Assessment of Groundwater Quality in Mowe Ibafo, Ogun State, Nigeria

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Being a MSc Thesis Submitted to the Department of Biological Sciences, Faculty of Natural & Applied Sciences, Lead City University, Ibadan, Oyo State, Nigeria

In Partial Fulfilment of the Requirements for the Award of Master of Science Degree (MSc) in Environmental Management and Toxicology

2025

Certification

This is to certify that **Adenike Onaolapo FASANMI** with Matriculation Number LCU/PG/005711, carried out this research titled "**Assessment of Groundwater Quality in Mowe Ibafo, Ogun State, Nigeria**" in the Department of Biological Sciences, Faculty of Natural and Applied Sciences, Lead City University, Ibadan, Oyo State, Nigeria, for the award of Master of Science Degree (M.Sc.) in Environmental Management and Toxicology, and this has not been previously submitted.

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Dedication

I dedicate this project work to the Almighty God**.**

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Acknowledgement

I wish to express my profound gratitude to God Almighty for His grace, wisdom, and strength throughout the duration of this project and my programme. I would like to express my profound gratitude to the management of Lead City University for a conducive learning environment.

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Abstract

Groundwater remains the primary source of drinking water for many communities in Nigeria, including the rapidly urbanizing Mowe Ibafo corridor in Ogun State. With increasing population growth and urban development, concerns about the safety and sustainability of groundwater resources have become more pressing. This study was conducted to assess the physicochemical characteristics and heavy metal concentrations of groundwater in the Mowe Ibafo area, with a view to determining its suitability for domestic and drinking purposes. Water samples were collected from selected boreholes and wells across six different streets in the study area. Laboratory analyses were carried out to determine key physicochemical parameters such as pH, temperature, turbidity, electrical conductivity, total dissolved solids (TDS), and total hardness. Heavy metals, including lead (Pb), iron (Fe), manganese (Mn), and zinc (Zn), were also analyzed using standard methods. The results obtained were compared with the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines. However, heavy metal analysis revealed elevated levels of iron and lead in some sampling points, which pose potential health risks such as neurological disorders, anemia, and other long-term health issues. The presence of these contaminants is attributed to both natural geological factors and anthropogenic activities such as indiscriminate waste disposal and possible industrial discharges. This study underscores the urgent need for regular monitoring of groundwater quality in Mowe Ibafo, public sensitization on potential risks, and the implementation of appropriate water treatment and management strategies to ensure safe and sustainable water supply for the growing population.

Keywords: Groundwater Quality, Mowe Ibafo, Physicochemical Parameters, Heavy Metals, Water Pollution, Public Health, Nigeria.

Word Count: 249 words

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Chapter One

Introduction

1.1 Background to the Study

Water is essential for life, serving as a critical resource for domestic, agricultural, and industrial purposes[1]. Across the globe, water is one of the most utilized natural resources, vital not only for sustaining human life but also for supporting ecosystems and enabling socio-economic development[2]. Among water resources, groundwater plays a particularly significant role in meeting the demands of growing populations. It serves as a reliable source of freshwater, especially in regions where surface water availability is limited or unreliable[3]. However, despite its critical importance, the quality of groundwater is under increasing threat due to various natural and human-induced activities. These threats have profound implications for water security, public health, and sustainable development[4].

Groundwater pollution is a growing concern worldwide, driven by factors such as agricultural runoff, improper waste disposal, industrial discharges, and rapid urbanization[5]. Agricultural activities, in particular, contribute significantly to groundwater contamination. The use of chemical fertilizers, pesticides, and herbicides often results in the leaching of harmful substances into the underlying aquifers, compromising water quality[6]. Similarly, industrial discharges, often containing heavy metals and hazardous chemicals, contribute to the degradation of groundwater resources[7]. Urbanization exacerbates the issue by increasing the concentration of pollutants, as unregulated construction, poor drainage systems, and the absence of effective waste management systems contribute to groundwater contamination[8].

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In Nigeria, groundwater serves as the primary source of drinking water for a significant proportion of the population, particularly in areas where public water supply systems are

either unavailable or unreliable[9]. Groundwater sources such as boreholes and wells have become indispensable for meeting the water needs of urban and rural communities alike[10]. These sources provide water for a range of domestic uses, including drinking, cooking, and sanitation, as well as for agricultural and industrial applications[11]. However, the increasing dependence on groundwater has not been matched by adequate regulatory oversight or infrastructure for monitoring and protecting these resources[12].Contaminants in groundwater, particularly heavy metals, pose serious health risks even in trace amounts[13]. Heavy metals such as zinc (Zn), cadmium (Cd), copper (Cu), and arsenic (As) are known to have toxic effects on human health, including neurological disorders, kidney damage, and increased risks of cancer[14]. Chronic exposure to these metals through contaminated drinking water can result in long-term health complications, particularly for vulnerable populations such as children, pregnant women, and the elderly[15]. Additionally, the presence of other pollutants, including nitrates, sulfates, and microbial pathogens, further exacerbates the risks associated with groundwater consumption[16].

In the context of Mowe Ibafo, Ogun State, the lack of comprehensive data on groundwater quality limits the ability of stakeholders to address emerging challenges effectively[17]. Existing studies on groundwater contamination in Nigeria have primarily focused on broader regional patterns, with limited attention to localized areas such as Mowe Ibafo Ogun State[18]. This gap in knowledge hinders the development of targeted interventions and policies aimed at safeguarding groundwater resources[19]. Moreover, the absence of systematic monitoring and regulatory frameworks allows contamination sources to persist unchecked, further compromising water quality over time[20].

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Given these concerns, this study aims to address the critical gap in knowledge by examining the physicochemical properties and heavy metal concentrations of groundwater in Mowe Ibafo Ogun State. Physicochemical properties, including parameters such as pH, electrical conductivity, total dissolved solids, and turbidity, provide valuable insights into the quality and safety of water for various uses. Meanwhile, the analysis of heavy metal concentrations enables the identification of specific contaminants and their potential sources. By comparing the findings with international and local water quality standards, this research seeks to assess the suitability of groundwater in Mowe Ibafo, Ogun State for human consumption and other applications. An understanding of groundwater quality in Mowe Ibafo, Ogun State and other urbanizing communities in Nigeria is anticipated to be greatly enhanced by the study's results, which will serve as a foundation for the creation of evidence-based plans to reduce the risk of contamination and guarantee the sustainable management of groundwater resources.

1.2 Statement of the Problem

The assessment of groundwater quality in Mowe Ibafo, Ogun State, is crucial due to increasing population growth, urbanization, and industrial activities in the region, which may lead to contamination and depletion of this vital resource. Groundwater serves as the primary source of potable water for local communities, but with limited monitoring, the sustainability and safety of this water source remain uncertain. This study aims to assess the physicochemical parameters and level heavy metals of groundwater in Mowe Ibafo to determine its potability and identify potential pollutants. relevant parameters such as PH, total dissolved solid, chloride, phosphate, nitrate will be analyzed to evaluate water quality. Additionally, the study will investigate the potential anthropogenic activities that contribute to groundwater contamination, such as industrial activities and agricultural

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practices. The findings will provide critical data to inform water management policies and safeguard public health in the study area.

1.3 Justification of the Study

The justification for this study lies in the critical role that groundwater plays in ensuring water security, public health, and sustainable development, particularly in regions experiencing rapid urbanization, Groundwater serves as a primary source of water for domestic, agricultural, and industrial use, making its quality and availability essential for socioeconomic stability. However, escalating urban expansion, agricultural practices, and industrial activities have significantly increased the risk of groundwater contamination and over exploitation. This has far-reaching implications for public health, food security, and environmental sustainability.

The challenges associated with groundwater quality and availability are particularly acute. Many urban and peri-urban areas face water scarcity and contamination due to inadequate management practices, poor infrastructure, and insufficient regulatory frameworks. The presence of heavy metals and other pollutants in groundwater poses a severe threat to human health, especially in regions where access to alternative water sources is limited. Furthermore, the lack of comprehensive data and consistent monitoring systems exacerbates the issue, hindering effective policy formulation and implementation.

This study is justified by the pressing need to address these challenges through a detailed assessment of groundwater quality, pollution sources, and management practices. By providing a nuanced understanding of these issues, the research will contribute to developing sustainable strategies for groundwater protection and efficient use in Nigeria. Moreover, the findings will support policymakers, environmental agencies, and other stakeholders in implementing evidence-based interventions to mitigate risks and promote

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long-term water security. Ultimately, the study aligns with global efforts to achieve the Sustainable Development Goals (SDGs), particularly Goal 6, which focuses on ensuring access to clean water and sanitation for all.

1.4 Aim and Objectives of the Study

The aim of this study is to evaluate the water quality parameters in ground water of Residential Areas in Mowe Ibafo, Ogun State.

The specific objectives include:

1. To ascertain the groundwater physiochemical parameters in Mowe Ibafo, Ogun state.
2. To determine the level of heavy metals that is present in the groundwater in Mowe Ibafo, Ogun State.
3. To assess heavy metal contamination in groundwater and link it to land use practices, using certain indices

1.5 Research Questions

1. What are the physicochemical parameters of groundwater samples from Mowe Ibafo Residential Area?
2. What is the concentration of heavy metals in groundwater samples from Mowe Ibafo Residential Area?
3. Do groundwater samples from Mowe Ibafo Residential Area meets WHO water quality guideline?

1.6 Significance of the Study

This work is important because it helps manage, preserve, and comprehend groundwater resources in rapidly urbanizing places like Mowe Ibafo, Nigeria. A vital supply of fresh water is groundwater, especially in areas with inadequate or contaminated surface water

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supplies. Rapid population increase and urbanization, however, frequently put groundwater supplies under tremendous strain, which results in contamination and overextraction. These issues are clarified by this study, which also provides practical advice for overcoming them, This study is crucial as it aims to provide a comprehensive analysis of the current status of groundwater quality in Mowe Ibafo. By assessing key contaminants such as heavy metals, and physicochemical parameters the study will help determine whether the groundwater is safe for consumption and other uses. It will also identify the sources of contamination, including industrial waste, agricultural runoff, and inadequate sanitation, providing vital data that has been lacking in the region. The findings of this study will offer valuable insights for local authorities, policymakers, and environmental agencies, enabling them to design and implement effective water management strategies. By pinpointing pollution hotspots and understanding contamination levels, the study will guide the development of sustainable practices that ensure the protection and safe use of groundwater resources..

1.7 Scope of the Study

This study focuses on evaluating the quality of groundwater in Mowe Ibafo, a rapidly urbanizing area near Lagos, Nigeria. Given its dependence on groundwater as a primary water source, this region serves as a critical case study for understanding the broader implications of urbanization and inadequate environmental management on water quality.

The study is primarily concerned with two major aspects of groundwater quality: physicochemical properties and heavy metal contamination. These include parameters such as pH, turbidity, dissolved oxygen, and the presence of heavy metals such as cobalt (Co), iron (Fe), cadmium (Cd), copper(Cu) ,zinc (Zn), manganese (Mn) and arsenic (As). By examining these factors, the research aims to provide a comprehensive picture of the

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groundwater's suitability for human consumption and other domestic uses. Additionally, the study considers the health risks posed by the identified contaminants, highlighting their potential impact on the community's well-being.

1.8 Limitations of the Study

This study acknowledges certain limitations that may impact its scope and findings. One of the challenges is the variability of groundwater conditions across different regions of Nigeria. Groundwater contamination and quality issues are influenced by local geological, hydrological, and anthropogenic factors, making it difficult to generalize findings to the entire country. The study is focused on selected urban and peri-urban areas, which may not comprehensively represent rural regions where groundwater is equally vital.

Furthermore, resource constraints, including time and funding, limit the extent of fieldwork and laboratory analyses that can be conducted. This restricts the depth of the study's primary data collection efforts and its ability to explore long-term trends in groundwater quality comprehensively. Despite these limitations, the study aims to provide valuable insights to inform sustainable groundwater management practices.

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Chapter Two

Literature Review

2.1 Water Quality and Groundwater Contamination

Groundwater is one of the most vital natural resources, providing essential support for both human and environmental sustainability[1]. It is a crucial element of the Earth's hydro logical system and is responsible for maintaining ecosystems, replenishing aquifers, and sustaining various human activities. According to estimates, groundwater constitutes about 30% of the world's total freshwater supply[2], a significant amount considering the increasing global demand for clean and reliable water sources. This resource is indispensable for countless uses, from drinking water for households and agricultural irrigation to supporting industrial processes and economic activities. The increasing dependence on groundwater, particularly in regions where surface water is limited or unavailable, underscores its critical importance in sustaining communities and ecosystems across the globe.

The global reliance on groundwater is underscored by its extensive use in various sectors. Nearly half of the global population depends on groundwater as their primary source of drinking water[3]. This is particularly true in many developing regions, where surface water sources may be scarce or contaminated, making groundwater the most reliable and often the only viable source of potable water. In addition to providing drinking water, groundwater plays a crucial role in agriculture. It serves as a vital irrigation resource in areas where rainfall is irregular or insufficient to support crops. This is especially critical in regions where agriculture is the backbone of the economy, and crop yields are heavily dependent on consistent and reliable irrigation.

Groundwater is also an essential component in industrial processes, especially in industries that require large amounts of water for cooling, processing, and cleaning.

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Mining, manufacturing, and energy production industries all rely heavily on groundwater as a primary water source. In these settings, groundwater can be used not only for direct consumption but also for secondary uses such as cooling systems, washing raw materials, or even for wastewater treatment purposes. Therefore, the quality of groundwater is a critical factor in determining its suitability for these various purposes[4]. Whether used for domestic, agricultural, or industrial purposes, the safety and purity of groundwater are fundamental to human health and economic development. Polluted or contaminated groundwater can pose significant risks to human well-being, ranging from acute waterborne diseases to long-term health issues such as cancer and neurological disorders.

However, despite its significance, groundwater quality has increasingly come under threat in many parts of the world. The rapid pace of industrialization, urbanization, and population growth in the last century has placed an enormous strain on natural resources, including groundwater. Industrial activities, such as mining, manufacturing, and energy production, have introduced a wide range of contaminants into groundwater systems. Heavy metals, chemicals, and toxic substances from industrial waste have seeped into aquifers and contaminated underground water reserves, making them unsafe for human consumption and agricultural use. Similarly, agricultural activities, particularly the use of fertilizers, pesticides, and herbicides, have significantly contributed to groundwater contamination. These chemicals, while essential for modern farming, have led to the leaching of harmful substances into the groundwater, affecting both the quality of water and the surrounding ecosystems. The impact of these contaminants is not only felt by human populations but also by the natural environment. Contaminated groundwater can adversely affect plant and animal life that relies on clean water sources, disrupting entire ecosystems and threatening biodiversity.

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Table 2.1: The Difference Between Water Quality And Ground Water Contamination

Aspect	Water Quality	Groundwater Contamination
Definition	The physical, chemical, and biological characteristics of water that determine its suitability for use.	The presence of harmful substances in groundwater that degrade its safety and usability.
Focus	Ensuring that water is clean, safe, and suitable for drinking, agriculture, and industry.	Identifying and preventing pollutants from affecting groundwater sources.
Causes	Natural mineral content, water source, and treatment processes.	Industrial waste, agricultural runoff, sewage discharge, and urbanization.
Measurement	Assessed using indicators like pH, dissolved oxygen, turbidity, and contaminant levels.	Evaluated by detecting pollutants such as heavy metals, pesticides, bacteria, and nitrates.
Impact on Health	Good water quality promotes health and well-being.	Contaminated groundwater can cause diseases like cholera, cancer, and neurological disorders.
Environmental Impact	Supports biodiversity and healthy ecosystems.	Leads to ecosystem disruption, affecting plant and animal life.
Management Strategies	Water treatment, filtration, and regular quality monitoring.	Pollution control, sustainable land use, and stricter industrial regulations.

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In addition to industrial and agricultural pollution, urbanization has played a crucial role in the deterioration of groundwater quality. As cities expand and populations grow, the demand for water increases, leading to over-extraction of groundwater resources. Over-extraction, often without adequate recharge, results in a phenomenon known as groundwater depletion. In many urban centers, this has led to falling water tables and the drying up of wells. Moreover, urban areas contribute to groundwater contamination through the discharge of untreated sewage and wastewater into underground water sources. The high density of infrastructure, such as roads, buildings, and sewage systems, in urban environments exacerbates the risk of contamination, as pollutants from various sources, such as domestic waste, runoff, and industrial discharges, find their way into aquifers.

Additionally, rapid urbanization often leads to the construction of poorly managed landfills and waste disposal sites, which, over time, contribute to the leaching of hazardous chemicals and heavy metals into the groundwater. While modern landfills are designed to minimize such risks, in many developing regions, outdated waste disposal practices continue to be prevalent, exacerbating the contamination of groundwater resources. This urban-centric pollution can also result in the salinization of groundwater, particularly in coastal areas, where the over-extraction of groundwater causes seawater to intrude into freshwater aquifers.

The vulnerability of groundwater to contamination is also influenced by climate change, which affects precipitation patterns, groundwater recharge rates, and the availability of fresh water. As global temperatures rise, many regions are experiencing more extreme weather events, such as droughts and floods, which affect the availability and quality of groundwater. Extended periods of drought reduce the natural replenishment of aquifers,

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leading to over-extraction and contamination of existing groundwater supplies. On the other hand, heavy rainfall and flooding can cause surface water to infiltrate aquifers, carrying with it contaminants such as bacteria, chemicals, and sediment. This dynamic further complicates the challenge of maintaining clean and accessible groundwater resources, especially in regions where climate variability is becoming more pronounced.

Furthermore, the increasing global population, particularly in urban areas, further intensifies the pressure on groundwater resources. As cities and towns expand to accommodate growing populations, demand for water increases, often leading to over-extraction of groundwater reserves. In some regions, the rate of extraction far exceeds the natural replenishment rate, resulting in the depletion of aquifers and the deterioration of groundwater quality. This exacerbates the risk of water scarcity, particularly in areas where surface water resources are already limited or polluted.

The contamination of groundwater, therefore, represents a multifaceted challenge that requires concerted efforts at local, regional, and global levels to mitigate its impact. Sustainable groundwater management strategies are essential to ensure that this invaluable resource remains available for future generations. Governments, industries, and local communities must work together to adopt policies and technologies that promote the responsible extraction and protection of groundwater. Additionally, there is a need for enhanced monitoring of groundwater quality, particularly in areas prone to contamination, to detect harmful substances early and prevent the widespread deterioration of water quality. Public education campaigns on the importance of groundwater conservation and protection can also play a significant role in raising awareness and fostering collective responsibility for this shared resource.

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Groundwater remains one of the most critical resources for sustaining human life and the environment. However, its vulnerability to contamination from industrial, agricultural, and urban activities has raised serious concerns about its future availability and quality. Ensuring the continued viability of groundwater as a reliable resource requires comprehensive and coordinated efforts to reduce pollution, promote sustainable extraction practices, and protect this essential resource for future generations. Without such efforts, the availability of clean and safe groundwater could be severely compromised, impacting human health, food security, and overall environmental well-being[5].

2.1.1 Importance of Groundwater Quality

Groundwater quality is crucial for both environmental sustainability and human health.[6] Clean groundwater serves as a vital source of drinking water for billions of people, especially in regions where surface water is scarce or unreliable[7]. Poor groundwater quality, due to contamination from pollutants like industrial waste, agricultural runoff, or improper waste disposal, can lead to serious health issues, including waterborne diseases, poisoning from heavy metals, and long-term chronic illnesses[8]. Additionally, groundwater supports agricultural irrigation, which is essential for food production. If contaminated, it can negatively affect crop yields and food safety[9]. Groundwater quality also plays a role in maintaining the ecological balance of aquatic systems and ecosystems dependent on underground water supplies[11].

