their persistence, toxicity, and tendency to accumulate in living organisms and the environment. Although some of these metals are vital for metabolic processes in plants and animals at low concentrations, their presence in elevated concentrations profoundly affects water quality, becoming toxic and threatening human lives. From the table 3.4 which shows the statistical summary of the analyzed heavy metals, Cadmium concentrations ranged from not detectable (Market Road) to 0.03±0.02 mg/L (Edo Street), while lead ranged from 0.02±0.01 to 0.03±0.01 mg/L across several locations. Both metals exceeded the WHO and NIS permissible limits of 0.003 mg/L for cadmium and 0.01 mg/L for lead, indicating a significant health risk. Chronic exposure to these metals may result in kidney damage, neurological impairment, and other toxic effects due to their tendency to bioaccumulate. In contrast, zinc concentrations (0.03±0.01–0.09±0.02 mg/L) remained within safe limits, posing no immediate concern. The exceedance of lead and Cadmium underscores the need for proper treatment of borehole water before consumption.

Table 3.5: Triplicate Result from Microbial Analysis

Parameters	Sample locations														
	E1	E2	E3	M1	M2	M3	N1	N2	N3	J1	J2	J3	B1	B2	B3
T-	16.00	14.00	13.00	1.00	1.00	1.00	1.00	1.00	1.00	3.00	5.00	1.00	3.00	1.00	2.00
Coliform (CFU/ml) $\times 10^1$															
E-coli (CFU/ml) $\times 10^1$	8.00	11.00	8.00	ND	ND	ND	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
THBC $\times 10^2$	76	73	78	4	3	5	15	17	13	12	9	15	3	5	2

Table 3.6: Results from Microbial analysis (Mean \pm Standard Deviation)

Parameters	Units	Sample Mean and Standard Deviation					NIS	WHO
		E	M	N	J	B	(2015) Standard	(2017) Standard
T-Coliform $\times 10^1$	(CFU/ml)	14.33 \pm 1.53	1.00 \pm 0.00	1.00 \pm 0.00	3.00 \pm 2.00	2.00 \pm 1.00	1.00	0.00
E-coli $\times 10^1$	(CFU/ml)	9.00 \pm 1.73	ND	1.00 \pm 0.00	1.00 \pm 0.00	1.00 \pm 0.00	0.00	0.00
THBC $\times 10^2$	(CFU/ml)	76 \pm 2.52	4.00 \pm 1.00	15.00 \pm 2.00	12.00 \pm 3.00	3.00 \pm 1.53	-	1.00

Discussion for Microbial Analysis

Bacterial properties of borehole water in selected areas of Ekosodin in table 3.6 above reveals that bacterial counts were above WHO standard of 100 CFU/ mL, E-coli counts (0 CFU/mL) as well as coliform count (0 CFU/mL). The detection of bacteria in the water samples is an indication of Faecal contamination (Uhuo *et al.*, 2014), which introduces pathogens that makes the water unsuitable for drinking.

Moreso alarm should be raised because of the high number of total heterotrophic bacteria present in these water samples. The values of the Total Heterotrophic bacteria count in the samples ranged from 3.00±1.53 CFU/ml (Boundary Road) to 76±2.52 CFU/ml (Edo Street). From the results, all samples exceeded the permissible limits of both NIS and WHO (100 CFU/ml) standards, indicating maximal health risks from these bacteria.

Table 3.7: Distribution of Bacteria across samples

	ESCHERICHIA		STAPHYLOCOCCUS	ENTEROBACTER	
	COLI	SALMONELLA	SP	SP	KLEBSHIELLA
E	+	+	+	+	+
M	-	-	+	+	-
N	-	+	-	+	-
J	+	+	+	+	-
B	+	-	+	+	-

Discussion for Distribution of Bacteria across Samples

The distribution of bacteria across the water samples shows a varying range as shown in table 3.7, except for Edo Street, which is seen to contain all bacteria. This could be as a result of the fact that two septic tanks were built in the house, not too far from the

borehole. According to (Uhuo *et al.*, 2014), Faecal contamination introduces pathogens like *Escherichia coli*, *Salmonella*, *Staphylococcus sp*, *Enterobacter sp*, and *Klebsiella*, which make the water unsuitable for drinking. These pathogens in water sources lead to diseases such as typhoid, cholera, and diarrhea (Adesakin *et al.*, 2020), therefore, water from these boreholes should be properly treated before usage.

CONCLUSION

This study shows that most physicochemical parameters of the Ekosodin borehole water, such as turbidity, conductivity, total dissolved solids (TDS), hardness, sulphates, nitrates, and nitrites, meet the WHO and NIS guideline values. However, there are significant variations in temperature, pH, and especially in heavy metal levels. Lead and cadmium levels surpass permissible limits, indicating potential long-term health risks. Microbiological analysis also reveals that the water is unsafe for direct human consumption because of high heterotrophic bacterial counts and signs of faecal contamination. The presence of both heavy metals and microbial contaminants emphasizes the urgent need for proper pre-consumption treatment, improved borehole hygiene, and routine monitoring to mitigate public health risks.

RECOMMENDATION

The government should improve access to safe drinking water by investing in modern treatment systems and extending municipal supply to Ekosodin. Stronger policies on waste management and groundwater protection will also reduce contamination risks and promote sustainable use of water resources.

Regulatory Agencies and community leaders should enforce water quality standards through regular testing, proper borehole construction, and safe siting practices. Public reporting of results and community awareness programs will help ensure accountability and protect residents from health risks.