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1. **Ensuring Safe Drinking Water**

a. Groundwater serves as the primary source of drinking water in many rural and urban communities.

b. Good quality groundwater prevents waterborne diseases caused by microbial

contamination (e.g., E. coli, coliforms) and chemical pollutants (e.g., nitrates, heavy metals).

c. Safe drinking water supports public health, reduces morbidity and mortality, and enhances overall community well-being.

2. Domestic and Household Applications

a. Clean groundwater is essential for bathing, cooking, laundry, cleaning, and other domestic activities.

b. Contaminated water can cause skin irritation, gastrointestinal disorders, and eye infections, directly affecting quality of life.

c. Availability of safe groundwater improves household hygiene and sanitation standards.

3. Environmental and Ecosystem Support

a. Groundwater maintains wetlands, rivers, lakes, and soil moisture, which are critical for supporting plants, animals, and biodiversity.

b. It regulates aquatic ecosystems by ensuring water supply during dry seasons.

c. Poor-quality groundwater can disrupt ecosystems, reduce species diversity, and impair natural ecological processes.

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2.1.2 Natural Factors Contributing to Contamination

Some groundwater contamination arises from natural factors. Aquifers may naturally contain elevated levels of certain elements, such as arsenic or fluoride[14]. In regions with volcanic activity or high geothermal gradients, heavy metals like selenium or mercury

may leach into the water system . Similarly, high salinity in coastal aquifers often results from seawater intrusion[15].

Natural contamination, while less frequent than anthropogenic sources, presents unique challenges. For example, the Indo-Gangetic Plain in South Asia is known for its arsenic-rich groundwater[16], affecting millions of residents. In Nigeria, certain regions report high levels of fluoride, contributing to dental fluoroscopic in affected populations[17]. Addressing these natural issues often requires advanced treatment technologies that are not readily accessible in resource-limited settings[18].While human activities are major contributors to groundwater contamination, natural (geogenic) factors also play an important role. These factors arise from the natural composition of soil, rocks, and hydrological processes, which can introduce minerals, metals, and other contaminants into groundwater. Understanding natural sources is essential for differentiating between anthropogenic and geogenic pollution. Groundwater contamination is not always caused by human activities. Natural factors arising from geology, hydrology, and geochemical processes can introduce contaminants into aquifers. These factors are important to consider when assessing groundwater quality[19].

1. Geological and Lithological Factors

a. Rock Composition, Groundwater flowing through mineral-rich rocks can dissolve metals such as iron (Fe), manganese (Mn), arsenic (As), and fluoride (F^-).

b. Soil Minerals, Certain soils naturally contain high levels of salts or heavy metals that leach into groundwater.

c. Faults and Fractures, Cracks in rocks and soils allow contaminants to move directly into aquifers.

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2. Geochemical Processes

a. Dissolution of Minerals, Natural minerals in rocks and sediments dissolve into groundwater over time.

b. Oxidation-Reduction Reactions, Can release metals like arsenic and iron into groundwater.

c. Weathering, Physical and chemical breakdown of rocks releases natural contaminants.

4. Hydrological Factors

a. Groundwater Flow, Water movement can transport naturally occurring contaminants through aquifers.

b. Recharge from Rainwater or Rivers, Can carry dissolved minerals from surface to groundwater.

c. Shallow Aquifers, More vulnerable to natural contamination due to shorter filtration pathways.

4. Organic Matter

a. Decaying Vegetation, Releases natural compounds such as humic and fulvic acids into groundwater.

b. These compounds can interact with metals and affect water chemistry.

5. Volcanic and Geothermal Activity

a. Volcanic rocks and geothermal regions may naturally enrich groundwater with arsenic, boron, fluoride, and other trace metals.

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b. Thermal springs often contain naturally high levels of dissolved minerals[20].

6. Natural Salinity

a. Saltwater Intrusion: In coastal areas, seawater mixes with freshwater aquifers, increasing chloride and sodium content.

b. Evaporation in Arid Regions: Leads to high salt concentrations in shallow groundwater.

2.1.3 Anthropogenic Sources of Contamination

Human activities contribute significantly to groundwater contamination[21]. The discharge of untreated industrial effluents is a major concern, introducing hazardous chemicals such as cadmium, chromium, and lead into aquifers[22]. Similarly, the overuse of pesticides and fertilizers in agricultural practices often results in nitrate contamination[23]. High nitrate levels are particularly concerning in rural areas reliant on shallow wells for drinking water[24].Groundwater contamination can originate from natural sources such as mineral dissolution in rocks, but human activities anthropogenic sources are the major contributors to groundwater pollution in urban and peri-urban areas. Anthropogenic activities introduce harmful chemicals, pathogens, and heavy metals into the subsurface, threatening water quality and public health.

Urbanization exacerbates contamination through improper waste management[25]. Leachates from landfills, septic tanks, and open dumpsites percolate into aquifers, introducing organic and inorganic pollutants. A case study in Lagos, Nigeria, highlighted significant groundwater pollution caused by uncontrolled urban sprawl[27]. In addition, oil exploration activities in the Niger Delta have been associated with hydrocarbon contamination of groundwater[26].

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Groundwater quality is significantly influenced by human activities, which introduce microbial, chemical, and physical pollutants into aquifers. Anthropogenic contamination is a major concern in areas experiencing rapid urbanization, industrialization, and agricultural development, such as Mowe Ibafo. Understanding these sources is essential for designing effective monitoring, management, and mitigation strategies.

1. Domestic and Household Activities

a. Sewage and Wastewater: Improperly managed sewage from homes and communities, including leaking septic tanks and pit latrines, introduces pathogens, nitrates, phosphates, and organic matter into groundwater.

b. Domestic Waste Disposal: Household chemicals, detergents, and pharmaceuticals leach into soil and percolate to aquifers.

c. Health Implications: Increased risk of microbial infections, waterborne diseases, and chemical toxicity[27]

2. Industrial Activities

a. Factories and manufacturing plants release heavy metals, dyes, solvents, hydrocarbons, and chemical effluents.

b. Improper disposal or accidental spills lead to infiltration into groundwater.

c. Examples: Lead, cadmium, chromium, and nickel contamination from metal processing; petroleum hydrocarbons from fuel storage.

d. Impacts: Toxicity, carcinogenic effects, and ecological damage.

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3. Agricultural Activities

a. Fertilizers: Excessive use introduces nitrates, phosphates, and potassium, which can leach into aquifers.

b. Pesticides and Herbicides: Chemicals like organophosphates, carbamates, and glyphosate contaminate groundwater.

c. Livestock Farming: Animal waste contributes microbial pathogens and nutrients.

d. Consequences: Eutrophication, soil degradation, and health risks from chemical exposure.

4. Urbanization and Land Development

a. Construction activities disturb soil layers and increase surface runoff, carrying pollutants into groundwater recharge areas[28].

b. Impermeable surfaces such as roads and pavements reduce natural filtration, concentrating contaminants.

c. Impacts: Increased turbidity, heavy metal load, and contamination from urban runoff.

5. Solid Waste Disposal and Landfills

a. Leachates from dumpsites and landfills contain heavy metals, organic pollutants, plastics, and toxic chemicals.

b. Poorly managed waste disposal allows these substances to infiltrate aquifers.

c. Consequences: Severe groundwater pollution and long-term ecological damage.

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2.1.4 Health Implications of Groundwater Contamination

Groundwater contamination poses serious health risks, especially in regions where alternative water sources are unavailable[29]. Heavy metals such as lead, cadmium, and arsenic are known to cause neurological, developmental, and carcinogenic effects[30]. Nitrate contamination has been linked to methemoglobinemia or "blue baby syndrome" in infants[31]. Microbial contamination is another significant concern, especially in areas with inadequate sanitation[32]. Pathogens like *Escherichia coli*, *Salmonella*, and *Vibrio cholerae* are frequently detected in polluted aquifers[33]. In Nigeria, groundwater outbreaks of cholera and typhoid fever have been attributed to poor water quality[34]. Addressing these issues requires a multi-pronged approach, including improved water monitoring, effective treatment technologies, and community education. Groundwater can be contaminated by bacteria, viruses, protozoa, and parasites, often originating from sewage, pit latrines, and animal waste

a. Common Pathogens like Escherichia coli, Salmonella, Vibrio cholerae, Giardia, Cryptosporidium.

b. Health Impacts: Diarrhea, dysentery, and gastroenteritis,

c. typhoid and cholera outbreaksHepatitis A and E

d. Infant and child mortality in severe cases

e. Chronic Exposure: Repeated exposure to low-level microbial contamination can cause long-term gastrointestinal disorders and weaken immunity.

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2.1.5 Global Efforts and Regulatory Frameworks

International organizations like the WHO and the United Nations have emphasized the need for sustainable groundwater management[36]. Sustainable Development Goal 6 (SDG 6) aims to ensure access to safe water and sanitation for all by 2030[37]. Countries have also developed national policies and standards to regulate water quality[38]. For instance, Nigeria's National Water Policy outlines measures for monitoring, assessment, and enforcement of groundwater quality standards[39]. However, challenges remain. Limited financial and technical resources hinder effective implementation of these frameworks, particularly in developing countries[40]. In addition, the lack of public awareness about water quality issues further complicates efforts to address contamination.

2.1.5.1 Global Recognition of Groundwater Importance

Internationally, groundwater has been recognized as a vital freshwater resource requiring protection and sustainable management:

1. United Nations (UN) Initiatives: The UN Sustainable Development Goals (SDGs), particularly Goal 6: Clean Water and Sanitation, emphasize access to safe drinking water and sustainable management of water resources, including groundwater.

2. World Health Organization (WHO): WHO develops guidelines for drinking water quality, including permissible limits for chemical and microbial contaminants in groundwater.

3. United Nations Educational, Scientific and Cultural Organization (UNESCO): Through the International Groundwater Resources Assessment Centre (IGRAC), UNESCO promotes global groundwater monitoring, management, and data sharing.

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4. World Bank and FAO: These organizations support projects to monitor groundwater quality, implement sustainable irrigation practices, and reduce contamination in vulnerable regions[41].

Groundwater has increasingly been recognized as one of the most critical freshwater resources worldwide due to its reliability, sustainability, and role in human and ecological systems. Unlike surface water, which is subject to seasonal fluctuations, groundwater provides a stable source of water year-round, making it vital for drinking water, agriculture, industry, and ecosystem maintenance. International organizations, governments, and research institutions have emphasized its protection and sustainable management through policies, initiatives, and monitoring programs

2.1.6 Advancements in Monitoring and Assessment

Recent advancements in water quality assessment have improved our ability to monitor groundwater contamination[42]. Techniques such as atomic absorption spectroscopy (AAS) and inductively coupled plasma mass s*pectrometry* (ICP-MS) provide accurate measurements of trace elements[43]. In microbial analysis, polymerase chain reaction (PCR) techniques have enhanced the detection of pathogenic organisms[44].

Pollution indices, including the Heavy Metal Pollution Index (HPI) and the Groundwater Quality Index (GQI), have been developed to simplify the evaluation of water quality data[45]. These tools enable researchers and policymakers to assess contamination levels and prioritize interventions[46]. Despite these advancements, data gaps remain a significant challenge, particularly in under-researched regions[47].

Monitoring and assessment of groundwater quality are essential for ensuring safe water supply, environmental protection, and sustainable resource management. Traditional methods relied on manual sampling and laboratory analyses, which, although effective,

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were time-consuming, labor-intensive, and limited in spatial and temporal coverage. Recent technological advancements have transformed groundwater monitoring, enabling real-time, precise, and large-scale assessments. These advancements are critical for areas like Mowe Ibafo, where groundwater contamination from industrial, agricultural, and urban activities is a growing concern.

1. Traditional Groundwater Monitoring Methods

Historically, groundwater quality assessment involved:

a. Manual sampling of wells, boreholes, and springs.

b. Laboratory analysis for physicochemical parameters (pH, EC, TDS, hardness, major ions) and microbial contaminants.

c. Use of basic field instruments for temperature, turbidity, and dissolved oxygen (DO).

Limitations:

a. Delayed results due to laboratory processing time.

b. Limited spatial coverage.

c. Inability to detect rapid changes in water quality.

d. High labor and operational costs.

2. Modern Instrumentation and Sensors:

a. Multi-Parameter Probes; Measure several water quality parameters simultaneously, including pH, EC, TDS, DO, temperature, and turbidity, Provide instant readings,

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reducing the need for frequent laboratory analysis. Portable and suitable for field monitoring, enabling rapid assessment of groundwater sources.

b. Electrochemical and Optical Sensors: Ion-selective electrodes (ISEs): Detect specific ions like nitrate, fluoride, and heavy metals in real time, Optical sensors: Measure parameters such as turbidity, chlorophyll, and organic content using light absorption techniques.High sensitivity allows detection of trace pollutants at low concentrations.

3. Remote Sensing and Geographic Information Systems (GIS)

a. Remote sensing (satellite or drone-based) monitors surface features, vegetation cover, and potential contamination sources that affect groundwater recharge areas.

b. GIS enables spatial mapping of groundwater quality, contamination hotspots, and vulnerability zones.

c. Integration of remote sensing and GIS allows predictive modelling and assessment of contamination spread.

4: Advanced Laboratory Techniques

a. Spectroscopic Techniques, Atomic Absorption Spectrophotometry (AAS): Detects metals like lead, cadmium, and iron with high sensitivity, Inductively Coupled Plasma-Mass Spectrometry (ICP-MS): Allows detection of multiple trace metals simultaneously at extremely low concentrations. UV–Visible Spectrophotometry: Rapid determination of nitrates, phosphates, and organic pollutants.

b. Chromatographic Techniques ,High-Performance Liquid Chromatography (HPLC) and Gas Chromatography-Mass Spectrometry (GC-MS) detect pesticides, hydrocarbons, and

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emerging contaminants. Essential for detecting persistent organic pollutants that are not captured by conventional methods.

Advancements in monitoring and assessment of groundwater quality—from multi-parameter sensors and remote sensing to AI-driven modelling have transformed how groundwater is evaluated. These technologies enable accurate, rapid, and comprehensive assessment of water quality, supporting public health protection, environmental sustainability, and informed water resource management. In regions like Mowe Ibafo, adopting these advanced monitoring techniques is critical for preventing contamination, ensuring safe water supply, and promoting sustainable development.

2.1.7 Case Studies of Groundwater Contamination

Internationally, the contamination of groundwater with per- and polyfluoroalkyl substances (PFAS) has raised significant concern[50]. PFAS, often referred to as "forever chemicals," are widely used in industrial applications and have been detected in aquifers across the United States, Europe, and parts of Asia[51]. These chemicals are resistant to natural degradation and accumulate over time, posing long-term risks to human and environmental health[52].Another noteworthy example is the arsenic crisis in Bangladesh, where millions rely on arsenic-contaminated wells for drinking water[53]. This contamination has been linked to severe health problems, including skin lesions, cancer, and cardiovascular diseases[54].

In Nigeria, rural communities often face microbial contamination due to the proximity of wells to latrines or open defecation sites[55]. Studies in Mowe-Ibafo have demonstrated that poor waste management practices significantly increase coliform counts in groundwater, rendering it unsafe for consumption[56]. These case studies highlight the diverse sources

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and impacts of groundwater contamination, underscoring the need for targeted interventions and long-term monitoring[57].

2.2 Physicochemical Parameters of Groundwater

Groundwater quality assessment is a crucial process in ensuring the safety and sustainability of water resources for various uses, including drinking, irrigation, and industrial applications. One of the fundamental steps in this assessment is the evaluation of its physicochemical parameters. These parameters offer a detailed understanding of the water's quality, helping to determine its suitability for human consumption, agricultural productivity, and industrial processes. The analysis of physicochemical properties provides insights into the presence of contaminants, natural characteristics, and the overall health of groundwater systems. Among the most critical parameters in groundwater quality assessment are pH, total dissolved solids (TDS), electrical conductivity (EC), hardness, and the concentration of both essential and non-essential elements[58].

The pH of groundwater is one of the most important physicochemical parameters, as it indicates the acidity or alkalinity of the water. The pH scale ranges from 0 to 14, with values below 7 indicating acidity, values above 7 indicating alkalinity, and a value of 7 representing neutrality. The pH of groundwater plays a significant role in determining the solubility and availability of nutrients and contaminants in the water. For instance, acidic water (with a pH lower than 7) can increase the solubility of heavy metals, such as lead, cadmium, and copper, which can be toxic to human health and ecosystems. On the other hand, highly alkaline water (with a pH above 7) may cause issues such as the formation of scale deposits in pipes and equipment, reducing their efficiency[59].

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The pH of groundwater is influenced by various factors, including the geological composition of the aquifer, the presence of organic matter, and anthropogenic activities such as industrial waste disposal and agricultural runoff. Groundwater in limestone-rich regions, for example, tends to be more alkaline due to the dissolution of calcium carbonate, while groundwater in areas with a high presence of organic materials may become more acidic due to natural decomposition processes. Anthropogenic activities, such as mining, agricultural practices, and wastewater discharge, can also contribute to changes in groundwater pH. For example, the use of nitrogen-based fertilizers in agriculture can lead to the acidification of groundwater due to the formation of nitric acid in the water.

Total dissolved solids (TDS) refer to the combined concentration of all dissolved substances in water, including minerals, salts, and organic materials. TDS is an important parameter in groundwater quality assessment because it provides an overall measure of the water's salinity or mineral content. High TDS levels can affect the taste of drinking water and may render it unsuitable for irrigation and industrial use. Elevated TDS levels in groundwater often indicate the presence of dissolved ions such as sodium, chloride, and sulfate, which can have detrimental effects on human health and the environment. For example, excessive sodium concentrations in groundwater can lead to soil salinization, which negatively impacts agricultural productivity by reducing the soil's ability to retain moisture and nutrients[60].

TDS is influenced by various factors, including the geological composition of the aquifer, the recharge rate of groundwater, and human activities. In arid regions, groundwater may naturally have high TDS levels due to the dissolution of minerals in the surrounding rocks. Similarly, the over-extraction of groundwater can increase the concentration of dissolved

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substances, as the water table declines and more minerals are brought into contact with the aquifer. Anthropogenic activities such as mining, industrial processes and the use of fertilizers and pesticides can also contribute to increased TDS levels in groundwater. For example, the leaching of chemicals from agricultural fields into the groundwater can raise the TDS levels, making the water unsuitable for human consumption and agricultural irrigation.

Electrical conductivity (EC) is another important physicochemical parameter that is often used to assess groundwater quality. EC measures the ability of water to conduct electricity, which is directly related to the concentration of dissolved ions in the water. A higher EC indicates a greater concentration of dissolved salts and minerals, while a lower EC indicates purer water. EC is often used as a proxy for TDS, as both parameters are correlated, with higher TDS levels generally resulting in higher EC values. EC is useful in identifying the salinity of groundwater and assessing its suitability for irrigation, as high salinity can have adverse effects on plant growth and soil structure. In industrial applications, high EC values may also indicate the presence of dissolved chemicals that could interfere with manufacturing processes[58].

Hardness is another key parameter in groundwater quality assessment, as it is related to the concentration of calcium and magnesium ions in the water. Hard water can cause the buildup of scale in pipes, boilers, and other equipment, leading to increased maintenance costs and reduced efficiency. While hardness does not typically pose a direct threat to human health, it can affect the effectiveness of soap and detergent, making it harder to clean clothes and dishes. Hardness is generally classified into three categories: soft, moderately hard, and hard. Soft water has low concentrations of calcium and magnesium, while hard water has higher concentrations. Groundwater in areas with limestone or

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gypsum deposits tends to be harder due to the dissolution of calcium and magnesium salts in the aquifer[59]. In addition to these basic physicochemical parameters,the concentration of essential and non-essential elements in groundwater is an important

aspect of its quality. Essential elements, such as calcium, potassium, and magnesium, are required for human health and plant growth. In contrast, non-essential elements, such as arsenic, mercury, and lead, can be toxic to humans and the environment, even at low concentrations. The presence of non-essential elements in groundwater can occur naturally due to the dissolution of minerals in the surrounding rocks, or as a result of anthropogenic activities, such as mining, industrial discharges, and agricultural runoff. For example, groundwater in areas with naturally occurring arsenic deposits can become contaminated with high levels of arsenic, posing a significant health risk to those who rely on it for drinking water.