Students can protect themselves by treating borehole water through boiling, chlorination, or filtration before use. Clean storage practices and active participation in water safety campaigns, as well as promptly reporting poor water quality, are vital steps to safeguard their health.

REFERENCES

- A. Rawlings, S. Seghosime. (2022). Evaluation of Water Supply, Sanitation and Hygiene Facilities in Ekosodin Community of Ovia North-East LGA, Benin City, Edo State, Nigeria. *Nigerian Journal of Technology (NIJOTECH)* Vol. 41, No. 4, July, 2022, pp.632-643 www.nijotech.com
- Abanyie, S., Apea, O., Abagale, S., Amuah, E., & Sunkari, E. (2023). Sources and factors influencing groundwater quality and associated health implications: A review. *Emerging Contaminants*.
- Abata, E., & Ekwere, D. (2024). Assessment of physicochemical, minerals and microbiological qualities of borehole and well water: A case study of Akure Metropolis, Nigeria. *GSC Advanced Research and Reviews*.
- Adeleke, I., & Faraday, E. (2024). Assessment of the Microbial and Physicochemical Quality of Water: Evidence from Selected Groundwater Sources from The Coastal Region of Ondo State, Nigeria. *Dutse Journal of Pure and Applied Sciences*.
<https://doi.org/10.4314/dujopas.v10i1b.9>
- Adesakin, T. A., Oyewale, A. T., Bayero, U., Mohammed, A. N., Aduwo, I. A., Ahmed, P. Z., Abubakar, N. D., & Barje, I. B. (2020). Assessment of bacteriological quality and physico-chemical parameters of domestic water sources in Samaru community, Zaria, Northwest Nigeria. *Heliyon*, 6(8), e04773.
- Adewumi, J. R., Olaniyan, O. S., & Ojo, T. A. (2024). Groundwater security in Nigeria: Status, challenges and adaptive strategies. *Journal of Hydrology*, 625, 129–142.
- Adimalla, N. (2021). Application of the Entropy Weighted Water Quality Index (EWQI) and the Pollution Index of Groundwater (PIG) to Assess Groundwater Quality for Drinking Purposes: A Case Study in a Rural Area of Telangana State, India. *Archives of Environmental Contamination and Toxicology*, 1-10.

- Adubor, C., Ekperusi, A. O., Michael, A., & Olomukoro, J. O. (2025). Physicochemical properties of surface water, heavy metals levels in sediments and macrobenthic invertebrates community of Ikpoba River, Benin City, Edo State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 29(5), 1653–1663.
- Akerele, D. D., Obunadike, C., & Abiodun, P. O. (2023). Assessment of physicochemical and bacteriological parameters of borehole water: A case study from Lekki, Lagos, Nigeria. *Journal of Sensor Networks and Data Communications*, 3(1), 201–214.
- Akoji, J. (2019). Evaluation of groundwater quality in some rural areas of the Federal Capital Territory, Abuja, Nigeria.
- Akoto, O., Samuel, A., Gladys, L., Sarah, O. A. A., Apau, J., & Opoku, F. (2022). Assessment of groundwater quality from some hostels around Kwame Nkrumah University of Science and Technology. *Scientific African*, 17, e01361.
- Akpan, E. F., Akpan, V. M., & Inyang, U. U. (2020). Geoelectrical investigation of groundwater quality through estimates of total dissolved solids and electrical conductivity in parts of Akwa Ibom State, Southern Nigeria. *Malaysian Journal of Geosciences*, 4(1), 32–37.
- Alice Magha, M. T. A., Kouankap Nono, G. D., Tamfuh, P. A., Wotchoko, P., Adoh, M., & Kamgang Kabeyene, V. B. (2021). Assessment of groundwater quality for domestic and irrigation purposes in Northern Bamenda (Cameroon). *Journal of Water Resource and Protection*, 13(1), Article ID:106622.
- Alogayell, H., El-Bana, E., & Abdelfattah, M. (2023). Groundwater quality and suitability assessment for irrigation using hydrogeochemical characteristics and pollution indices: A case study of North Al-Quwayiyah Governorate, Central Saudi Arabia. *Water*.
- Aluma, V., Igwe, O., Omeka, M., & Anyanwu, I. (2024). Combining multiple numerical and chemometric models for assessing the microbial and pollution level of

- groundwater resources in a shallow alluvial aquifer, Southeastern Nigeria. *Arabian Journal of Geosciences*.
- American Public Health Association (APHA). (2017). *Standard methods for the examination of water and wastewater* (23rd ed.).
- Andrade, L., Kelly, M., Hynds, P., Weatherill, J., Majury, A., & O'Dwyer, J. (2019). Groundwater resources as a global reservoir for antimicrobial-resistant bacteria. *Water research*, 170, 115360.
- Andrade, L., O'Dwyer, J., O'Neill, E., & Hynds, P. (2018). Surface water flooding, groundwater contamination, and enteric disease in developed countries: A scoping review of connections and consequences. *Environmental Pollution*, 236, 540–549.
- APHA. *Standard Methods for Examination of Water and Wastewater*, 22nd edn. American Public Health Association, Washington (2012).
- Aremu, E. A., Ejizu, A. N., Ugwu, R. A and Chiawa, O. C (2024). Evaluation of the physico-chemical properties of water samples from ata/ ehimiri stream watershed ecosystem in umudike, abia state, Nigeria. *Journal of Research in Forestry, Wildlife & Environment* Vol. 16(4) December, 2024
- Atemoagbo, O. (2024). Investigating the impact of sanitation infrastructure on groundwater quality and human health in peri-urban areas. *International Journal of Medical Science and Clinical Invention*.
- Awomeso, J., Ahmad, S., & Taiwo, A. (2020). Multivariate assessment of groundwater quality in the basement rocks of Osun State, Southwest, Nigeria. *Environmental Earth Sciences*, 79, 1-9.
- Barzegar, R., Moghaddam, A. A., & Kazemian, N. (2015). Assessment of heavy metal concentrations with emphasis on arsenic in the Tabriz plain aquifers, Iran. *Environmental Earth Sciences*, 74, 297–313.

- Chiemeka H. Ezechinyere & Obong U. Stanislaus. (2023). Investigating the quality of groundwater in Ibeju-Lekki Local Government Area, Lagos State. *Water Science, 2023*
- Chique, C., Hynds, P., Burke, L., Morris, D., Ryan, M., & O'Dwyer, J. (2020). Contamination of domestic groundwater systems by verotoxigenic escherichia coli (VTEC), 2003-2019: A global scoping review. *Water research, 188*, 116496.
- Danert, K., & Healy, A. (2021a). Monitoring groundwater use as a domestic water source by urban households: Analysis of data from Lagos State, Nigeria and Sub-Saharan Africa with implications for policy and practice. *Water, 13*(4), 568.
- Danert, K., & Healy, A. (2021b). Monitoring groundwater use as a domestic water source by urban households: Analysis of data from Lagos State, Nigeria and Sub-Saharan Africa with implications for policy and practice. *Water, 13*(4), 568.
- Drasovean, R., & Murariu, G. (2021). Water quality parameters and monitoring soft surface water quality using statistical approaches.
- Edet W. Nsi, Emaime J. Uwanta, Aniekan E. Akpakpan, Ifiok O. Ekwere (2020). Analytical Assessment of Borehole Water in Some Local Government Areas of Akwa Ibom State, South-South Nigeria. *European Scientific Journal April 2020*.
- Egbueri, J. (2019). Water quality appraisal of selected farm provinces using integrated hydrogeochemical, multivariate statistical, and microbiological technique. *Modeling Earth Systems and Environment, 1–17*.
- Egbueri, J., & Agbasi, J. (2022). Data-driven soft computing modeling of groundwater quality parameters in southeast Nigeria: Comparing the performances of different algorithms. *Environmental Science and Pollution Research, 29*, 38346–38373.
- Egbueri, J., Agbasi, J., Ayejoto, D., Khan, M., & Khan, M. (2023). Extent of anthropogenic influence on groundwater quality and human health-related risks:

- an integrated assessment based on selected physicochemical characteristics. Geocarto International, 38.
- Egbueri, J., Agbasi, J., Ezugwu, A., Omeka, M., Ucheana, I., Aralu, C., & Abugu, H. (2024). Metal(loid)s, nitrate, polycyclic aromatic hydrocarbons, and radioactive contaminants in Nigerian water resources: state-of-the-art of their ecological and health risk assessments. *Environment, Development and Sustainability*.
- Egereonu UU. Physico-chemical assessment of raw water from two Rain gauged Stations in the Rainforest region. *J. Chem Soc. Nigeria*. 2006; 1: 429-437.
- Eletta, O. A. A., Adeniyi, A. G., & Dolapo, A. F. (2010). Physico-chemical characterisation of some ground water supply in a school environment in Ilorin, Nigeria. *African Journal of Biotechnology*, 9(22), 3293–3297.
- Enuneku, A., Omoruyi, O., Tongo, I., Ogbomida, E., Ogbeide, O., & Ezemonye, L. (2018). Evaluating the potential health risks of heavy metal pollution in sediment and selected benthic fauna of Benin River, Southern Nigeria. *Applied Water Science*, 8, 224.
- Eyankware, M., Ufomata, D., Solomon, E., & Akakuru, O. (2015). Physicochemical and bacteriological assessment of groundwater quality in ughelli and its environs, delta state nigeria. *International journal of innovation and scientific research*, 14, 236-243.
- Fatokun, E., Olalekan, S., & Fayemi, S. (2024). Assessment of antibiotic resistance in groundwater bacterial strains: A community-based study. *South Asian Journal of Research in Microbiology*.
- Federal Ministry of Water Resources. (2020). *Water, sanitation and hygiene: National Outcome Routine Mapping (WASH NORM) 2019: A report of findings*.