Human activities such as industrial waste disposal, mining, and the use of pesticides and fertilizers can introduce non-essential elements into groundwater systems. These contaminants can remain in the water for extended periods, as groundwater is often slow to recharge and may not be easily filtered by natural processes. Long-term exposure to toxic elements in groundwater can lead to a variety of health issues, including neurological disorders, kidney damage, and cancer. Therefore, the assessment of essential and non-essential elements in groundwater is a critical component of water quality monitoring, helping to identify potential risks to human health and the environment[60].

Groundwater quality assessment also involves the identification of potential sources of contamination and the development of strategies to mitigate these risks. Natural geological processes, such as the dissolution of minerals and the leaching of substances from rocks, can contribute to changes in groundwater quality. However, human activities,

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including industrial processes, urbanization, and agricultural practices, have become the primary drivers of groundwater contamination. Effective groundwater management requires understanding the relationship between physicochemical parameters and the potential sources of contamination, as well as implementing policies and technologies that protect this vital resource.

Groundwater quality assessment is an essential process in ensuring that this critical resource remains safe for various uses. The evaluation of physicochemical parameters, including pH, TDS, EC, hardness, and the concentration of essential and non-essential elements, provides valuable insights into the water's quality and its suitability for drinking, irrigation, and industrial purposes. Variations in these parameters are influenced by both natural processes and anthropogenic activities, making it essential to monitor groundwater quality regularly to detect potential risks and ensure sustainable water management practices. As the demand for clean water continues to rise globally, it is increasingly important to protect and preserve groundwater resources for future generations[60].

2.2.1 Importance of Monitoring Physicochemical Parameters

Monitoring physicochemical parameters is vital for understanding and managing environmental quality, particularly in water, soil, and air. In an MSc project, this monitoring provides critical data for assessing the health of ecosystems, detecting conta mination, and ensuring regulatory compliance[61]. For instance, parameters such as pH, dissolved oxygen, turbidity, and concentrations of heavy metals are key indicators of water quality[62]. Tracking these factors helps in identifying pollution sources, such as industrial discharge or agricultural runoff, which can negatively affect both human health and biodiversity[63].

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Physicochemical parameters also play a crucial role in sustainable resource management[64]. In agriculture, monitoring soil pH, nutrient levels, and salinity ensures optimal crop growth and food safety[65], while in water management, it aids in maintaining safe drinking water and preventing eutrophication[66]. By regularly monitoring these parameters, early warning systems can be established to detect changes that may lead to ecological degradation or public health risks[67].

2.2.2 Key Physicochemical Parameters

2.2.2.1 pH

The pH of groundwater typically ranges from 6.5 to 8.5, as recommended by the WHO[68]. However, deviations can occur due to factors such as mineral dissolution, industrial discharge, and agricultural runoff[69]. Acidic groundwater (pH < 6.5) is often associated with the dissolution of heavy metals like iron and manganese, which can pose health risks[70]. Conversely, alkaline groundwater (pH > 8.5) may indicate the presence of bicarbonates or carbonate rocks[71].

2.2.2.2 Total Dissolved Solids (TDS)

TDS is a measure of the combined content of all inorganic and organic substances dissolved in water[72]. High TDS levels (>1000 mg/L) can impart a salty taste to water and cause scaling in pipelines and appliances[73]. Low TDS levels, while aesthetically pleasing, may lack essential minerals such as calcium and magnesium[74]. In areas like the Sahel region of Nigeria, high TDS levels are often linked to evaporative concentration and saltwater intrusion[75].

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2.2.2.3 Electrical Conductivity (EC)

EC reflects the water's ability to conduct electrical current, which is proportional to its ion concentration[76]. High EC values typically indicate elevated levels of dissolved salts, making water unsuitable for irrigation due to the risk of soil s*alinization*[77]. In contrast, low EC values may signal limited ion content, which can affect crop productivity[78]. Studies in southwestern Nigeria have revealed significant correlations between EC and groundwater salinity[79].

2.2.2.4 Hardness

Groundwater hardness is primarily caused by the presence of calcium and magnesium ions[80]. Hard water, while not harmful to health, can lead to scale formation in plumbing systems and reduce the efficiency of soap and detergents[81]. Soft water, on the other hand, may increase the corrosiveness of pipes and leach metals like lead[82]. Groundwater in regions with limestone or dolomite deposits often exhibits high hardness levels[83].

2.2.2.5 Dissolved Oxygen (DO)

DO is an essential parameter that reflects the level of oxygen available in water for aquatic life and chemical reactions[84]. Low DO levels (<5 mg/L) can lead to anaerobic conditions, promoting the growth of harmful bacteria and reducing water quality[85]. Groundwater systems with high organic content or limited recharge often exhibit depleted DO levels[86].

2.2.3 Trace Elements and Heavy Metals

The presence of trace elements and heavy metals in groundwater is a critical concern due to their toxicity and potential health impacts[87]. While some trace elements like zinc and copper are essential in small quantities, excessive concentrations can be detrimental[88].

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a. *Iron* (Fe) and *Manganese* (Mn): Elevated levels of iron and manganese are common in groundwater systems with reducing conditions[89]. While these metals are not highly toxic, they can cause staining of plumbing fixtures and impart an unpleasant metallic taste to water[90].

b. *Arsenic* (As): *Arsenic* contamination is a significant issue in regions with sedimentary aquifers, such as Bangladesh and parts of Nigeria[91]. Chronic exposure to arsenic can lead to skin lesions, cancer, and cardiovascular diseases[92].

c. *Lead* (Pb) and *Cadmium* (Cd): These heavy metals are often introduced into groundwater through industrial discharge and improper waste disposal[93]. Even at low concentrations, lead and cadmium are highly toxic and can cause developmental and neurological disorders[94].

2.2.4 Geochemical Processes Influencing Physicochemical Parameters

As water moves through soil and rock formations, it interacts with minerals, organic matter, gases, and microbial communities. These interactions influence key parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), hardness, alkalinity, redox potential, and concentrations of major ions and trace metals. Understanding these processes is important for assessing groundwater quality in areas like Mowe–Ibafo. Several *geo chemical* processes influence the physicochemical characteristics of groundwater. These include mineral dissolution, ion exchange, and red-ox reactions[95]. For example, the dissolution of carbonate minerals often increases water hardness and pH[96]. Similarly, ion exchange processes between groundwater and surrounding soil can alter the concentrations of sodium, calcium, and magnesium[97]. Red-ox reactions, which involve the transfer of electrons between chemical species, play a critical role in determining the availability of trace elements[98]. For instance, under reducing conditions, iron and manganese are mobilized, leading to elevated concentrations in groundwater[99].

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2.2.5 Impact of Anthropogenic Activities

Anthropogenic activities are one of the leading causes of groundwater contamination worldwide. As urbanization, industrialization, and population growth increase, more pollutants infiltrate soils and percolate into aquifers. In rapidly developing areas like Mowe–Ibafo, the pressure from human activities significantly affects the physicochemical and microbial quality of groundwater. Anthropogenic activities significantly influence the physicochemical properties of groundwater. Agricultural practices, such as the excessive use of fertilizers, often lead to nitrate contamination, which increases TDS and alters pH[100]. Similarly, industrial discharges introduce a wide range of pollutants, including heavy metals and synthetic organic compounds, that affect groundwater quality[101]. Urbanization exacerbates these impacts through increased impervious surfaces, reduced recharge rates, and the generation of leachates from landfills[102]. In Lagos, Nigeria, for example, studies have shown elevated levels of TDS, EC, and heavy metals in groundwater due to uncontrolled urban sprawl[103].

2.2.6 Regulatory Standards and Guidelines

The World Health Organization (WHO) and national regulatory bodies have established guidelines to ensure the safety of groundwater based on its physicochemical parameters[104]. These standards serve as benchmarks for water quality monitoring and management[105]. For instance, the WHO recommends a maximum TDS level of 1000 mg/L for drinking water, while Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA) sets specific limits for parameters like pH, EC, and heavy metals[106].

U.S. Environmental Protection Agency (EPA) Standards,the EPA establishes Maximum Contaminant Levels (MCLs) for drinking water quality, including for substances such as lead, arsenic, and coliform bacteria. These MCLs serve as benchmarks for assessing groundwater contamination. The Safe Drinking Water Act (SDWA) regulates

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groundwater sources for public drinking water systems, requiring regular monitoring and reporting[107].

The EU WFD sets out regulations for maintaining and improving the quality of groundwater across Europe, emphasizing the protection of water resources from pollution and over-exploitation,it also focuses on assessing the ecological status of groundwater bodies and sets limit values for pollutants[108].

National Standards: Each country typically has its own regulatory body or environmental agency (e.g., Central Pollution Control Board in India, Environment Agency in the UK) that sets national water quality standards. These standards often include permissible levels of contaminants like total dissolved solids (TDS), nitrates, and harmful microorganisms[109].

Groundwater Sustainability and Pollution Prevention: Some regulations focus on preventing groundwater pollution, such as limits on agricultural runoff (fertilizers and pesticides), industrial discharge, and improper waste disposal. These guidelines help ensure that groundwater resources remain viable for future generation[110].

2.2.7 Technological Advances in Physicochemical Analysis

Technological progress has significantly improved the accuracy, sensitivity, and efficiency of physicochemical analysis used to assess water quality. Modern techniques allow researchers to detect contaminants at very low concentrations, identify complex chemical interactions, and monitor water quality in real time. These advancements are essential for groundwater studies in areas like Mowe Ibafo, where contamination from natural and human activities is a concern.Advances in analytical techniques have significantly improved the ability to monitor physicochemical parameters. Instruments like atomic absorption spectrophotometers(AAS) and inductively coupled plasma mass spectrometers (ICP-MS) provide precise measurements of trace elements and heavy

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metals. Similarly, portable sensors and field kits allow for real-time monitoring of parameters such as pH, TDS, and EC[111].

The physicochemical parameters of groundwater are critical indicators of its quality and usability. Understanding these parameters requires a comprehensive approach that considers both natural geochemical processes and anthropogenic influences. Continued monitoring, coupled with adherence to regulatory standards, is essential for ensuring the sustainable management of groundwater resources.

2.3 Heavy Metals in Groundwater: Sources and Effects

Groundwater plays a critical role in providing essential water resources for drinking, irrigation, and industrial use. However, one of the growing threats to the quality of groundwater is contamination by heavy metals. Heavy metals, defined as metallic elements with high atomic weights and densities, are naturally found in the Earth's crust. Despite their natural presence, heavy metals become hazardous when their concentrations exceed permissible levels in the environment. Unlike organic pollutants, which can be broken down by natural processes, heavy metals are non-biodegradable and can persist in ecosystems for long periods. Over time, they accumulate in living organisms, potentially causing serious health risks and environmental damage[112].

The sources of heavy metals in groundwater are diverse, ranging from natural geological processes to human activities. Naturally occurring heavy metals in the Earth's crust are often released into groundwater through processes such as weathering, erosion, and mineral dissolution. For instance, elements like arsenic, cadmium, copper, lead, and mercury are commonly found in rocks, soils, and sediments. Over time, these elements can leach into groundwater through natural processes like groundwater movement, especially in regions with specific geological formations. In such cases, the

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concentrations of these metals in groundwater tend to be relatively low, but they can still pose a significant risk to human health when consumed over long periods of time.

While natural sources of heavy metals contribute to groundwater contamination, anthropogenic (human-made) activities have become the leading cause of elevated concentrations of heavy metals in groundwater. Industrial activities, mining operations, agriculture, and improper waste disposal are major contributors to heavy metal contamination in groundwater. Industrial processes, such as the production of electronics, textiles, and chemicals, often involve the use of heavy metals like lead, mercury, and cadmium. Improper disposal of industrial waste containing heavy metals can lead to contamination of surrounding groundwater resources. For example, the discharge of untreated wastewater containing heavy metals into rivers, lakes, or groundwater sources can result in elevated concentrations of these metals in drinking water supplies and irrigation systems.

Mining activities are another significant source of heavy metals in groundwater. Mining for precious metals, coal, and other minerals can release heavy metals into the environment through the process of excavation and ore processing. As mining waste is often stored in tailing ponds or left in open pits, the metals can leach into the surrounding groundwater over time. This process, known as acid mine drainage (AMD), occurs when sulfide minerals in mined rocks react with water and air, leading to the formation of acidic water with elevated concentrations of heavy metals like copper, arsenic, and zinc. In some regions, mining activities have caused significant contamination of nearby groundwater aquifers, rendering them unsafe for human consumption and agricultural use.

Agricultural activities, particularly the use of chemical fertilizers and pesticides, can also contribute to heavy metal contamination of groundwater. Many fertilizers contain metals

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like cadmium, lead, and arsenic, which can accumulate in the soil and leach into the groundwater over time. Similarly, the widespread use of pesticides and herbicides in farming can introduce metals such as mercury and copper into the environment, which can eventually contaminate groundwater supplies. Improper disposal of chemical containers, runoff from agricultural fields, and the overuse of certain pesticides and fertilizers exacerbate this issue, leading to long-term contamination of water resources.

Another major source of heavy metals in groundwater is the improper disposal of waste, including municipal, industrial, and medical waste. The uncontrolled disposal of solid waste and sewage can lead to the leaching of heavy metals into the surrounding environment, particularly when waste is disposed of in landfills or dumpsites located near groundwater sources. In some regions, waste disposal practices have resulted in the contamination of groundwater with a wide range of toxic metals, including lead, cadmium, and mercury. These contaminants can enter drinking water supplies, posing serious health risks to people who rely on groundwater as their primary water source.

Once heavy metals enter groundwater, they are transported through the aquifer by the movement of water. In many cases, these metals are difficult to remove once they have contaminated water supplies. Unlike organic pollutants, which can be broken down by natural processes, heavy metals remain in the environment for extended periods, accumulating in soil, sediment, and living organisms. This persistence makes heavy metals a long-term environmental concern, as they can continue to pose risks even after the source of contamination has been removed.

The effects of heavy metal contamination on human health and ecosystems can be devastating. When consumed through drinking water, heavy metals can accumulate in the human body over time, leading to a range of health problems. For example, long-term

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exposure to arsenic, which is a common heavy metal contaminant in groundwater, can cause skin lesions, respiratory issues, cardiovascular problems, and an increased risk of cancer. Chronic exposure to cadmium can lead to kidney damage, bone fractures, and lung diseases. Lead poisoning, which can occur as a result of drinking contaminated water, is particularly harmful to young children, as it can impair cognitive development, cause learning disabilities, and damage the nervous system.

In addition to direct health effects, heavy metals can have a detrimental impact on the environment. Heavy metals that enter groundwater can eventually find their way into surface water bodies, affecting aquatic life. High concentrations of heavy metals in rivers, lakes, and wetlands can lead to the *bio-accumulation* of these metals in fish and other organisms, disrupting ecosystems and food chains. Aquatic organisms exposed to heavy metals may experience reduced growth, impaired reproduction, and even death, which can have cascading effects on the entire ecosystem.

Heavy metal contamination can also impact agriculture. When heavy metals are present in groundwater used for irrigation, they can accumulate in the soil and be absorbed by crops, making them unsafe for human consumption. This not only affects food security but also poses a significant risk to human health. For example, crops like rice and vegetables grown with contaminated water can contain elevated levels of arsenic, cadmium, and other metals, posing a risk to consumers who rely on these crops for nutrition.

The adverse effects of heavy metal contamination on both human health and ecosystems emphasize the need for effective monitoring and management strategies to prevent and mitigate contamination. Groundwater monitoring programs that track the concentrations of heavy metals in water sources are essential for identifying contamination hot-spots and taking appropriate action. Governments and environmental agencies must enforce strict

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regulations on industrial practices, mining operations, and agricultural activities to reduce the release of heavy metals into the environment. In addition, efforts to raise public awareness about the dangers of heavy metal contamination and the importance of safe waste disposal practices can help minimize human exposure to these toxic metals.

Heavy metal contamination of groundwater is a growing concern with significant implications for human health, agriculture, and the environment. The sources of heavy metals in groundwater are diverse, ranging from natural geological processes to human activities such as industrial pollution, mining, agriculture, and improper waste disposal. The persistence and non-biodegradable nature of heavy metals make them a long-term environmental threat, requiring comprehensive monitoring and management efforts. Addressing the issue of heavy metal contamination in groundwater is essential to ensure the safety and sustainability of this vital resource for future generations. Effective strategies, including improved waste management, stricter regulations, and public awareness campaigns, are necessary to reduce the risk of heavy metal contamination and protect groundwater resources from further degradation.

2.3.1 Sources of Heavy Metals in Groundwater

Heavy metals are naturally occurring elements with high atomic weight and density. While some (like iron and zinc) are essential in trace amounts, excessive concentrations in groundwater can be toxic to humans and the environment. The presence of heavy metals in groundwater arises from both natural (geogenic) and human-induced (anthropogenic) sources. The contamination of groundwater with heavy metals originates from natural and anthropogenic sources. Understanding these sources is critical for identifying hot-spots of pollution and implementing mitigation strategies.

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2.3.1.1 Natural Sources

1. Geogenic Activities: Naturally occurring heavy metals, such as arsenic, lead, and mercury, are often mobilized through weathering and dissolution of mineral-rich rocks[111]. For instance, groundwater in sedimentary basins may contain arsenic due to reductive dissolution of arsenic-bearing minerals[112]. Similarly, high levels of cadmium are associated with zinc and phosphate deposits that leach into aquifers under specific geo chemical conditions[113].

2. Volcanic Activity: Volcanic eruptions release significant quantities of heavy metals, including lead, mercury, and chromium, into the atmosphere and hydrosphere[114]. These metals eventually percolate into groundwater systems, particularly in volcanic regions like East Africa and parts of Nigeria[115].

2.3.1.2 Anthropogenic Sources

1. Agricultural Practices: Agricultural runoff is a major contributor to heavy metal contamination in groundwater. Fertilizers, pesticides, and herbicides contain metals such as cadmium, copper, and zinc, which leach into aquifers over time[116]. In Nigeria, studies in agricultural zones reveal elevated cadmium levels in groundwater due to over-application of phosphate fertilizers[117].

2. Industrial Discharges: Industrial activities, including mining, smelting, and manufacturing, are significant sources of heavy metals[118]. Wastewater effluents from industries often contain toxic metals like chromium, nickel, and lead[119]. In regions with inadequate industrial waste management, these effluents seep into aquifers, contaminating groundwater supplies[120].

3. Urbanization and Landfills: Urbanization contributes to heavy metal contamination through leaches from municipal solid waste, electronic waste, and untreated sewage[121].

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Metals such as lead, cadmium, and mercury are commonly found in landfill leaches, posing a severe threat to shallow aquifers[122].

4. Artisanal and Small-Scale Mining (ASM): In Nigeria, artisanal gold mining activities have been linked to mercury and lead contamination in groundwater, especially in mining-intensive regions such as Zamfara State[123]. Miners often use toxic chemicals in ore processing, which directly infiltrate nearby water sources[124].

2.3.2 Pathways of Heavy Metals into Groundwater

Heavy metals enter groundwater through various pathways influenced by geological, hydro logical, and human factors.

1. Leaching and Percolation: Heavy metals in surface soils and sediments migrate into groundwater through leaching, especially during rainfall or irrigation[125]. This process is accelerated in areas with high soil permeability and fractured aquifers[126].

2. Point and Non-Point Sources: Industrial discharge pipes represent point sources of heavy metal pollution, while agricultural runoff and atmospheric deposition act as diffuse (non-point) sources[127]. Both pathways contribute significantly to groundwater contamination.

3. Saltwater Intrusion: In coastal regions, over-abstraction of groundwater leads to saltwater intrusion, which introduces metals like lead and cadmium into aquifers[128]. This phenomenon has been observed in Lagos, Nigeria, where urbanization and excessive groundwater pumping exacerbate the problem[129].

4. Geo-chemical Reactions: Geochemical reactions, such as oxidation-reduction and complexion, control the mobility and bio availability of heavy metals in groundwater[130].

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For example, arsenic is more mobile under reducing conditions, while chromium tends to persist under oxidizing conditions[131].

2.3.3 Effects of Heavy Metals on Human Health

Heavy metals pose severe health risks, particularly when present in groundwater used for drinking and cooking. The toxic effects depend on the type of metal, its concentration, and duration of exposure.

1. Zinc: Zinc is essential for immune function, wound healing, DNA synthesis, and cell division. It supports growth and development, particularly during pregnancy, infancy, and childhood[132]. Deficiency can lead to weakened immunity, stunted growth, hair loss, and delayed wound healing. Excess zinc may cause nausea, vomiting, and interfere with copper absorption, leading to potential deficiencies.[133]

2. Lead (Pb): Lead contamination, often linked to industrial discharge and urban runoff, affects neurological development, particularly in children[134]. Prolonged exposure is associated with reduced IQ, kidney damage, and hypertension[135].

3. Cadmium (Cd): Cadmium accumulates in the kidneys and liver, leading to renal dysfunction and osteoporosis[136]. In agricultural communities, cadmium exposure is often linked to the overuse of phosphate-based fertilizers[137].

4. **Mercury (Hg):** Mercury in groundwater primarily originates from mining and industrial discharges[138]. Chronic exposure affects the central nervous system, causing tremors, memory loss, and impaired cognitive function[139].

5. Chromium (Cr): Chromium contamination, particularly in its hexavalent form (Cr^{6+}), is carcinogenic. It affects the respiratory tract, gastrointestinal system, and kidneys[140].

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6. Copper: Copper is vital for energy production, red blood cell formation, immune function, and brain health. It aids in collagen formation and iron absorption. Deficiency can lead to anemia, weakened bones, and immune issues. Excessive copper can cause liver damage, gastrointestinal problems, and neurological symptoms. Balanced copper intake is crucial for overall health and well-being.

2.3.4 Environmental Impacts of Heavy Metals in Groundwater

Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), mercury (Hg), zinc (Zn), copper (Cu), and nickel (Ni) are naturally occurring elements that can become toxic at elevated concentrations. Their presence in groundwater poses serious environmental challenges due to their persistence, bioaccumulation, and non-biodegradability.

Beyond human health, heavy metal contamination has profound environmental consequences:

1. Soil and Crop Contamination Heavy metals in groundwater used for irrigation accumulate in soils and crops, affecting agricultural productivity[141]. Crops grown in contaminated fields, such as cassava and maize, often exhibit high levels of cadmium and lead, making them unsafe for consumption[142].

2. Ecosystem Disruption Aquatic ecosystems are particularly vulnerable to heavy metal pollution. High concentrations of metals like copper and zinc in groundwater discharge can harm fish, invertebrates, and microbial communities[143].

3. Bio-accumulation and Bio magnification Heavy metals bio-accumulate in organisms and biomagnify up the food chain, affecting higher trophic levels, including humans[144].

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Mercury, for instance, accumulates in fish, posing risks to both aquatic species and fish-consuming populations[145].

Heavy metals in groundwater, originating from both natural and anthropogenic sources, pose significant risks to human health and ecosystems. Their persistence and toxicity necessitate proactive measures, including stringent regulatory enforcement, periodic monitoring, and public awareness campaigns. Addressing this issue requires a collaborative approach involving governments, industries, and local communities to ensure the sustainable management of groundwater resources.

2.4 Microbial Contamination of Groundwater

Microbial contamination of groundwater has become an increasingly critical public health concern, especially in developing countries where untreated water sources are heavily relied upon. Groundwater, a key resource for drinking, agriculture, and industrial uses, is vulnerable to contamination by various microbial agents, particularly pathogens such as bacteria, viruses, and protozoa. These microbial contaminants can enter aquifers through both natural and human-induced processes, leading to significant risks for communities that depend on groundwater for their daily needs[151]. Groundwater is generally considered cleaner and safer than surface water because it is filtered through layers of soil, sand, and rock. However, in many developing regions, especially areas with rapid urbanization like Mowe Ibafo, groundwater is increasingly contaminated by microbial pathogens. Microbial contamination poses serious public health risks because it introduces disease-causing organisms into drinking water sources.

The primary sources of microbial contamination in groundwater include human and animal waste, inadequate sanitation facilities, and poor waste disposal practices. In areas where sanitation infrastructure is either non-existent or insufficient, pathogens from

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sewage can easily infiltrate groundwater systems. This is particularly common in rural or peri-urban areas where pit latrines and septic tanks are used, and these can leak or overflow, allowing pathogens to reach groundwater sources. The infiltration of surface water, which may carry microbial contaminants from agricultural runoff or urban waste, is another significant pathway for contamination in groundwater systems.

Agricultural practices, including the use of untreated manure and the application of fertilizers containing organic matter, can also introduce pathogens into groundwater. In regions with heavy farming activities, microbial contaminants from irrigation systems can contaminate wells and boreholes, further compromising water quality. Contamination from animal waste is particularly prevalent in areas where livestock farming is common, as improper disposal of animal excrement can lead to the introduction of harmful microorganisms into water supplies. Additionally, the improper handling and disposal of hospital waste or other medical waste can introduce a wide range of pathogens into the groundwater system, exacerbating the risk of contamination.

The mechanism by which microbial contaminants enter aquifers involves the movement of water through the soil and rock layers. When rainwater or surface water containing pathogens seeps into the ground, it can infiltrate the porous media of aquifers, carrying pathogens along with it. Groundwater in shallow aquifers is especially susceptible to microbial contamination, as these aquifers are often in close proximity to surface water and the contaminants in it. However, deeper aquifers, although generally more protected from surface contaminants, can still become contaminated if there is improper well construction or if there are faults in the geological layers that allow for the movement of contaminated water from shallower layers.

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The impact of microbial contamination on public health is significant. The ingestion of contaminated groundwater can lead to waterborne diseases, including cholera, dysentery, typhoid fever, and gastroenteritis. These diseases are caused by various pathogenic microorganisms that thrive in contaminated water, particularly in areas with poor water treatment systems. In some cases, the pathogens can cause chronic health problems, especially in children, the elderly, and immunocompromised individuals. Microbial contamination occurs when groundwater becomes polluted with microorganisms such as bacteria, viruses, protozoa, and fungi. These microbes originate from human and animal waste and enter the aquifer through various pathways. For example, *Escherichia coli* (*E. coli*), a common bacterial contaminant, can cause severe gastrointestinal illnesses, and rotavirus, a viral pathogen, can lead to widespread diarrhea outbreaks.

Moreover, the long-term exposure to contaminated groundwater can have adverse environmental effects. Microbial contamination can disrupt aquatic ecosystems, leading to the degradation of water quality and biodiversity. For example, the presence of harmful bacteria and viruses can alter the microbial balance in surface water bodies, affecting fish populations and other aquatic organisms that rely on clean water for survival.

Microbial contamination of groundwater remains a serious threat to public health, particularly in regions where access to safe and clean water is limited. The primary sources of contamination include human and animal waste, agricultural runoff, and inadequate sanitation practices. Understanding the mechanisms by which pathogens infiltrate groundwater and the associated risks can help to inform effective management strategies for mitigating microbial contamination. Improved sanitation infrastructure, better waste disposal practices, and water treatment techniques are crucial to ensuring the safety of groundwater resources and protecting public health.

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2.4.1 Sources of Microbial Contamination in Groundwater

The infiltration of microbial pathogens into groundwater systems occurs through a variety of pathways influenced by human activity and environmental factors. These sources can be categorized into natural, anthropogenic, and mixed origins.

2.4.1.1 Natural Sources

1. Soil and Sediment Microbes: The natural microbial flora of soil and sediments includes bacteria, such as coliforms, which may infiltrate groundwater under specific hydrological conditions[153]. In regions with porous soils, these microorganisms can migrate deeper into aquifers[154].

2. Wildlife Activities: Animals, particularly in areas near water bodies, contribute to microbial contamination through fecal deposition[155]. During heavy rainfall, pathogens from animal excreta are washed into shallow aquifers[156].

2.4.1.2 Anthropogenic Sources

1. Poor Sanitation Practices: In many developing regions, open defecation and inadequate waste disposal are major contributors to microbial contamination of groundwater[157]. Fecal coliforms, such as Escherichia coli (E. coli), are commonly detected in wells located near latrines[158].

2. Agricultural Runoff: Runoff from farms, particularly those employing animal husbandry, introduces pathogenic bacteria, such as Salmonella and Campylobacter, into groundwater sources[159]. The overuse of manure as fertilizer exacerbates this issue[160].

3. Leakage from Septic Systems: Improperly constructed or poorly maintained septic systems often release untreated effluents into the surrounding soil, contaminating nearby wells[161]. In areas with high water tables, this risk is significantly heightened[162].

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4. Landfills and Waste Dumps: Municipal solid waste, particularly in unlined landfills, serves as a reservoir for microbial pathogens[163]. Leachates from such dumps infiltrate groundwater, carrying bacteria, viruses, and protozoa[164].

2.4.1.3 Mixed Sources

1. Flooding Events: During floods, contaminants from multiple sources, including agricultural lands, septic tanks, and waste dumps, mix and infiltrate groundwater systems[165]. These events often result in a surge of waterborne disease outbreaks[166].

2. Urban Runoff: Urbanization exacerbates microbial contamination as runoff from streets, parks, and construction sites introduces diverse microbial species into aquifers[167].

2.4.2 Mechanisms of Microbial Contamination

Microbial pathogens enter and persist in groundwater through several mechanisms determined by the interaction of geological, hydrological, and biological factors.

a. **Transport through Soil and Rock** Microbial pathogens migrate through soil profiles and fractures in bedrock, influenced by soil type, porosity, and moisture content[168]. Sandy and gravelly soils are particularly prone to facilitating rapid microbial transport[169].
b. **Percolation through Unsaturated Zones** In regions with shallow water tables, microorganisms from surface sources percolate directly into aquifers[170]. The unsaturated zone acts as a natural filter, but its effectiveness varies depending on soil composition and microbial size[171].
c. **Adsorption and Desorption** Pathogens interact with soil particles through adsorption and desorption processes. While adsorption temporarily reduces microbial mobility, desorption can release pathogens back into the water column[172].

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d. **Biofilm Formation** Microorganisms form biofilms on surfaces within aquifers, enhancing their survival and persistence[173]. Biofilms protect pathogens from environmental stressors and facilitate their spread in groundwater systems[174].

2.4.3 Health Effects of Microbial Contamination

Microbial contamination of groundwater poses significant public health risks, especially in communities that rely on untreated wells and boreholes. When pathogens such as bacteria, viruses, and protozoa enter groundwater, they can cause a wide range of waterborne diseases, many of which are severe and sometimes fatal. The health implications of consuming microbial contaminated groundwater are profound, ranging from mild gastrointestinal disorders to life-threatening illnesses.

1. Bacterial Infections: Common bacterial pathogens in contaminated groundwater include E. coli, Salmonella, and Vibrio cholerae[175]. These bacteria cause diarrhea, cholera, and typhoid fever, with vulnerable populations such as children and the elderly being most affected[176].

2. Viral Infections: Enteric viruses, such as norovirus, rotavirus, and hepatitis A, are frequently transmitted through contaminated groundwater[177]. These viruses are highly infectious, causing gastroenteritis and liver damage[178].

3. Protozoan Infections: Protozoa like Giardia lamblia and Cryptosporidium parvum are significant contributors to waterborne diseases[179]. These pathogens form cysts that are resistant to conventional water treatment methods, making them persistent threats to groundwater users[180].

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4. Emerging Pathogens: Emerging microbial threats, including antibiotic-resistant bacteria, have been detected in groundwater[181]. These pathogens complicate treatment options and pose severe risks to public health[182].

2.4.4 Environmental Impacts of Microbial Contamination

Microbial contamination does not affect only human health; it also has significant environmental consequences. When groundwater becomes polluted with pathogenic microorganisms from human and animal waste, it disrupts natural ecological systems, degrades soil and water quality, and creates long-term environmental hazards.

1. Impact on Aquatic Ecosystems: Contaminated groundwater that discharges into rivers and lakes introduces pathogens into aquatic ecosystems[183]. This leads to algal blooms, reduced biodiversity, and degradation of aquatic habitats[184].

2. Soil and Crop Contamination: Irrigation with microbial contaminated groundwater results in soil and crop contamination, reducing agricultural productivity and posing risks to food safety[185].

3. Aquifer Degradation: Persistent microbial contamination alters the microbiome of aquifers, disrupting natural purification processes[186]. This makes aquifers more susceptible to long-term degradation[187].

2.5 Pollution Indices for Water Quality Assessment

Water quality assessment is a critical process for understanding the extent of pollution in groundwater and ensuring its safety for various uses. Pollution indices are quantitative tools used to classify water quality based on specific parameters, including chemical, microbial, and physical characteristics[198]. These indices simplify complex water quality data into comprehensible values, enabling policymakers and researchers to assess,

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compare, and monitor groundwater pollution levels systematically[199]. This section discusses the concept of pollution indices, their types, methodologies, and applications in assessing groundwater quality.

Pollution indices are mathematical formulations that consolidate multiple water quality parameters into a single numerical value or category for classification. These indices serve several purposes:

1. Simplifying Data Interpretation: Water quality data often involve multiple variables, which can be overwhelming to analyze individually. Pollution indices provide a consolidated metric for easier interpretation[200].

2. Monitoring Pollution Trends: Indices facilitate the monitoring of water quality trends over time, allowing researchers to identify improvements or deteriorations in pollution levels[201].

3. Decision-Making Tool: For environmental managers and policymakers, pollution indices guide decisions on resource allocation and remediation efforts[202].

4. Public Awareness: By translating technical data into user-friendly scores, indices help raise public awareness about groundwater quality issues[203].

2.5.1 Types of Pollution Indices

Several pollution indices are used to assess groundwater quality, each with its focus and methodology. The most commonly employed indices include:

1. Water Quality Index (WQI): The WQI is one of the most widely used indices for evaluating overall water quality based on weighted parameters such as pH, dissolved oxygen (DO), nitrate, and heavy metals[204].

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a. **Calculation:** WQI is calculated using the weighted arithmetic mean of selected water quality parameters[205]. Each parameter is assigned a weight based on its relative importance to human health and environmental sustainability[206].

b. **Categories:** The WQI scores are divided into categories, such as "Excellent," "Good," "Poor," and "Unsuitable for Drinking"[207].

2. Heavy Metal Pollution Index (HPI): HPI evaluates the presence and impact of heavy metals in groundwater[208]. Since heavy metals pose serious health risks, this index is crucial for regions with significant industrial or agricultural activities[209].

a. Key Metals: Commonly included metals are lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg)[210].

b. Application: HPI is particularly useful in identifying specific sources of metal contamination[211].

3. Nitrate Pollution Index (NPI): NPI assesses nitrate contamination, which is a major concern in agricultural areas due to fertilizer runoff[212]. High nitrate levels in groundwater are associated with methemoglobinemia (blue baby syndrome)[213].

Thresholds: The World Health Organization (WHO) sets the permissible limit for nitrates in drinking water at 50 mg/L[214].

4. Microbial Water Quality Index (MWQI): MWQI evaluates the presence of microbial contaminants such as Escherichia coli and coliforms[215]. This index is essential for regions with inadequate sanitation infrastructure[216].

2.5.2 Methodologies for Pollution Indices Calculation

1. Parameter Selection: The first step in calculating pollution indices involves selecting

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relevant water quality parameters. These are chosen based on the intended use of the water and local pollution concerns[217].

2. Weight Assignment: Each parameter is assigned a weight or significance factor, reflecting its impact on overall water quality[218]. For example, heavy metals often receive higher weights due to their toxicity[219].

3. Normalization: The values of each parameter are normalized using their respective permissible limits[220]. Normalization ensures consistency across parameters with different units of measurement[221].

4. Aggregation: Normalized values are aggregated using mathematical formulas to compute the final pollution index score[222]. This score is then interpreted based on pre-defined thresholds[223].

2.5.3 Applications of Pollution Indices

Pollution indices have diverse applications in groundwater quality assessment, ranging from research to policy implementation.

1. Identifying Pollution Hotspots: Pollution indices enable the identification of areas with critically polluted groundwater, facilitating targeted interventions[224].

2. Monitoring Remediation: Efforts Indices provide a benchmark for evaluating the effectiveness of remediation programs over time[225].

3. Comparative Studies: Researchers use pollution indices to compare groundwater quality across regions or aquifers[226].

4. Policy Development: Indices inform environmental regulations and standards, guiding sustainable water resource management[227].

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Chapter Three

Methodology

3.1 Study Area

Mowe Ibafo is a community located in Obafemi-Owode Local Government Area of Ogun State, along the Lagos–Ibadan Expressway. Positioned just outside Lagos, the area has experienced significant population growth. This growth is as result of migration of people from Lagos to this area due to affordable housing.Mowe Ibafo is characterized by mixed land uses residential, commercial agricultural, recreational, transportation and industrial activities; but faces infrastructure challenges such as inadequate roads, poor drainage, and limited public utilities. These informed its choice as the study area.

3.2 Sample Site Selection

Sampling in the Mowe Ibafo area was based on dominant land use types to study how human activities affect the environment over time. Key sites included industrial (Mowe), agricultural (Shimawa), commercial (Ibafo), recreational (Magboro), residential (Arepo), and transportation (Lotto) zones. This land-use-specific approach supports long-term environmental monitoring by identifying pollution sources, trends, and potential risks to public health. Each site was georeferenced using a GPS device to ensure accurate location tracking. Arepo with (Latitude: 6.7552° N, Longitude: 3.2578° E), Magboro (Latitude 6.7148° N, Longitude 3.4025° N), Ibafo (Latitude 6.7401° N, Longitude 3.4221° N), Mowe (Latitude 6.8107° N, Longitude 3.4366° N), Shimawa, (Latitude 6.7641° N, Longitude 3.4884° N) and Lotto (Latitude 6.80199° N, Longitude 3.42117° N) .