- Ferrer, N., Folch, A., Masó, G., Sanchez, S., & Sanchez-Vila, X. (2019). What are the main factors influencing the presence of faecal bacteria pollution in groundwater systems in developing countries?. *Journal of contaminant hydrology*, 103556.
- Ganiyu, S. A., Olurin, O. T., Awaye, K. T., & Adeleke, O. O. (2017). Heavy metals content and physico-chemical status of groundwater around lead smelting area in southwestern Nigeria urban settlement. *African Review of Physics*, 12, 14–22.
- Ganiyu, S., Oyadeyi, A., & Adeyemi, A. (2021). Assessment of heavy metals contamination and associated risks in shallow groundwater sources from three different residential areas within Ibadan metropolis, Southwest Nigeria. *Applied Water Science*, 11.
- Garba, Y. I., Gano, U. T., Yusuuf, M. S., & Musa, D. M. (2018). Assessment of physicochemical and microbiological quality of borehole water in Dutse metropolitan Jigawa State, Nigeria. *Science World Journal*, 13(3).
- Gemechu, B., Aberra, D., & Fufa, F. (2019). Evaluation of the suitability of groundwater for drinking and irrigation purposes in Jimma Zone of Oromia. *Journal of Geoscience and Environment Development*.
- Godfrey, S., & Smith, M. (2005). Improved microbial risk assessment of groundwater. *Hydrogeology Journal*, 13, 321-324.
- Grönwall, J., & Danert, K. (2020). Regarding groundwater and drinking water access through a human rights lens: Self-supply as a norm. *Water*, 12(2), 419.
- He, X., Li, P., Wu, J., Wei, M., Ren, X., & Wang, D. (2020). Poor groundwater quality and high potential health risks in the Datong Basin, northern China: Research from published data. *Environmental Geochemistry and Health*.
- Health Canada. Guidelines for Canadian Drinking Water Quality (2025). pubsadmin@hc-sc.gc.ca. 978-0-660-74972-3

- Igboekwe, M. U., Eke, A. B., Emeka-Chris, C. C., & Ihekweaba, G. (2013). Geophysical assessment and groundwater quality in Michael Okpara University of Agriculture, Umudike, Abia State. *The Pacific Journal of Science and Technology*, 14(2), November 2013.
- Imarhiagbe, E. E., & Onwudiwe, C. C. (2023). Evaluation of water supply, sanitation and hygiene facilities in Ekosodin Community of Ovia North-East LGA, Benin City, Edo State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 27(11), 2611–2616.
- Ir, I. (2020). Comparative Assessment of physicochemical Characteristics, Metal Levels and Anion Contents of water from Different Aquatic Environments in Ebonyi State. *Biomedical Journal of Scientific & Technical Research*, 29(5).
- Islam, M., Iqbal, M., D’Souza, N., & Islam, M. (2021). A review on present and future microbial surface water quality worldwide. *Environmental Nanotechnology, Monitoring and Management*, 16, 100523.
- Jha, M., Shekhar, A., & Jenifer, M. (2020). Assessing groundwater quality for drinking water supply using hybrid fuzzy-GIS-based water quality index.. *Water research*, 179, 115867.
- Johnbosco C. Egbueri (2019). Evaluation and characterization of the groundwater quality and hydrogeochemistry of Ogbaru farming district in southeastern Nigeria. Springer Nature Switzerland AG 2019
- Khan, N., Hussain, S. T., & Saboor, A. (2013). Physicochemical investigation of the drinking water sources from Mardan, Khyber Pakhtunkhwa, Pakistan. *International Journal of Physical Sciences*, 8, 1661–1671.
- Kim-Shapiro, D. B., Gladwin, M. T., Putel, R. P., & Hogg, N. (2005). The reaction between nitrites and hemoglobin, the role of nitrite in hemoglobin-mediated hypoxic vasodilatation. *Journal of Inorganic Biochemistry*, 99(1), 237–247.

- Kolawole, O. M., Alamu, F. B., & Olayemi, A. B. (2013). Bacteriological analysis and effects of water consumption on the hematological parameters in rats. *International Journal of Plant, Animal and Environmental Sciences*, 3, 125–131.
- Masood, M., Rashid, M., Haider, S., Naz, I., Pande, C., Heddami, S., Alshehri, F., Elkhachy, I., Ahsan, A., & Sammen, S. (2023). Exploring Groundwater Quality Assessment: A Geostatistical and Integrated Water Quality Indices Perspective. *Water*.
- Masood, M., Rashid, M., Haider, S., Naz, I., Pande, C., Heddami, S., Alshehri, F., Elkhachy, I., Ahsan, A., & Sammen, S. (2023). Exploring Groundwater Quality Assessment: A Geostatistical and Integrated Water Quality Indices Perspective. *Water*.
- Masoud, M., Osta, E., Alqarawy, A., Elsayed, S., & Gad, M. (2022). Evaluation of groundwater quality for agricultural under different conditions using water quality indices, partial least squares regression models, and GIS approaches. *Applied Water Science*, 12.
- Mathaba, K., & Schmitz, P. (2025). A GIS-based approach to analyse potable water accessibility in Langelooop village in Ehlanzeni District Municipality, Mpumalanga, South Africa. *South African Journal of Geomatics*, 14(1).
- Mumtaz, M., Jahanzaib, S., Khan, S., Ismail, S., Hussain, W., & Khan, F. (2024). Implementation Of Water Quality Index for Measuring Groundwater Quality. *Migration Letters*.
- Mustapha, M., Balarabe, M., & Bilal, B. (2024). Spatial assessment of groundwater quality in Panteka Market Tudun Nupawa, Kaduna, Nigeria. *Science World Journal*.
- Natishah, A., Samuel, M., Velmurugan, K., Showparnickaa, S., Indumathi, S., & Kumar, M. (2025). Contamination of Groundwater by Microorganisms and Risk

Management: Conceptual Model, Existing Data, and Challenges. *Groundwater for Sustainable Development*.

Nwankwoala, H. O. (2011). The role of communities in improved rural water supply systems in Nigeria: Management model and its implications for sustainability. *Journal of Applied Technology in Environmental Sanitation*, 1(1), 45–53.

Nzelibe, I. U., Akinboyewa, T. E., Nzelibe, T. N., & Inekwe, G. G. (2022). Geospatial assessment of the potentials of rooftop rainwater harvest at the Federal University of Technology, Akure, Nigeria. *FUOYE Journal of Engineering and Technology*, 7(2), 249–256.

Obuekwe, I. S., Oshoma, C. E., & Omorogbe, J. N. (2021). Evaluation of physicochemical and bacteriological properties of borehole water in selected areas of Benin City, Edo State. *Nigerian Journal of Life Sciences*, 11(1 & 2), 10–17.

Ogbeifun, D. E., Archibong, U. D., Chiedu, I. E., & Ikpe, E. E. (2019). Assessment of the water quality of boreholes in selected areas in Benin City, Edo State, Nigeria. *Chemical Science International Journal*, 28(2), 1–13.

Ojekunle, O. Z., Adeyemi, M. B., Adedeji, A. A., Anumah, A. O., Taiwo, A. M., & Ganiyu, S. A. (2020). Effects of industrialization on groundwater quality in Shagamu and Ota industrial areas of Ogun State, Nigeria.

Ojo, J., Ojo, O., Olabanji, T., & Aluko, R. (2024). Urbanization impact on groundwater quality of selected rural and urban areas in Ondo State, Nigeria using Water Quality Index. *Discover Water*.

Okeke, D. O., Ifemeje, J. C., & Eze, V. C. (2022). Determination of the levels of heavy metals and physicochemical properties of borehole water within selected mining sites in Ebonyi State, Nigeria. *Health & Environment*, 3(1), 162–168.

- Olasoji, S., Oyewole, N., Abiola, B., & Edokpayi, J. (2019). Water Quality Assessment of Surface and Groundwater Sources Using a Water Quality Index Method: A Case Study of a Peri-Urban Town in Southwest, Nigeria. *Environments*.
- Omeka, M., Igwe, O., Onwuka, O., Obajaja, H., Omang, B., Unigwe, C., & Aluma, V. (2024). Modeling the vulnerability of water resources to pollution in a typical mining area, SE Nigeria using speciation, geospatial, and multi-path human health risk modeling approaches. *Modeling Earth Systems and Environment*.
- Onwukeme, V. I., & Okechukwu, V. U. (2021). Leaching matrix of selected heavy metals from soil to ground water sources in active dumpsites: A case study of Southern Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, 15(4), 1–18.
- Oyedele, A., Ayodele, O., & Olabode, O. (2019). Groundwater quality assessment and characterization of shallow basement aquifers in parts of ado ekiti metropolis, Southwestern Nigeria. *SN Applied Sciences*, 1, 1-13.
- Patil, P. N., Sawant, D. V., & Deshmukh, R. N. (2012). Physico-chemical parameters for testing of water – A review. *International Journal of Environmental Sciences*, 3(3).
- Pawari, M. J., & Gawande, S. G. (2015). Ground water pollution and its consequence. *International Journal of Engineering Research and General Science*, 3, 773–776.
- Pedley, S., & Howard, G. (1997). The public health implications of microbiological contamination of groundwater. *Quarterly Journal of Engineering Geology*, 30, 179 - 188.
- Peiyue, L., Karunanidhi, D., Subramani, T., & Srinivasamoorthy, K. (2021). Sources and consequences of groundwater contamination. *Archives of Environmental Contamination and Toxicology*, 80, 1–10.
- Pham, N., & Nguyen, G. (2024). Evaluating Groundwater Quality Using Multivariate Statistical Analysis and Groundwater Quality Index. *Civil Engineering Journal*.

- Pointet, T. (2022). The United Nations World Water Development Report 2022 on groundwater, a synthesis. *LHB*, 108(1), 2090867.
- Poulin, C., Peletz, R., Ercumen, A., Pickering, A., Marshall, K., Boehm, A., Khush, R., & Delaire, C. (2020). What environmental factors influence the concentration of fecal indicator bacteria in groundwater? Insights from explanatory modelling in Uganda and Bangladesh. *Environmental science & technology*.
- Qureshi, S. S., Channa, A., Memon, S. A., Khan, Q., Jamali, G. A., Panhwar, A., & Saleh, T. A. (2021). Assessment of physicochemical characteristics in groundwater quality parameters. *Environmental Technology & Innovation*, 24, 101877.
- Rao, S., Das, R., Sahoo, H., & Gugulothu, S. (2023). Hydrochemical characterization and water quality perspectives for groundwater management for urban development. *Groundwater for Sustainable Development*.
- Rezaei, A., & Hassani, H. (2018). Hydrogeochemistry study and groundwater quality assessment in the north of Isfahan, Iran. *Environmental Geochemistry and Health*, 40, 583–608.
- Rezaei, A., Hassani, H., Tziritis, E., Mousavi, S., & Jabbari, N. (2020). Hydrochemical characterization and evaluation of groundwater quality in Dalgan basin, SE Iran. *Groundwater for Sustainable Development*.
- Safo-Adu, G. (2022). Water Quality Index Model Application in Evaluation of Groundwater Quality in a Waste Treatment Facility. *International Journal of Sustainable Engineering*, 15, 286 - 298.
- Sajib, A., Diganta, M., Rahman, A., Dabrowski, T., Olbert, A., & Uddin, M. (2023). Developing a novel tool for assessing the groundwater incorporating water quality index and machine learning approach. *Groundwater for Sustainable Development*.
- Shakerkhatibi, M., Mosaferi, M., Pourakbar, M., Ahmadnejad, M., Safavi, N., & Banitorab, F. (2019). Comprehensive investigation of groundwater quality in the