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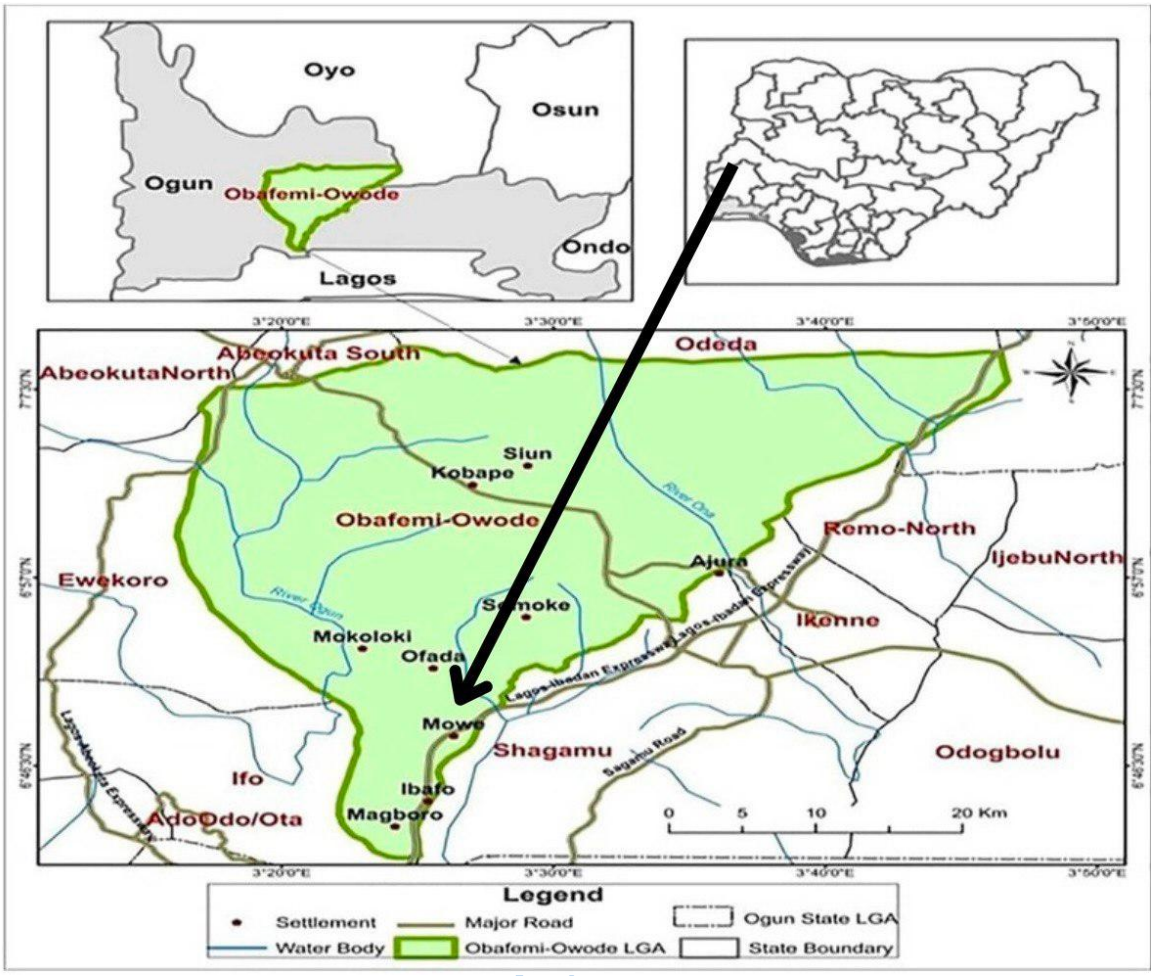


Figure 3.1: Map Showing the Study Site

Source[1].

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3.2.1 Collection of Water Sample

Between December 2024 and January 2025, 24 water samples (from 12 boreholes and 12 wells) were collected corresponding to the transition period between dry and rainy seasons. This period is characterised by variation in temperature, precipitation and surface runoff all of which can significantly influence the quality and composition of water. The seasonal transition was particularly imported to the study as it affect both physciochemical parameters and heavy metals of water bodies, during dry season limited rainfall and high evapouration rate often lead to the concentration of dissolved ions and metal. The samples were collected in pre-washed and sterilized plastic bottles, covered tightly, and transported immediately in a sealed polyethylene bag into the laboratory. The samples were stored in a refrigerator at about 4 °C prior to analysis.

3.3 Determination of Physicochemical Parameters

Physicochemical Parameters such as pH, conductivity total dissolved solids (TDS) alkalinity, bicarbonate, total hardness, calcium (Ca), magnesium (Mg), chloride, sulphate, phosphate, nitrate, dissolved oxygen (DO), turbidity and chemical oxygen demand (COD) were determined using the American Public Health procedures[2].

3.3.1 pH

pH of the water was measured using a pH meter equipped with a glass combination electrode saturated with potassium chloride (KCl), 1M KCl solution was prepared by dissolving 74.5 g of KCl in distilled water and diluting it to a final volume of one liter[3]. For calibration, buffer solutions with pH values of 4, 7, and 9 were used. Before measuring the sample, the pH meter was calibrated with these buffer solutions. A 50 ml water sample was then transferred to a 100 ml flask, the electrode was immersed in the solution, and the pH value was recorded.

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3.3.2 Carbonate and Bicarbonate (CO_3^{2-} & HCO_3)

Concentrated sulphuric acid (2.8 ml) was added to 500 ml of distilled water and diluted to one litre to obtain approximately 0.1N H_2SO_4. This was then diluted tenfold and standardized by titration with a standard alkali, also 0.25 g of phenolphthalein was dissolved in 100 ml of 60% ethanol, and 0.50 g of methyl orange was dissolved in 100 ml of 95% ethanol to prepare the respective indicators[4]. 10 ml water sample was transferred to a 100 ml conical flask. Two drops of phenolphthalein indicator were added, and the appearance of a pink color indicated the presence of carbonate. The sample was titrated with 0.01N H_2SO_4 until the pink color disappeared, and the volume used was recorded as 'A'. Then, two drops of methyl orange indicator were added, turning the solution yellow. Titration continued until the color changed to red, and the final volume was noted as 'B'.

Calculation

CO_3^{2-} (mg/L) = $\frac{2xNxAx1000}{mlofsample}$

HCO_3^-(mg/L) = $Nx(B-A)x1000$

Where N = Normality of acid, 2 = Valancy of carbonate, A = Volume of titrant against phenolphthalein indicator. B = Volume of titrant against methyl orange indicator.

30 = Equivalent weight of CO_3, 61 = Equivalent weight of HCO_3[5].

3.3.3 Chloride (Cl^-)

Ten millilitres of the sample was transferred to a 100 ml conical flask, and two drops of potassium chromate indicator were added, resulting in a yellow color. The sample was then titrated with 0.01N silver nitrate ($AgNO_3$) until the color changed to brick red.

The chloride concentration was calculated using the following formulas:

Cl^- (mg/L) = $\frac{(N\times V\times 1000)}{volumeofsample}$/

Cl^- (mg/L) = $\frac{(N\times V\times 1000\times 35.5)}{volumeofsample}$

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$$NaCl(mg/L) = Cl^{-}(mg/L) \times 1.65$$

Where N referred to the normality of $AgNO_3$, V is the volume of $AgNO_3$ used, and 35.5 was the equivalent weight of chloride[6].

3.3.4 Sulphate (SO_4^{2-})

Calcium solution (0.02 N) was prepared by dissolving 1.001 g of AR grade, dried calcium carbonate ($CaCO_3$) in approximately 5 ml of diluted hydrochloric acid (1:50). The solution was boiled to expel carbon dioxide (CO_2) and then diluted to one litre with distilled water. For the Eriochrome Black T (EBT) indicator, 0.5 g of EBT dye and 4.5 g of hydroxylamine hydrochloride (AR grade) were dissolved in 100 ml of ethyl alcohol. hydrochloric acid solution (0.02 N) was prepared by diluting an appropriate volume of concentrated HCl and then standardized against a standard alkali to achieve exact normality, the buffer solution was prepared by dissolving 8.25 g of ammonium chloride (NH_4Cl) and 113 ml of concentrated ammonia solution (NH_4OH) in one litre of distilled water to achieve a pH of 10, 10 ml of this buffer was added to 50 ml of the sample solution during analysis[7].

Magnesium chloride ($MgCl_2$) solution (0.02 N) was prepared by dissolving 0.843 g of dried magnesium carbonate ($MgCO_3$) in a slight excess of dilute hydrochloric acid and diluting the mixture to one litre. This solution was standardized against 0.02 N EDTA, standard barium chloride solution (0.02 N) was prepared by dissolving 2.4428 g of AR grade barium chloride dihydrate ($BaCl_2 \cdot 2H_2O$) in about 300 ml of distilled water and diluting the solution to one litre. It was standardized against the 0.02 N calcium solution[8].

EDTA solution (0.02 N), 4.0 g of pure disodium EDTA salt was dissolved in approximately 200 ml of distilled water and diluted to one litre. This solution was standardized against the 0.02 N calcium solution.

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Calcium and magnesium ions (Ca^{2+} + Mg^{2+}) determination, 5 ml of the water sample was titrated , the carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) contents were determined by titration against 0.02 N HCl, following a method similar to that used for 0.01 N H_2SO_4[9].

In a separate aliquot, a known volume of 0.02 N HCl equivalent to the total alkalinity (carbonates + bicarbonates), with a slight excess, was added. The mixture was boiled to destroy carbonates and drive off CO_2. Then, $BaCl_2$ solution, sufficient to exceed the sulphate content in the aliquot, was added, and the solution was boiled briefly.

After cooling, 10 ml of buffer and 5 drops of EBT indicator were added. The sample was titrated with standard EDTA solution to the first endpoint, although initial result should not be considered final due to low accuracy. 2 ml of standard $MgCl_2$ solution was added, and titration was resumed to obtain a proper endpoint for Ca^{2+} + Mg^{2+} estimation.

The sulphate content (SO_4^{2-}) was calculated using the formula:

$$SO_4^{2-}(meq/L) = B + Ba + Mg - T$$

Where: B = Ca^{2+} + Mg^{2+} in the original sample (meq/L). Ba = milliequivalents of barium added. • Mg = milliequivalents of magnesium added and T = total milliequivalents of EDTA used in titration (including Ba and Mg contributions)[10].

3.3.5 Calcium and Magnesium (Ca^{2+}& Mg^{2+})

Five millilitre of the water sample was taken in a 100 ml conical flask. To this, 1 ml of buffer solution and 3 to 4 drops of Erichrome Black T (EBT) indicator were added. The sample was titrated with standard EDTA solution until the color changed from wine red to sky blue, indicating the endpoint[11].

The combined concentration of Ca^{2+} and Mg^{2+} ions (in milliequivalents per litre) was calculated using the formula: Ca^{2+} + Mg^{2+} (meq/L) = $\frac{(N \times V \times 1000)}{Volume of sample}$

Where:
N = Normality of the EDTA solution
• V = Volume of EDTA used during titration

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For the determination of calcium alone (Ca^{2+}), another 5 ml aliquot of the water sample was taken in a 100 ml conical flask. To this, 1 ml of NaOH solution and a pinch of murexide indicator were added. The solution was titrated with EDTA until the color changed from pink to purple, indicating the endpoint[12].

Calcium concentration (in milliequivalents per litre) was calculated as:

Ca^{2+} (meq/L) = (N × V × 1000) / Volume of sample

The magnesium concentration was determined by subtracting the calcium value from the total (Ca^{2+} + Mg^{2+}) value: $Mg^{2+}(meq/L) = (Ca^{2+} + Mg^{2+}) - Ca^{2+}$

The concentrations in mg/L were calculated using the following conversion factors

Mg^{2+} (mg/L) = Mg^{2+} (meq/L) × 12.16

Ca^{2+} (mg/L) = Ca^{2+} (meq/L) × 20.04

3.3.6 Dissolved Oxygen (DO) Determination

A 300 ml BOD bottle was filled with the water sample, taking special care to avoid the inclusion of air during the collection process[13]. Once filled, the bottle was sealed with a stopper. The stopper was then removed, and 1 ml of manganous sulfate solution was carefully added at the surface of the liquid. Subsequently, 1 ml of an alkaline-potassium iodide-sodium azide solution was added at the surface, and the stopper was immediately replaced while ensuring that no air bubbles were trapped.

The bottle was then shaken thoroughly by inverting it several times. After the initial formation of a flocculent precipitate, the bottle was allowed to stand until the floc had settled halfway. It was then shaken again and allowed to settle a second time, 1 ml of concentrated sulfuric acid was added by allowing it to run down the neck of the bottle so that it mixed gently with the sample without disturbing the floc[14]. The bottle was restoppered and shaken until the precipitate completely dissolved, indicating that the sample was ready for titration. A portion of the treated sample equivalent to 200 ml of the

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original volume was taken for titration. This volume was calculated using the formula:ml of sample to titrate = (200 × Total sample volume) / 300

The dissolved oxygen (DO) concentration in the sample was then calculated using the formula:

$$DO(mg/L) = \frac{(ml of titrant \times Normality of titrant \times 8000)}{Volume of sample(ml)}$$

Where:

ml of titrant refers to the volume of sodium thiosulfate used in titration

Normality of titrant is the exact normality of sodium thiosulfate

8000 is the oxygen equivalent factor used for conversion to mg/L[15].

3.3.7 Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

The EC (electrical conductivity) meter was calibrated using standard potassium chloride (KCl) solutions. The calibration was carried out by selecting one of three available standard KCl solutions, based on the expected range of the sample's conductivity[16]. The conductivity values of the standard solutions at 25°C were provided as follows:

0.1 M KCl: 12.88 dS/m (with a temperature coefficient of +1.90%)

0.01 M KCl: 1.413 dS/m (with a temperature coefficient of +1.94%)

0.001 M KCl: 0.146 dS/m (with a temperature coefficient of +2.04%)

The EC meter was set to the appropriate standard solution, and calibration was performed accordingly. Also a conductivity cell with a cell constant of 0.1 K should not be calibrated with the 0.1 M KCl solution, as its conductivity exceeds the cell's measurement range.

To determine the conductivity at a temperature other than 25°C, the following formula was used:

Conductivity at D°C = C_{25}°C + (C_{25}°C × Temperature Coefficient / 100 × (D°C − 25°C))

Where:

C_{25}°C = Conductivity at 25°C

D°C = Desired temperature

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Temperature Coefficient = Specific to the KCl concentration[17].

3.3.8 Chemical Oxygen Demand (COD) Open Reflux Method

Water sample (50 ml) was placed in a 500 ml refluxing flask along with five to seven glass boiling beads. To this, 1 g of mercuric sulphate ($HgSO_4$) and 5 ml of concentrated sulfuric acid containing silver sulphate were added. The mixture was stirred until the mercuric sulphate dissolved completely[18].

Subsequently, 25 ml of 0.25 N potassium dichromate ($K_2Cr_2O_7$) solution was added and mixed thoroughly. While mixing, an additional 70 ml of concentrated sulfuric acid-silver sulphate solution was introduced to the flask. After complete mixing, the flask was connected to a reflux condenser, and the mixture was refluxed for 2 hours[19].

A reagent blank was prepared using 50 ml of distilled water and the same reagents as the sample, and it was refluxed under identical conditions alongside each set of samples to ensure accurate comparison ,following the refluxing process, the flask was removed from the condenser and allowed to cool. The contents were then diluted to approximately 350 ml with distilled water. Four to five drops of Ferroin indicator and a magnetic stirring bar were added[20]. The solution was stirred using a magnetic stirrer and titrated rapidly with 0.25 N ferrous ammonium sulphate (FAS) until the first red-brown endpoint was observed.

The Chemical Oxygen Demand (COD) of the sample was calculated using the formula:

$$\text{COD (mg/L)} = (A - B) \times N \times 8000 / \text{Volume of sample (ml)}$$

Where:

A = Volume of FAS used for the reagent blank (ml)

B = Volume of FAS used for the sample (ml)

N = Normality of the FAS titrant[21].

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3.3.9 Nitrite Nitrogen (NO_2-N)

25 ml of the sample was transferred to a 50 ml volumetric flask. To this, 2 ml of color reagent was added, mixed thoroughly, and then diluted to the mark with distilled water. The color was allowed to develop, and the nitrite-nitrogen (NO_2-N) concentration was measured using a spectrophotometer at a wavelength of 543 nm. The reading was taken after 10 minutes, but not later than 30 minutes after the addition of the reagent[22].

To calibrate the spectrophotometer, NO_2-N solutions were prepared by taking 0, 1, 5, 10, 15, 20, and 25 ml of a 50 µg NO_2-N stock solution in separate 50 ml volumetric flasks. Each was treated in the same way as the sample by adding the color reagent, mixing, diluting to volume, and measuring the absorbance. A calibration curve was developed , and the NO_2-N concentration of the sample was determined by comparing its absorbance against this curve.

The final concentration of NO_2-N in the sample was calculated using the formula:

$NO_2\text{-N (mg/L)} = \frac{(R \times 50)}{25}$

Where:

R is the spectrophotometer reading in mg/L (based on calibration curve)[23].

3.4 Heavy Metals Analysis

Atomic Absorption Spectroscopy (AAS) was used for the quantitative determination of copper, cadmium (Cd), arsenic (As), zinc , Manganese, cobalt and Iron .Samples were digested with (HNO_3) to remove organics; metal ions quantified using calibration curves from certified standards[24].

3.4.1 Digestion Procedures

Water sample (50 to 100 ml) was measured into a clean digestion vessel. To this, 5 to 10 ml of concentrated nitric acid (HNO_3) was added. The vessel was then placed on a hot

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plate or digestion block and heated gently to a temperature between 85°C and 95°C, ensuring that the sample did not boil[25]. Heating was continued until the volume of the sample was reduced by approximately half, and the suspended solids had broken down. Additional small amounts of nitric acid were added as needed to maintain digestion and promote complete decomposition of the sample matrix.

After digestion, the sample was allowed to cool to room temperature. It was then diluted with deionized water to the desired final volume. The solution was filtered to remove any insoluble residue, and the clear filtrate was transferred into a clean, labeled container for further analysis[26].

3.4.2 AAS Determination of Heavy Metals

The digested solution was transferred into a 100 ml volumetric flask and diluted to the mark with deionised or distilled water. This solution was then aspirated into the Buck 211 Atomic Absorption Spectrophotometer (AAS) via the suction tube for analysis. The instrument, a Buck 211VGP model manufactured by Buck Scientific, was operated using standard parameters specific to each element under investigation[27].

H = element, A = wavelength (nm), B = slit width (nm), C = working range (µg/ml), D = sensitivity (µg/ml), E = lamp current, F = flame type.

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Table 3.1: Analytical Wavelengths, Slit Widths, Working ranges ,Detection Limits, Lamp current, and Techniques for AAS

H	A	B	C	D	E	F
As	193.7	0.7	1-100	45.0	300.0	MHS
CO	240.7	0.2	1-20	0.2	6.0	Air-C_2H_2
Cd	228.8	0.5	0.5-5	0.03	15.0	Air-C_2H_2
Zn	213.9	0.5	0.5-5	0.03	15.0	Air-C_2H_2
Fe	248.3	0.2	2-20	0.1	30.0	Air C_2H_2
Mn	403.1	0.2	7-27	0.2	5.0	Air-C_2H_2
Cu	324.7	0.5	1-20	0.1	15.0	Air-C_2H_2

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The meter reading for each metal was recorded by the AAS and used to calculate the concentration of the respective element in the water samples. The concentration (in ppm or mg/kg) was determined using the following formula:

Ppm or mg/kg (of the elements) = Meter reading x Slope or Gradient x dilution factor,

% (of the elements) = ppm or mg/kg divided by 10000

3.5 Heavy Metal Pollution Index (HPI) and Heavy Metal Evaluation Index (HEI)

The Heavy Metal Pollution Index (HPI) is a tool used to evaluate the overall quality of water in relation to heavy metal contamination. The HPI is given by

$$HPI=\sum n\ WiQi$$

$$Qi=\sum n(Mi/Si)\ x100$$

$$Wi= 1/Si$$

Where;

n = Number of heavy metals considered;

Wi = Unit weight of the i-th heavy metal

Qi = Sub-index of the i-th heavy metal

Mi = Measured concentration of the i-th heavy metal in the water

Si = Standard permissible limit (WHO) for the i-th heavy metal

Interpretation of HPI:

- HPI < 100: Indicates low pollution
- 100 ≤ HPI < 200: Indicates moderate pollution.
- HPI ≥ 200: Indicates high pollution.

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While the Heavy Metal Evaluation Index (HEI) is used to assess the quality of water based on the concentrations of various heavy metals. It is calculated as follows;

$HEI=\sum n(Ci/Hi)$

Where:

n = Number of heavy metals considered

Ci = Measured concentration of the iii-th heavy metal in the water

Hi = Maximum permissible concentration of the i-th heavy metal according to the WHO standards

The **interpretation of the HEI** values is generally as follows:

HEI < 10: Low Contamination. Indicates that the water quality is within the acceptable limits for the heavy metals considered.

HEI = 10-20: Medium Contamination. Indicates that the water quality is at the threshold limit for the heavy metals considered.

HEI > 20: High Contamination. Indicates that the water quality exceeds the acceptable limits for the heavy metals considered, implying potential health risks and the need for remedial actions[28].