- northwest of Iran: Physicochemical and heavy metal analysis. *Groundwater for Sustainable Development*, 8, 156–168.
- Singhal, A., Gupta, R., Singh, A., & Shrinivas, A. (2020). Assessment and monitoring of groundwater quality in semi –arid region. *Groundwater for Sustainable Development*, 11, 100381.
- Soceanu, A., Dobrinas, S., Dumitrescu, C. I., Manea, N., Sirbu, A., Popescu, V., & Vizitiu, G. (2021). Physico-chemical parameters and health risk analysis of groundwater quality. *Applied Sciences*, 11(11), 4775.
- Sojobi, A. (2016). Evaluation of groundwater quality in a rural community in North Central of Nigeria. *Environmental Monitoring and Assessment*, 188, 1-17.
- Sojobi, A. O., Owamah, H. I., & Dahunsi, S. O. (2014). Comparative study of household water treatment in a rural community in Kwara State, Nigeria. *Nigerian Journal of Technology*, 33(1), 134–140.
- Talab, A. T., Odunaike, R. K., David, T. W., Ajetunmobi, A. E., Olubanwo, O. O., Ajiboye, O., & Oyebamiji, B. M. (2025). Assessment of heavy metals in flowing water at Ogun State, Southwestern Nigeria using water quality index approach. *East African Journal of Environment and Natural Resources*, 8(1), 107–120.
- Uhuo, C. A., Uneke, B. I., Okereke, C. N., Nwele, D. E., & Ogbanshi, M. E. (2014). The bacteriological survey of borehole waters in peri-urban areas of Abakaliki, Ebonyi State, Nigeria. *International Journal of Bacteriology Research*, 2(2), 28–31.
- US EPA. (2015). Private drinking water wells. Retrieved from <http://www2.epa.gov/privatewells> (Accessed April 28, 2021).
- USEPA “Methods for Chemical Analysis of Water and Wastes”, Ohio, (1983) (Method 150.1).

- Uwidia, I. E., & Ukulu, H. S. (2013). Studies on electrical conductivity and total dissolved solids concentration in raw domestic wastewater obtained from an estate in Warri, Nigeria. *Greener Journal of Physical Sciences*, 3, 110–114.
- Venkatesh, J., Partheeban, P., Baskaran, A., Krishnan, D., & Sridhar, M. (2024). Wireless sensor network technology and geospatial technology for groundwater quality monitoring. *J. Ind. Inf. Integr.*, 38, 100569.
- Vig, N., Ravindra, K., & Mor, S. (2022). Evaluation of groundwater for drinking and irrigation applications concerning physicochemical and ionic parameters through multiple indexing approach: a case study around the industrial zone, Punjab, India. *Environmental Geochemistry and Health*, 45, 2077-2097.
- Wami, M., Fisher, J., Akpila, S., & Radu, T. (2022). Current water, sanitation and hygiene (WASH) conditions in selected schools in Port Harcourt, Nigeria. *International Development Planning Review*, 44(4), 435–455.
- World Health Organization (WHO), & UNICEF. (2019). Progress on household drinking water, sanitation and hygiene 2000–2017: Special focus on inequalities. United Nations Children’s Fund (UNICEF) and World Health Organization (WHO) Joint Monitoring Programme for Water Supply and Sanitation.
- World Health Organization (WHO). (2011). Guidelines for drinking-water quality (4th ed.). Geneva: World Health Organization.
- Yang-Xiao, Z. (2008). Groundwater quality monitoring and assessment. *Hydrogeology and Engineering Geology*.
- Yilmaz, E., & Koc, C. (2014). Physically and chemically evaluation for the water quality criteria in a farm on Akcay. *Journal of Water Resource and Protection*, 6, 63–67.
- Young Godwin Irobehian, Ugbenyen Anthony Moses, Ajayi Olulope Olufemi, Onobun Desmond Odiamahi. (2023). Physicochemical and bacteriological assessment of

groundwater quality in Etsako east local government area of Edo state, Nigeria. *Ethiop. J. Sci. & Technol.* 16(2): 155-165, June 2023.

Zeyneb, K. (2020). The importance of water and conscious use of water. *International Journal of Hydrology*, 4(5).

Zhang, H., Cheng, S., Li, H., Fu, K., & Xu, Y. (2020). Groundwater pollution source identification and apportionment using PMF and PCA-APCA-MLR receptor models in a typical mixed land-use area in Southwestern China. *Science of The Total Environment*, 741, 140383.

APPENDIX 1

Graphs for the standard Concentrations

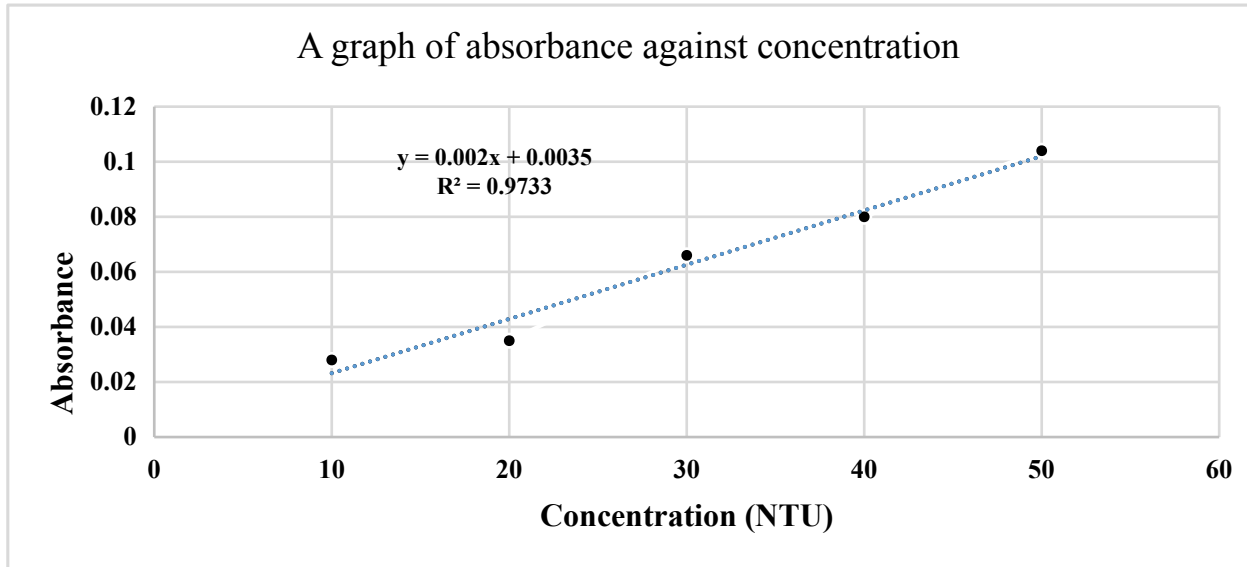


Figure A1. Turbidity Standard Graph (420nm)

APPENDIX 2

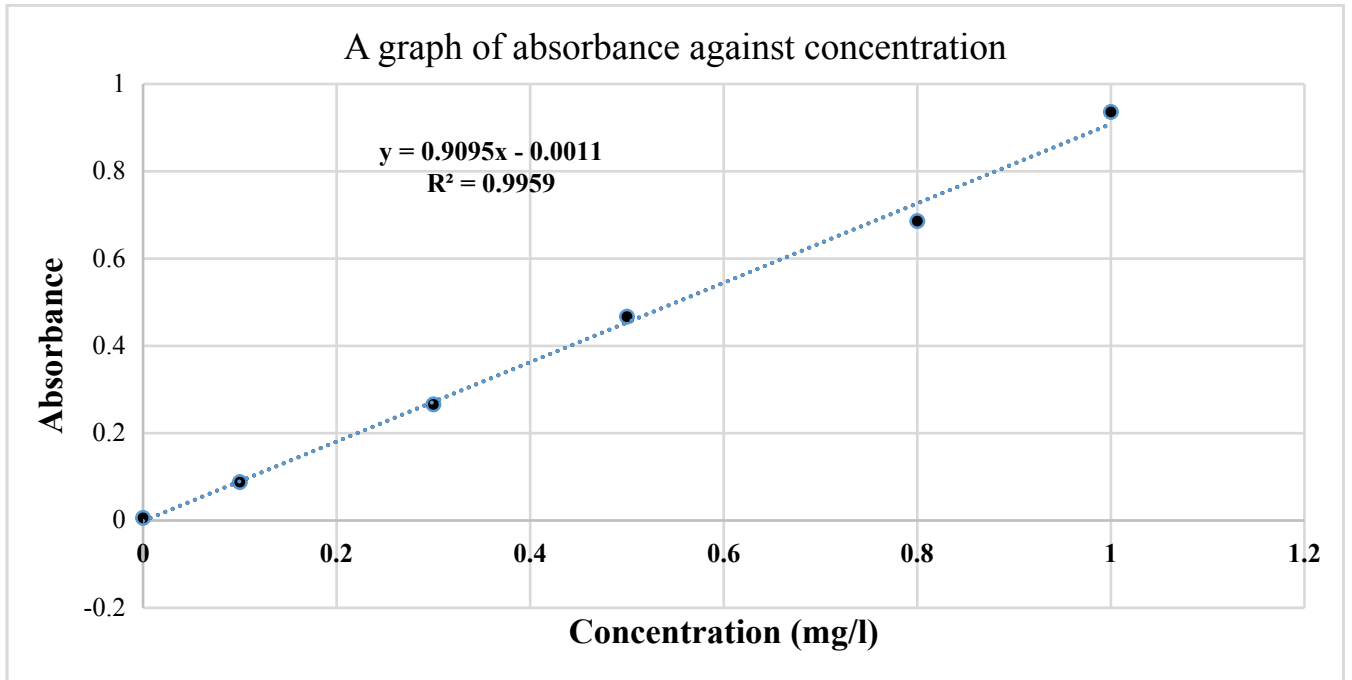


Figure A2. Nitrite Standard Graph (540nm)