3.6 Data A!nalysis

The data obtained from the analysis of physicochemical parameters and heavy metals concentration were statiticallyanalysed to determine spatial and temporal variation as well as to evaluate the degree of contamination within the study area .

Statistical analysis was performed using IBM SPSS statistics and microsoft excel to compute descriptive statistics and microsoft excel to compute descriptive statistics, establish correlation and assess the significance of variation among locations, Descriptive

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statistics including the mean range and standard deviation were used to summarize the overall distribution of the measured parameters[29].

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Chapter Four

Results and Discussion of Findings

4.1 Results

This chapter presents the results obtained from the determination of heavy metals and physicochemical parameters in groundwater samples collected from the *Mowe-Ibafo* area. It provides a detailed analysis of key water quality indicators, including pH, total dissolved solids (TDS), and electrical conductivity (EC), as well as the concentrations of selected heavy metals such as lead, cadmium, and copper. The results are discussed in relation to established water quality standards, potential health implications, and possible sources of contamination within the study area.

4.1.1 Result of Physicochemical Parameters

4.1.1.1 pH and Temperature

The pH of groundwater samples varied from 4.25 to 7.25. As illustrated in Figure 4.1, only borehole water samples from Mowe (7.25) and Shimawa (6.76) met the recommended range. These compliant samples are represented with blue bars, while the remaining twelve samples, highlighted in orange, indicate non-compliance.

The most acidic water sample was from *Mowe well* water sample (pH 4.25), followed by Lotto well water (4.65), suggesting influences from organic acid leaching or acid rain associated with industrial emissions or agricultural runoff, Such acidic conditions can corrode plumbing systems and increase metal leaching, potentially leading to public health concerns. Temperature remained relatively stable at approximately 28.2°C across all sites, consistent with values reported for surface and shallow groundwater in southern Nigeria. The stability of temperature suggests minimal thermal pollution or deep aquifer influence.

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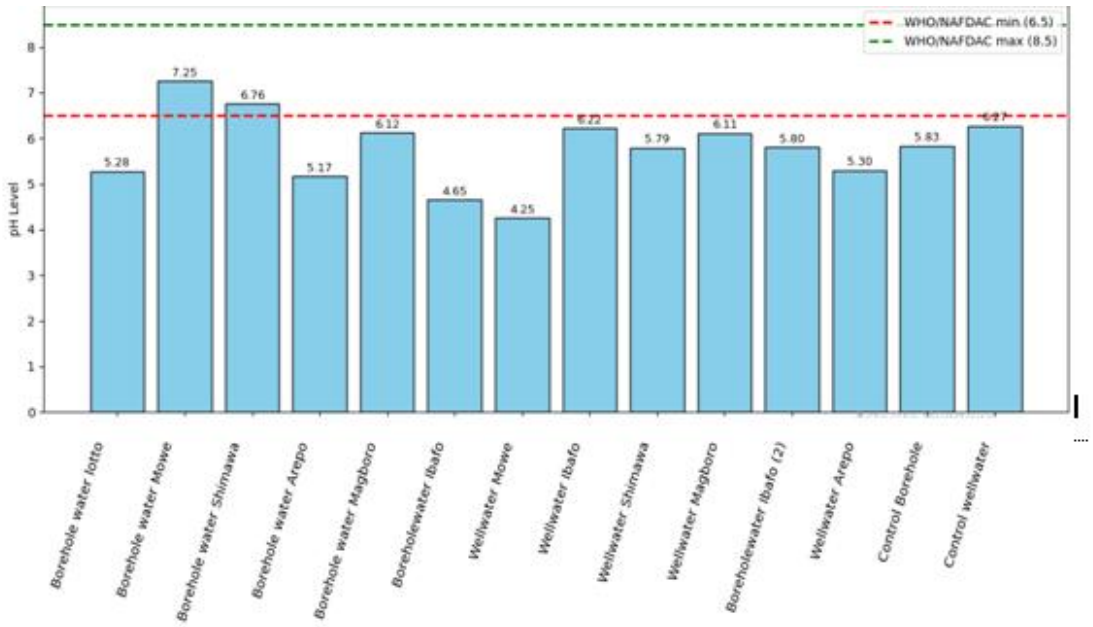


Figure 4.1: Bar Chart of the pH Values for all Water samples, with a Dotted Lines Representing the WHO/NAFDAC Permissible Limit (6.5-8.5).

Source: Author's Field Work, 2025

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4.1.1.2 Total Dissolved Solids (TDS) and Electrical Conductivity (EC)

TDS and EC are critical indicators of water quality, reflecting dissolved ion concentrations and potential contamination sources. Figure 4.2 depicts the distribution of TDS and EC across sampling locations.

Borehole samples from *Mowe, Shimawa,* and *Ibafo* recorded TDS values between 202 and 291 mg/L, and EC values between 405 and 582 µS/cm. , these figures suggest moderate mineralization possibly due to rock-water interactions or low-level anthropogenic inputs.

Lotto well water sample recorded the highest TDS (869 mg/L) and EC (1738 µS/cm), far exceeding WHO limits. This indicates serious contamination, likely from leachates, urban runoff, or wastewater infiltration. *Ibafo* and *Shimawa* well water samples also showed moderately elevated values but within permissible ranges.

Control borehole and well water samples, with TDS values of 160 and 162 mg/L respectively, and EC values of 318 and 325 µS/cm, served as baselines with minimal anthropogenic influence. The generally linear relationship between TDS and EC across all samples reinforces the ion-based conductivity theory.

4.1.1.3 Nitrate Concentration

Figure 4.3 shows spatial variability in nitrate concentration across sampling locations. Most samples fell below this threshold; however, *Ibafo* well (50.02 mg/L) and control well water (57.07 mg/L) slightly exceeded the limit, suggesting possible contamination from agricultural runoff, septic leakage, or domestic effluents. Other moderately elevated samples include *Shimawa*(45.05 mg/L), *Magboro* (30.25 mg/L), and *Arepo* well water samples (38.42 mg/L).

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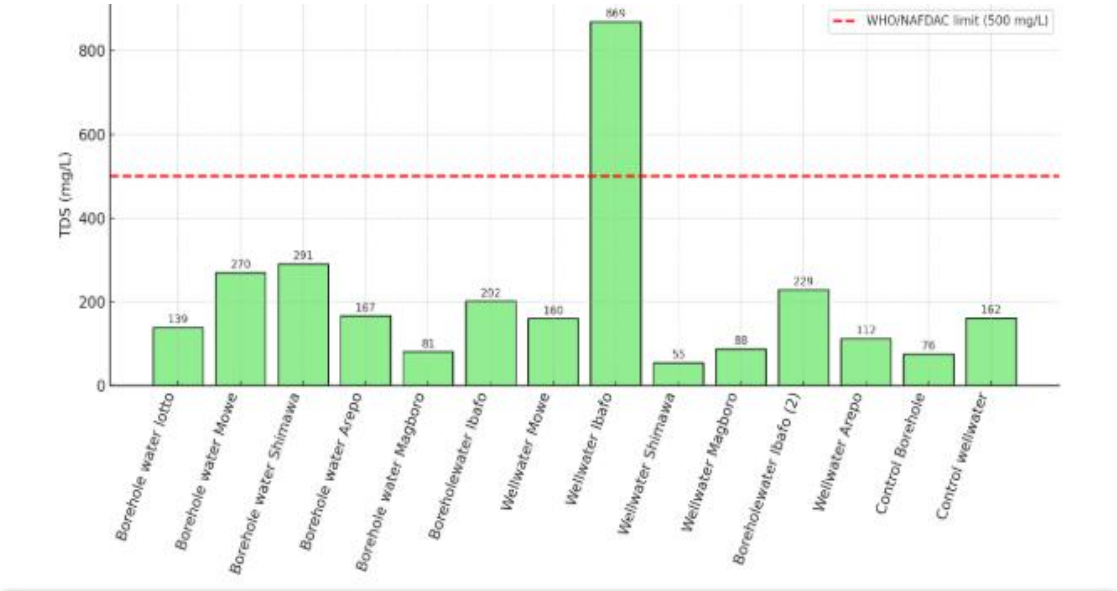


Figure 4.2: Bar Chart of the Total Dissolved Solids (TDS) Values for all Water Samples, with a Dotted Red Line Representing the WHO/NAFDAC Permissible Limit (500 mg/L).

Source: Authors Field work, 2025

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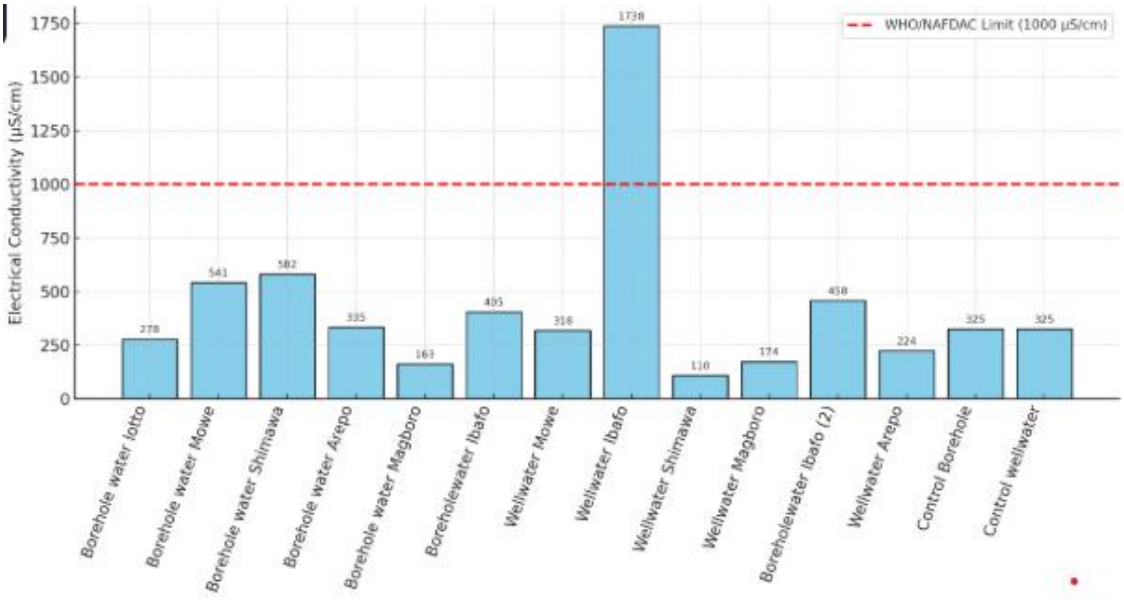


Figure 4.3: Bar Chart of the Conductivity Values for all Water Samples, with a Dotted Red Line Representing the WHO/NAFDAC Permissible Limit (1000 µS/cm).

Source: Authors Field work, 2025

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4.1.1.4 Sulphate Concentration

The highest recorded concentration was 51.04 mg/L (*Shimawa* well water), while the lowest (0.00 mg/L) was observed in *Lotto* and *Magboro* borehole water (Figure 4.4). The generally low sulphate levels indicate minimal industrial discharge or sulphide oxidation in the study area.

4.1.1.5 Hardness

Water hardness, defined by the concentration of calcium and magnesium ions, is not directly regulated by WHO due to its non-toxic nature. However, a practical limit of 200 mg/L is often referenced to avoid scaling and aesthetic issues. As shown in Figure 4.5, *Magboro* borehole recorded the highest hardness (489 mg/L), indicating excessive mineral content. *Lotto* (210 mg/L), *Mowe* (190 mg/L), and *Ibaf*o well water (240 mg/L) samples also approached or exceeded this practical threshold. Conversely, *Arepo* borehole water sample (0.25 mg/L) and *Shimawa* (0.45 mg/L) recorded extremely low hardness values, which could cause corrosiveness and lead to metal leaching in pipes .

4.1.1.6 Turbidity and Dissolved Oxygen (DO)

Turbidity and DO are vital parameters for assessing water clarity and aerobic conditions. As shown in Figure 4.6, all borehole and control borehole samples had turbidity values of 0 NTU, indicating the absence of suspended particles. In contrast, well water samples exhibited turbidity levels between 570 and 1064 NTU, far exceeding the WHO guideline of 5 NTU. These elevated turbidity levels imply high levels of particulate matter, potentially including microbial contaminants. The source of this turbidity could be surface infiltration, runoff, or poor well construction. DO concentrations were uniformly low across all samples, with none meeting the general benchmark of ≥5 mg/L for aerobic conditions. The highest DO value (3.5 mg/L) was recorded in Mowe well water, followed

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by the control well water (3.0 mg/L). Low DO levels are often linked to organic pollution and microbial decomposition raising concerns over potential septic contamination or oxygen demand from organic wastes.

4.1.1.7 Turbidity and Dissolved Oxygen (DO)

Oxidation–Reduction Potential (ORP) is a measure of a water body's ability to either gain or lose electrons, reflecting its redox status. It serves as a proxy for assessing the oxidative or reductive nature of water, and indirectly, its microbial activity and contaminant degradation potential. ORP is expressed in millivolts (mV), with higher values indicating oxidative conditions and lower (even negative) values reflecting reductive environments Figure 4.7 presents a histogram of ORP values across water samples from the *Mowe – Ibafo* axis of Ogun State,

4.1.2 Heavy Metals in Groundwater Samples across all locations

Heavy metals in groundwater are of great concern due to their non-biodegradable nature, toxicity at trace levels, and ability to accumulate in biological tissues (bio-accumulation). The histogram plots and concentration data (see Figures 4.2a–4.2g) illustrate the distribution of Arsenic (As), Copper (Cu),Cadmium (Cd),Zinc (Zn),Magnesium (Mg), cobalt C(o), and Iron (Fe) in borehole and well water sources across locations of the study area.

4.1.2.1 Arsenic (As)

Arsenic concentrations ranged from 0.015 mg/L (*Mowe* borehole) to 0.067 mg/L (Control well water)(figure 4.8a). According to WHO (2017), the maximum permissible limit for arsenic in drinking water is 0.010 mg/L. All samples exceed this threshold, with the highest levels observed in well water from *Arepo* and the control samples, indicating

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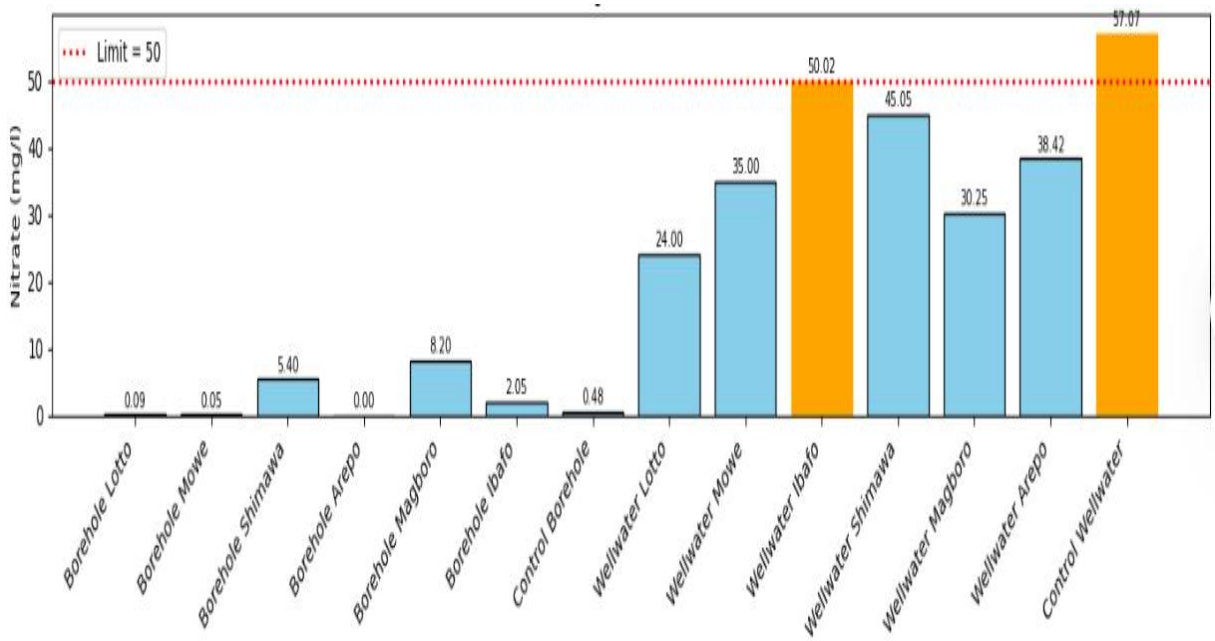


Figure 4.4: Bar Chart of the Nitrate Concentrations for all Water samples across Sample Locations, with a Dotted Red Line Representing the WHO/NAFDAC Permissible Limit (50 mg/L).

Source: Author's Field Work, 2025

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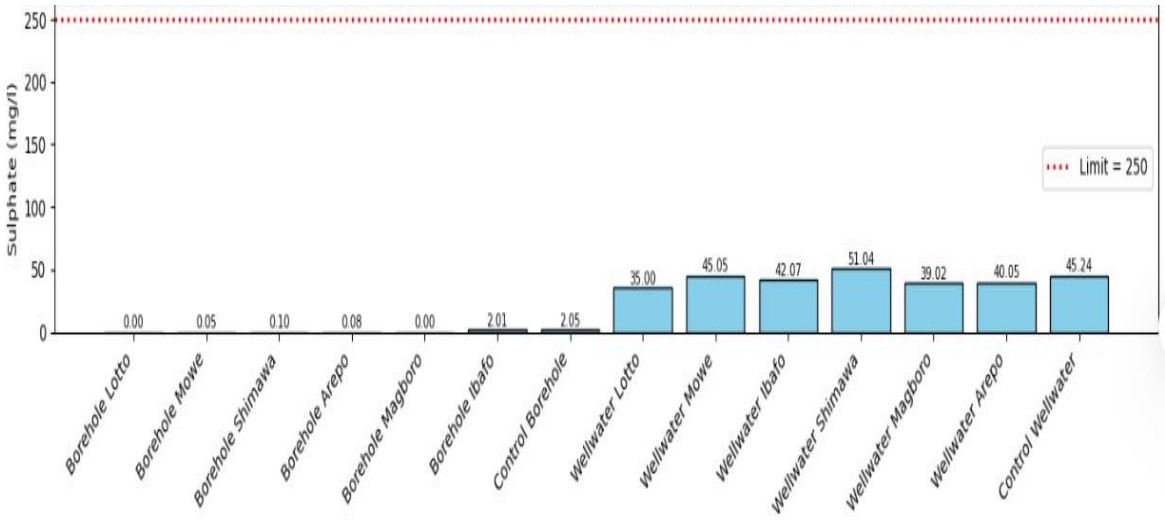


Figure 4.5: Bar Chart of the Sulphate Concentrations for all Water Samples across Sample Locations, with a Dotted Red Line Representing the WHO/NAFDAC Permissible Limit (250 mg/L).

Source: Author's Field Work, 2025

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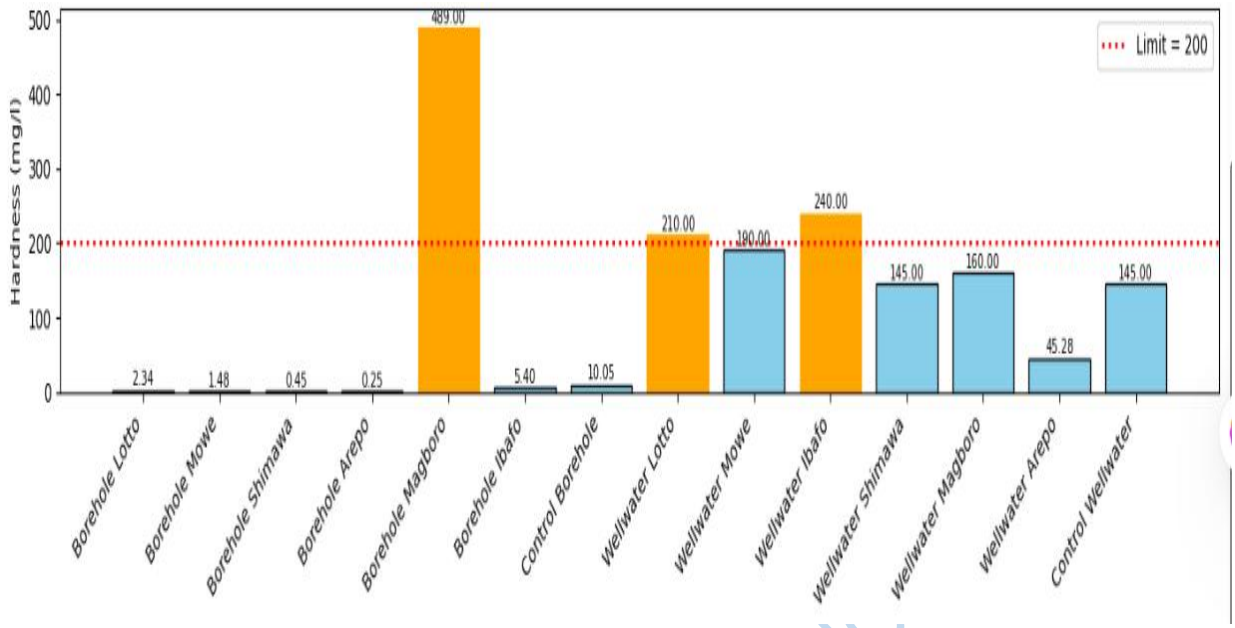


Figure 4.6: Bar Chart of the Hardness for all Water samples across Sample Locations, with a Dotted Red Line Representing the WHO/NAFDAC Permissible Limit (200 mg/L $CaCO_3$).

Source: Author's Field Work, 2025

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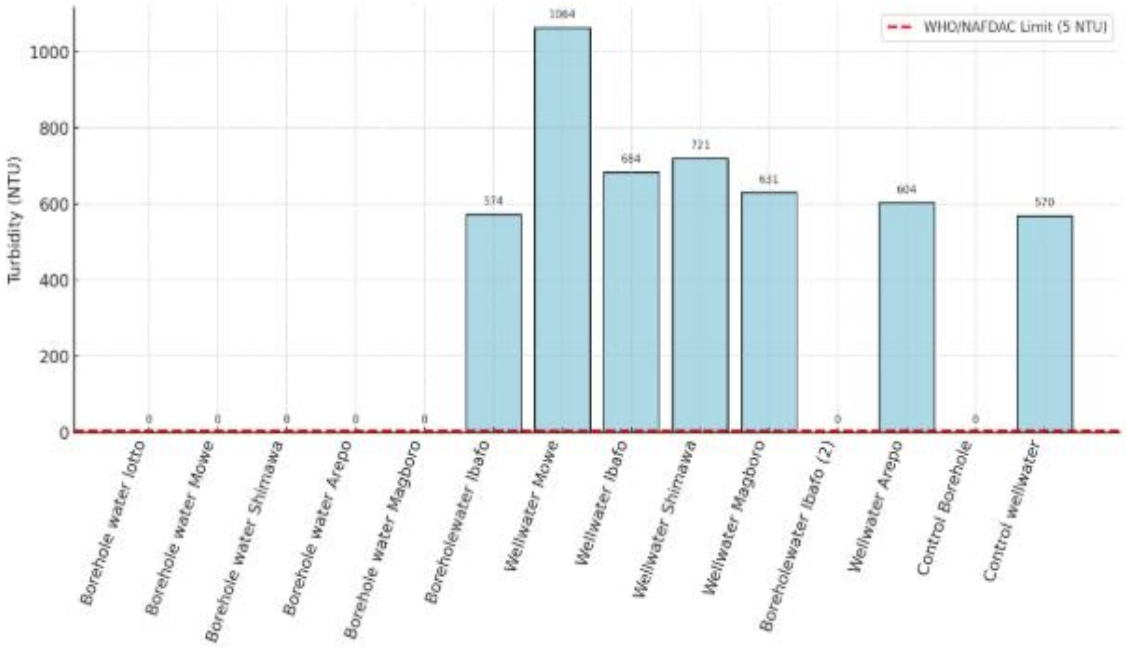


Figure 4.7: Bar Chart of the Turbidity of all Water Samples across Sample Locations, with a Dotted Red Line Representing the WHO/NAFDAC Permissible Limit (% NTU)

Source: Authors Field work, 2025

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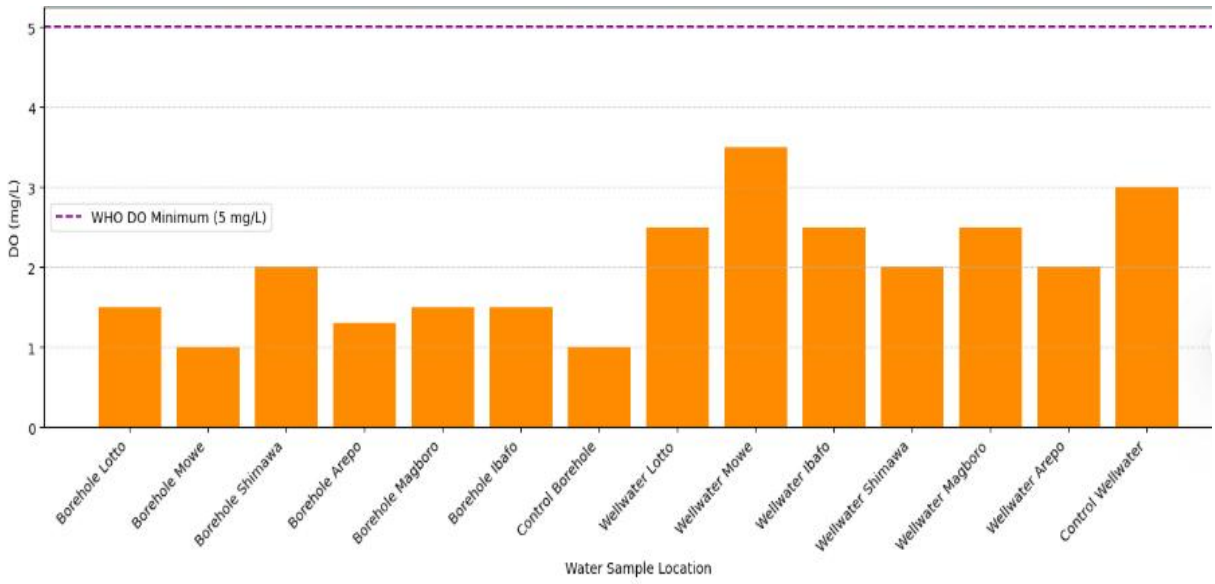
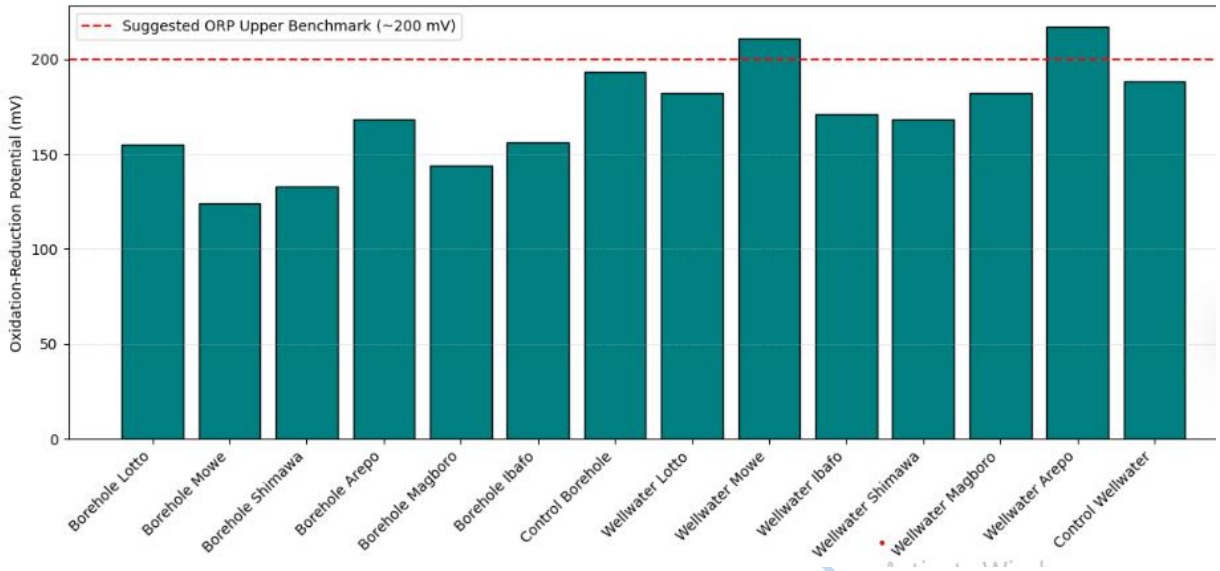


Figure 4.8: Bar Chart of the Dissolved Oxygen (DO) all Water Samples across Sample Locations, with a Dotted Red Line Representing the WHO/NAFDAC Permissible Limit (5 mg/l)

Source: Author's Field Work, 2025

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Sample Locations

Figure 4.9: Bar Chart of the Oxidation-Reduction Potential (ORP) of all Water samples across Sample Locations, with a Dotted Red Line Representing the WHO/NAFDAC Permissible Limit (200 mV)

Source: Author's Field Work, 2025

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widespread arsenic contamination. The elevated levels could stem from geogenic sources, including arsenic-rich bedrock or anthropogenic influences, such as pesticide residues, industrial waste, and improper waste disposal. Chronic exposure to arsenic through drinking water is associated with skin lesions, cardiovascular diseases, and increased cancer risk, underscoring the need for immediate mitigation.

4.1.2.2 Copper (Cu)

Copper levels ranged from 0.377 mg/L (*Mowe* borehole) to 0.623 mg/L (Control well water) (Figure 4.8b). indicating no immediate health risk. However, elevated copper levels, even within safe limits, may contribute to aesthetic issues such as bitter taste and blue-green staining of pipes. The relatively high levels in some locations may be linked to corroding plumbing systems, especially in acidic water environments (e.g., pH < 6.5), as observed in earlier sections of this study.

4.1.2.3 Cadmium (Cd)

Cadmium concentrations varied from 0.017 mg/L to 0.084 mg/L, with the highest value found in Control well water (Figure 4.9a). WHO's guideline value for cadmium is 0.003 mg/L, indicating that all sampled locations far exceed the permissible limit. Possible sources include industrial discharge, batteries, plastic degradation, andphosphate fertilizers leaching into groundwater. Long-term ingestion of cadmium-contaminated water may lead to kidney damage, bone demineralization, andhypertension.

4.1.2. 4 Zinc (Zn)

Zinc levels ranged from 0.568 mg/L to 0.806 mg/L, all well below the WHO maximum limit of 3.0 mg/L (Figure 4.9b). Zinc is an essential trace element and poses minimal health risk at these levels. However, excessive intake (>3 mg/L) can cause metallic taste

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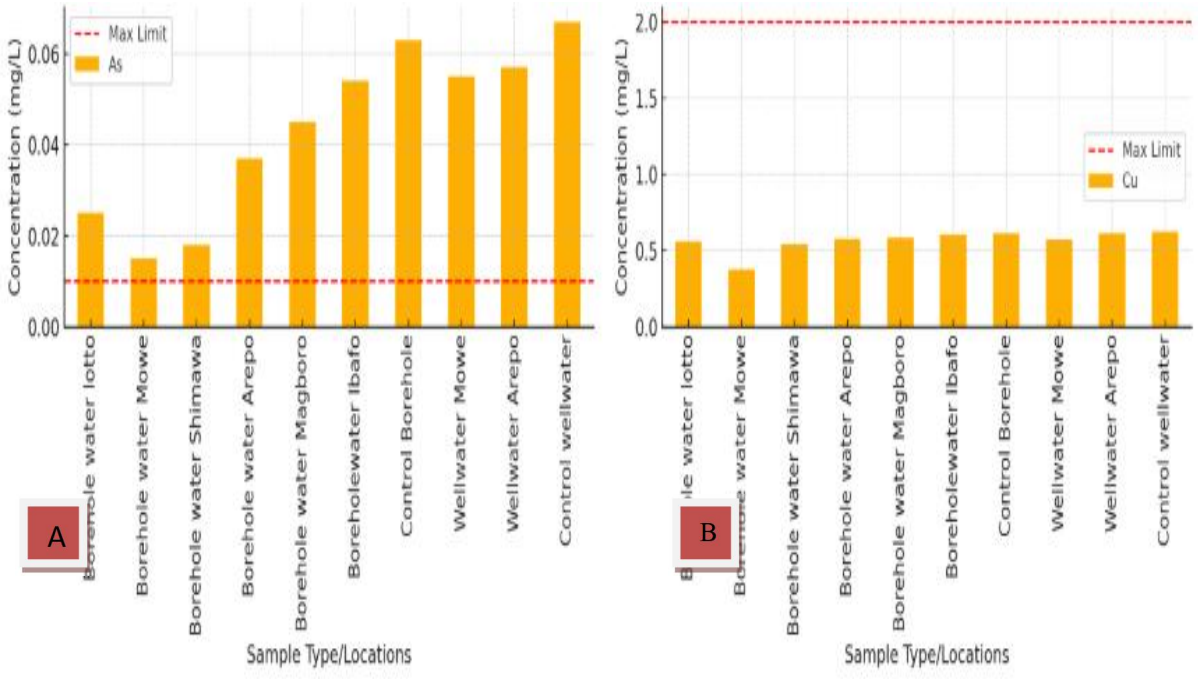


Figure 4.10: Bar Chart of the Heavy Metal Concentrations of all Water Samples across Sample Locations, with a Dotted Red Line Representing the WHO/NAFDAC Permissible Limits (A): Arsenic (B): Copper

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and gastrointestinal irritation. The detected concentrations suggest limited zinc pollution, possibly derived from minor industrial activities or galvanized plumbing systems.

4.1.2.5 Magnesium (Mg)

Magnesium values spanned 0.433–0.678 mg/L (Figure 4.10a), which are low and within safe thresholds for drinking water. Although not specifically regulated by WHO for health effects, excessive magnesium in combination with sulfate may cause a laxative effect. These values suggest natural geogenic origin from dolomite or magnesium-bearing rocks, which dissolve into groundwater.

4.1.2.6 Cobalt (Co)

Cobalt concentrations were between 0.062–0.136 mg/L (Figure 4.10b). WHO has no established guideline for cobalt in drinking water due to insufficient data. However, cobalt is toxic in excess and exposure greater than 0.1 mg/L is associated with cardiotoxicity and thyroid dysfunction. Several samples (e.g., Control well water, Ibafo borehole) exceed this threshold, suggesting potential contamination from industrial tools, pigments, or mining residues. Monitoring is advisable despite the lack of definitive WHO limits.

4.1.2.7 Iron (Fe)

Iron levels ranged from 0.008-0.057 mg/L, all below the WHO aesthetic limit of 0.3 mg/L (Figure 4.11). Although not hazardous at these levels, iron can cause taste, staining, and plumbing issuesabove threshold levels. The low iron values imply minimal corrosion or natural iron leaching, consistent with well-aerated aquifers.

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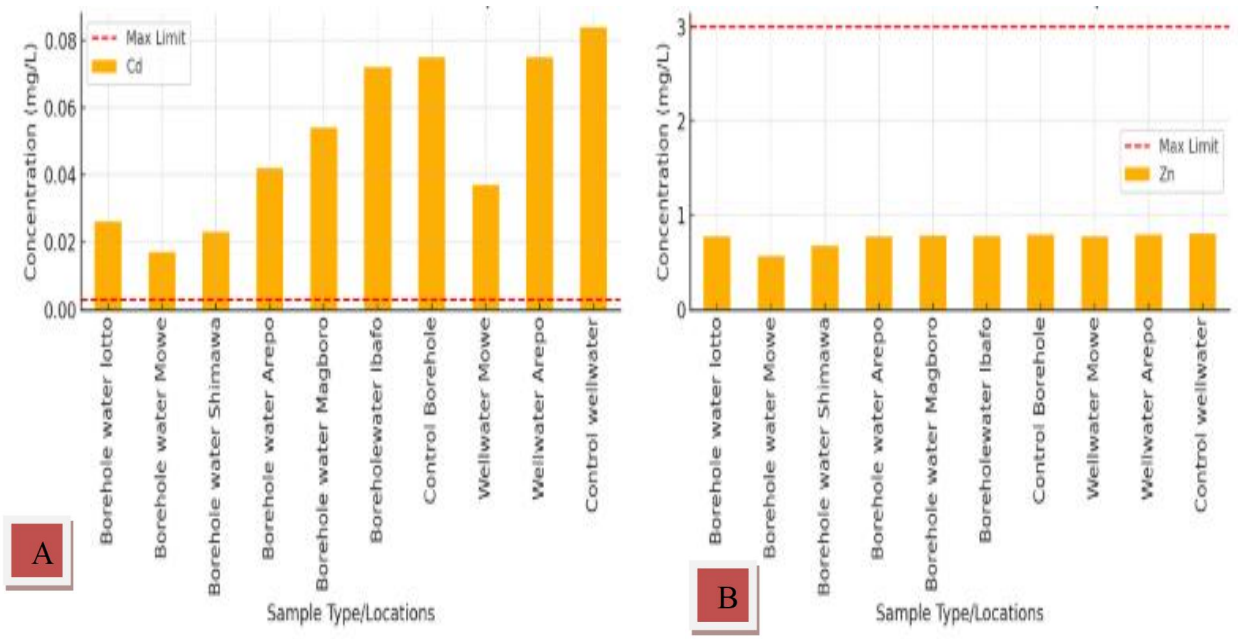


Figure 4.11: Bar Chart of the Heavy Metal Concentrations of all Water Samples across Sample Locations, with a Dotted Red Line Representing the WHO/NAFDAC Permissible Limits, (A): Cadmium (B): Zinc

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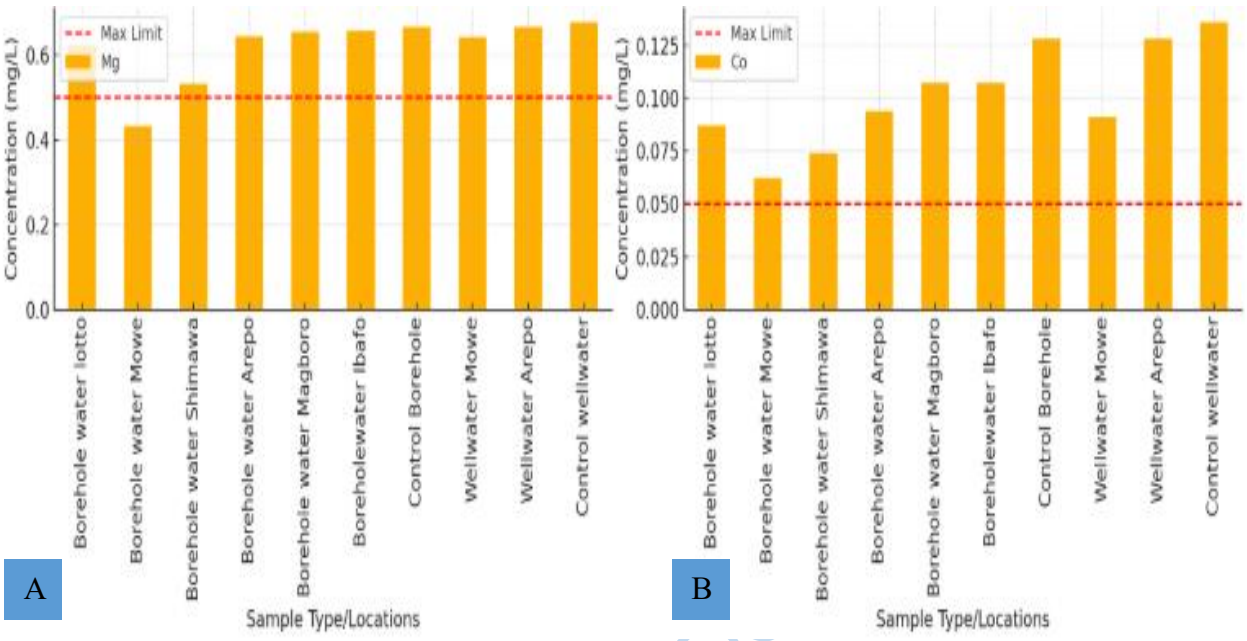