APPENDIX 3

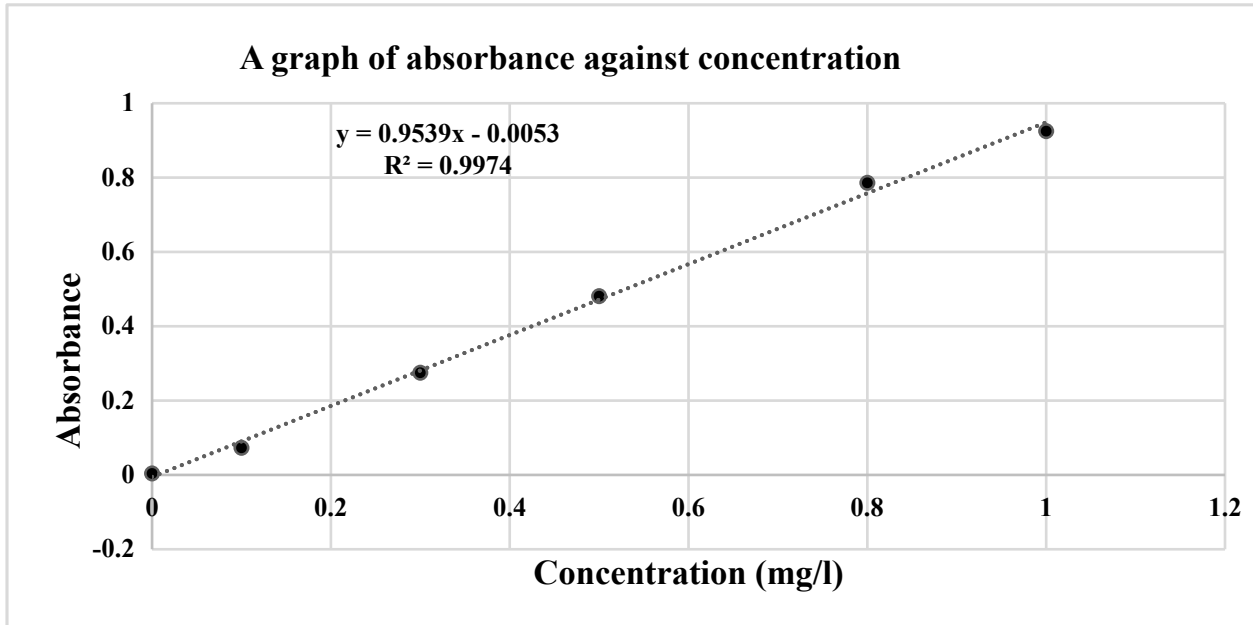


Figure A3. Sulphate Standard Graph (420 nm)

APPENDIX 4

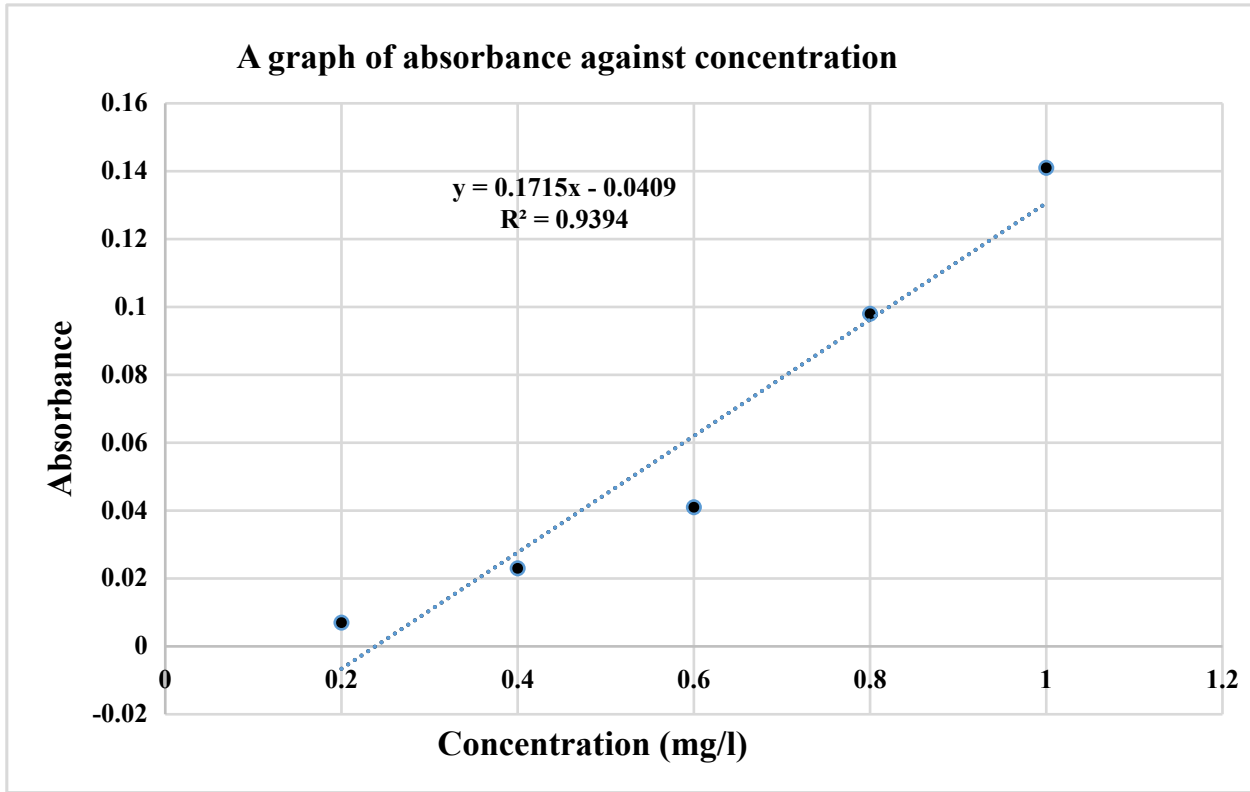


Figure A4. Nitrate Standard Graph (470 nm)