Figure 4.12: Bar Chart of the Heavy metal Concentrations of all Water samples across Sample Locations, with a Dotted Red Line Representing the WHO/NAFDAC Permissible Limits, (A): Magnesium (B): Cobalt

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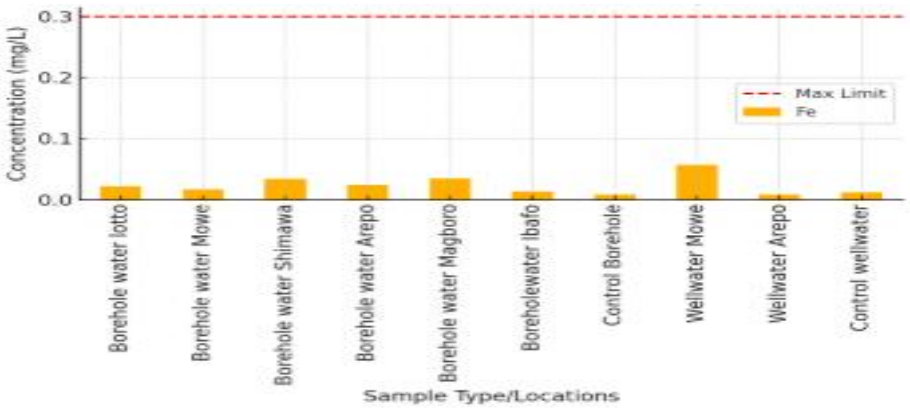


Figure 4.13: Bar Chart of the Heavy Metal Concentrations (Iron, Fe) of all Water Samples across Sample Locations, with a Dotted Red Line Representing the WHO/NAFDAC Permissible Limit

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Table 4.1: Summary of Heavy Metals Evaluation across all Locations

Metal	WHO Limit (mg/L) (NESREA)	Exceeding Samples	Potential Health Risks
As	0.01	All	Carcinogenicity, vascular damage
Cu	2.0	None	Aesthetic issues at >1.0
Cd	0.003	All	Kidney damage, osteoporosis
Zn	3.0	None	Rarely toxic, minor taste impact
Mg	Not strict	None	Laxative effect (at high levels)
Co	No WHO value	Some >0.1	Cardiotoxicity, thyroid disruption
Fe	0.3 (aesthetic)	None	Taste, staining, plumbing deposits

Source: Author's Field Work, 2025

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4.2 Discussion of Findings

This section presents the findings from the analysis of heavy metals and physicochemical parameters of groundwater samples obtained from the *Mowe–Ibafo* axis of Ogun State, Nigeria. This region, experiencing rapid urbanization and diverse land-use activities, was selected to assess the anthropogenic impacts on groundwater quality[1]. The study covered key land use types, including industrial (*Mowe*), agricultural (*Shimawa*), commercial (*Ibafo*), recreational (*Magboro*), residential (*Arepo*), and transport-influenced zones (Lotto). The physicochemical parameters investigated include salinity, temperature, pH, total dissolved solids (TDS), electrical conductivity (EC), oxidation-reduction potential (ORP), turbidity, dissolved oxygen (DO), hardness, nitrate, and sulphate.

The analysis reveals that arsenic and cadmium contamination is widespread, with potentially harmful health implications for the local population. Cobalt concentrations also raise concerns in a few locations, warranting monitoring despite limited global guideline values. Meanwhile, zinc, magnesium, copper, and iron levels generally comply with international standards[2].

Groundwater quality in the *Mowe - Ibafo* axis is at risk due to anthropogenic inputs, notably industrial runoff, agricultural leachates, and domestic waste infiltration. These findings necessitate urgent public health interventions, including point-of-use treatment, community educationandregulatory oversight of groundwater extraction and land-use practices. The contamination of groundwater, therefore, represents a multifaceted challenge that requires concerted efforts at local, regional, and global levels to mitigate its impact[3]. Sustainable groundwater management strategies are essential to ensure that this invaluable resource remains available for future generations. Recent advancements in water quality assessment have improved our ability to monitor groundwater

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contamination.Techniques such as atomic absorption spectroscopy (AAS) and inductively coupled plasma mass s*pectrometry* (ICP-MS) provide accurate measurements of trace elements[43]. In microbial analysis, polymerase chain reaction (PCR) techniques have enhanced the detection of pathogenic organisms[4].

Pollution indices, including the Heavy Metal Pollution Index (HPI) and the Groundwater Quality Index (GQI), have been developed to simplify the evaluation of water quality data. These tools enable researchers and policymakers to assess contamination levels and prioritize interventions. Groundwater pH is affected by multiple factors, including the geological characteristics of the aquifer, the presence of organic matter, and human activities like industrial waste disposal and agricultural runoff. For instance, groundwater in limestone-dominated areas often has higher alkalinity due to the dissolution of calcium carbonate[5]. In contrast, areas rich in organic matter may have more acidic groundwater because of natural decomposition. Human activities such as mining, intensive agriculture, and wastewater discharge can further alter groundwater pH. For example, the use of nitrogen-based fertilizers can acidify groundwater through the formation of nitric acid. Groundwater quality assessment is an essential process in ensuring that this critical resource remains safe for various uses. The evaluation of physicochemical parameters, including pH, TDS, EC, hardness, and the concentration of essential and non-essential elements, provides valuable insights into the water's quality and its suitability for drinking, irrigation, and industrial purposes. Variations in these parameters are influenced by both natural processes and anthropogenic activities, making it essential to monitor groundwater quality regularly to detect potential risks and ensure sustainable water management practices[6]. As the demand for clean water continues to rise globally, it is increasingly important to protect and preserve groundwater resources for future generations.

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Groundwater plays a critical role in providing essential water resources for drinking, irrigation, and industrial use. However, one of the growing threats to the quality of groundwater is contamination by heavy metals. Heavy metals, defined as metallic elements with high atomic weights and densities, are naturally found in the Earth's crust. Despite their natural presence, heavy metals become hazardous when their concentrations exceed permissible levels in the environment[7]. Unlike organic pollutants, which can be broken down by natural processes, heavy metals are non-biodegradable and can persist in ecosystems for long periods. Over time, they accumulate in living organisms, potentially causing serious health risks and environmental damage.

The sources of heavy metals in groundwater are diverse, ranging from natural geological processes to human activities. Naturally occurring heavy metals in the Earth's crust are often released into groundwater through processes such as weathering, erosion, and mineral dissolution[8]. For instance, elements like arsenic, cadmium, copper, lead, and mercury are commonly found in rocks, soils, and sediments. Over time, these elements can leach into groundwater through natural processes like groundwater movement, especially in regions with specific geological formations. In such cases, the concentrations of these metals in groundwater tend to be relatively low, but they can still pose a significant risk to human health when consumed over long periods of time.

While natural sources of heavy metals contribute to groundwater contamination, anthropogenic (human-made) activities have become the leading cause of elevated concentrations of heavy metals in groundwater. Industrial activities, mining operations, agriculture, and improper waste disposal are major contributors to heavy metal contamination in groundwater[9]. Industrial processes, such as the production of electronics, textiles, and chemicals, often involve the use of heavy metals like lead, mercury, and

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cadmium. Improper disposal of industrial waste containing heavy metals can lead to contamination of surrounding groundwater resources. For example, the discharge of untreated wastewater containing heavy metals into rivers, lakes, or groundwater sources can result in elevated concentrations of these metals in drinking water supplies and irrigation systems.

Mining activities are another significant source of heavy metals in groundwater. Mining for precious metals, coal, and other minerals can release heavy metals into the environment through the process of excavation and ore processing. As mining waste is often stored in tailing ponds or left in open pits, the metals can leach into the surrounding groundwater over time. This process, known as acid mine drainage (AMD), occurs when sulfide minerals in mined rocks react with water and air, leading to the formation of acidic water with elevated concentrations of heavy metals like copper, arsenic, and zinc[10]. In some regions, mining activities have caused significant contamination of nearby groundwater aquifers, rendering them unsafe for human consumption and agricultural use.

Agricultural practices, including the use of untreated manure and the application of fertilizers containing organic matter, can also introduce pathogens into groundwater. In regions with heavy farming activities, microbial contaminants from irrigation systems can contaminate wells and boreholes, further compromising water quality. Contamination from animal waste is particularly prevalent in areas where livestock farming is common, as improper disposal of animal excrement can lead to the introduction of harmful microorganisms into water supplies. Additionally, the improper handling and disposal of hospital waste or other medical waste can introduce a wide range of pathogens into the groundwater system, exacerbating the risk of contamination[11].

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The mechanism by which microbial contaminants enter aquifers involves the movement of water through the soil and rock layers. When rainwater or surface water containing pathogens seeps into the ground, it can infiltrate the porous media of aquifers, carrying pathogens along with it. Groundwater in shallow aquifers is especially susceptible to microbial contamination, as these aquifers are often in close proximity to surface water and the contaminants in it. However, deeper aquifers, although generally more protected from surface contaminants, can still become contaminated if there is improper well construction or if there are faults in the geological layers that allow for the movement of contaminated water from shallower layers[12].

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Chapter Five

Conclusion

5.1 Summary of Findings

The results of this study show that the groundwater quality in *Mowe–Ibafo* is affected by both natural factors and human activities, which have led to notable variations in heavy metal concentrations and key physicochemical parameters.

The pH levels of the groundwater samples ranged from slightly acidic to slightly alkaline. Some samples fell below the neutral pH of 7, indicating acidic conditions that can increase the mobility of toxic metals. Total Dissolved Solids (TDS) levels in some locations were found to be higher than recommended limits, suggesting increased mineral content and possible contamination from runoff, soil leaching, or human activities.

Electrical Conductivity (EC) values corresponded with the TDS results, confirming the presence of significant amounts of dissolved ions, which indicate higher salinity levels in some areas.

The concentrations of certain heavy metals, such as lead (Pb), cadmium (Cd), and copper (Cu), exceeded the safe limits recommended by WHO drinking water standards in some sampling sites. Elevated levels of lead and cadmium pose serious health risks, including potential damage to the nervous system, kidneys, and other organs if consumed over long periods ,The presence of these metals suggests possible contamination sources such as improper waste disposal, industrial activities, and leaching from surrounding soils.

5.2 Conclusion

The increasing degradation of water quality in the Mowe–Ibafo region can be attributed largely to unplanned urban expansion, improper waste disposal, intensive agriculture, and inadequate wastewater management systems. One major concern is nitrate contamination, which often results from excessive use of nitrogen-based fertilizers in farming and the

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leaching of untreated sewage and animal waste into groundwater sources. High nitrate levels pose serious health risks, particularly for infants, as they can cause conditions like *methemoglobinemia*('blue baby syndrome') and other health complications.

Turbidity, or the cloudiness of water caused by suspended particles, indicates possible contamination from soil erosion, surface runoff, or poorly managed construction activities. High turbidity reduces light penetration in water, affecting aquatic ecosystems and potentially harbouring harmful microorganisms that can cause waterborne diseases.

Increased salinity and high levels of total dissolved solids (TDS) may result from geological factors, but they are often exacerbated by human activities such as over-extraction of groundwater, industrial discharges, and improper waste dumping. Elevated salinity makes water unsuitable for drinking and irrigation, as it can damage crops and reduce soil fertility through salinization.

Acidic pH levels, meanwhile, can enhance the mobility of toxic heavy metals such as lead, cadmium, and copper in groundwater. This increases the likelihood of these metals entering the human food chain, posing additional health hazards like neurological damage, kidney problems, and other chronic diseases.

Altogether, these findings highlight that without immediate action, the communities within the Mowe–Ibafo region face significant threats to safe drinking water, agricultural productivity, and overall public health. There is therefore a pressing need for integrated land use planning, enforcement of stricter pollution control measures, investment in modern wastewater treatment facilities, and public education to promote sustainable agricultural practices. If these issues are not urgently addressed through coordinated

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policy and community engagement, the region risks facing an escalating cycle of environmental degradation and socio-economic challenges in the years to come.

5.3 Recommendations

Going by the findings from this study, the following recommendations are made:

1. There should be regular monitoring and surveillance through the:

i. Establishment of a community-based water quality monitoring framework, employing monthly testing of key parameters (DO, nitrate, sulphate, TDS, conductivity) using field kits and confirmatory laboratory tests.

ii. Development a GIS-enabled water quality database to track contamination hotspots and seasonal variations.

2. There should be pollution control check through the:

i. Implementation of buffer zones between agricultural lands and groundwater recharge areas, using vegetative strips or constructed wetlands to minimize leaching of nitrates and sulphates.

ii. Enforcement strict regulation of septic tank maintenance and industrial waste disposal in the region to prevent leaching into aquifers.

3. Establishment of public health intervention through the:

i. Provision of public access to decentralized water purification systems (e.g., point-of-use nitrate filters or solar-powered ultra-filtration systems).

ii. Sensitization of the community members on the health effects of unsafe water and promote rainwater harvestingas a complementary source of water for domestic usage.

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4. There should be further research on:

i. a comprehensive seasonal study covering both dry and wet seasons to evaluate temporal dynamics; and

ii. expanded future work to include bacteriological analysis and trace metal monitoring to assess broader contamination.

5.4 Contribution to Knowledge

This study adds to existing knowledge by providing updated and location-specific data on the current state of groundwater quality in the *Mowe–Ibafo* region, an area experiencing rapid urban growth and increasing human activity. The research highlights how land use practices, such as intensive farming, improper waste disposal, and poor wastewater management, directly impact key water quality indicators including nitrate levels, turbidity, salinity, and pH.

By identifying the link between human activities and the presence of pollutants such as nitrates and heavy metals in groundwater, this work emphasizes the need for better land use planning, stricter pollution control measures, and improved environmental policies.

The study also contributes practical insight by demonstrating how groundwater in peri-urban areas like Mowe–Ibafo can become unsafe if not properly monitored and managed. It serves as evidence that similar communities in developing countries face comparable risks when urbanization outpaces infrastructure development.

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5.5 Suggested Areas for Further Research

Groundwater Remediation Methods: Investigate cost-effective and locally appropriate technologies or methods for treating contaminated groundwater, including both in-situ (in the ground) and ex-situ (after extraction) techniques.

Seasonal Assessment: Future studies should investigate how groundwater quality parameters and heavy metal concentrations change between the dry and rainy seasons. This will help determine seasonal influences on contamination levels.

Detailed Source Identification: More advanced studies using isotopic or geochemical tracing techniques should be conducted to pinpoint specific sources of heavy metals and other pollutants, distinguishing between natural (geogenic) and human-made (anthropogenic) sources.

Policy and Governance Studies: Evaluate the effectiveness of existing water management and environmental protection policies in the region, and explore ways to strengthen enforcement and stakeholder collaboration for better groundwater protection.

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Appendices

Appendix I : Study Area Description

Location: Mowe–Ibafo is a rapidly developing peri-urban corridor located along the Lagos–Ibadan Expressway in Obafemi Owode Local Government Area, Ogun State, Southwestern Nigeria. the area has experienced significant population growth. This growth is as result of migration of people from Lagos to this area due to affordable housing.MoweIbafo is characterized by mixed land uses residential, commercial agricultural, recreational, transportation and industrial activities

Coordinates:

latitude: 6°40’N and 6°45’N

Longitudes: 3°24’E and 3°28’E

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Appendix II: Sampling Location

Arepo is primarily a residential area, characterized by housing communities. Magboro serves as a recreational area, featuring parks and leisure spots. Ibafo functions as a commercial center with markets and business activities. Mowe is an industrial area, hosting factories and production facilities. Shimawa is dedicated to agriculture, with farms and cultivated lands. Lotto acts as a transportation hub, connecting major roads and transit points.

Sample ID	Sampling location	GPS cordinates	Sample Types	Description
S1	Arepo	6.7552° N 3.2578° E	Water	Residential Area
S2	Magboro	6.7148° N 3.4025°N	Water	Recreational Area
S3	Ibafo	6.7401° N 3.4221° N	Water	Commercial Area
S4	Mowe	6.8107° N 3.4366° N	Water	Industrial Area
S5	Shimawa	6.7641° N 3.4884° N	Water	Agricultural Area
S6	Lotto	6.80199° N 3.42117° N	Water	Transportation Area

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Appendix III: Sample Preparation and Analytical Methods

- Pre-cleaned 1.5-litre polyethylene bottles were used for sampling.

- Before sampling, bottles were rinsed three times with the groundwater at each site to avoid contamination.

- For heavy metal analysis, samples were preserved by adding a few drops of concentrated nitric acid (HNO_3) to reduce the pH below 2.

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Appendix IV: List of Analyzed Physico-chemical Parameters and Heavy Metals

1. Salinity
2. Temperature
3. PH
4. Total Dissolved Solids
5. Conductivity
6. ORP
7. Turbidity
8. Dissolved Oxygen
9. Hardness
10. Nitrate
11. Sulphate

Heavy Metals

1. Asenic (As)
2. Copper (Cu)
3. Cadmium (Cd)
4. Zinc (Zn)
5. Maganese (Mn)
6. Combalt (Co)
7. Iron (Fe)

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Appendix V:Quality Assurance and Quality Control (QA/QC)

- Triplicate samples were taken at selected locations to check reproducibility.
- Glassware and sampling containers were cleaned with distilled water and acid-washed.
- All reagents used were of analytical grade.

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Appendix VI: Health Risk

• The primary pathway for human exposure is direct consumption of contaminated groundwater used for drinking and cooking.

• Ingestion of water containing heavy metals, nitrates, or pathogens can lead to both acute and chronic health effects.

• Residents may come into contact with contaminated water during bathing, washing, or other domestic uses.

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Appendix VII: Questionnaire

1 **.** How do you obtain your drinking water?

2. Are there any noticeable changes in the water quality?

3 . Have you experienced any water-borne diseases recently?

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Bio-data

A. Personal Data:

1. Full Name: Fasanmi Adenike Onaolapo

2. Address: Ekute Quarters, Ado Ekiti

3. Email: onaoalopoadenike67@gmail.com

4. Date and Place of Birth: 06 May 1998

5. Name and Address of Next of Kin: Fasanmi Damilola Adesewa, Ekute quarters, Ado Ekiti

B. Educational Background

Educational Institutions Attended with Dates and Qualifications:

i. Primary Education

Community Primary School ApowoImesinEkiti 2010

i. Secondary Education

Royal Jesuit College, AgbadoEkiti 2010 - 2015

i. Higher Educational Institutions

Ekiti State University, Ado Ekiti 2015- 2021

Qualifications Obtained

Primary School Leaving Certificate 2010

Secondary School Leaving Certificate 2015

B.Sc. Environmental Management 2021

C. Working Experience with Dates

Delta State Ministry of Environment 2021-2022

D. Awards and Fellowship

Nil

E. Membership of Academic Professional Bodies

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Nil

F. Major Conferences / Workshops Attended

Nil

G. Publication

Nil

H. Names and Addresses of Referees:

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I. Signature and Date

_____ _____

Date **Signature**

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The University Compliance Certification

This is to certify that the Thesis by **Fasanmi Adenike Onaolapo** with Matric No **LCU/PG/005711** in the Department of Biological Sciences, Faculty of Natural and Applied Sciences, Lead City University, is in full compliance with the approved University format and style.

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Name and Signature	**Date**