HYDROLOGICAL INVESTIGATION OF A MUNICIPAL SOLID WASTE DUMPSITE IN IYOWA, BENIN CITY, EDO STATE.

BY

Glory Onyekachukwu BOI (Miss)
LSC2009943

DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY
FACULTY OF LIFE SCIENCES
UNIVERSITY OF BENIN,
BENIN CITY.

NOVEMBER, 2025

HYDROLOGICAL INVESTIGATION OF A MUNICIPAL SOLID WASTE DUMPSITE IN IYOWA, BENIN CITY, EDO STATE.

BY

Glory Onyekachukwu BOI (Miss)
LSC2009943

PROJECT SUBMITTED TO THE DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF SCIENCE (BSc.) DEGREE IN SCIENCE LABORATORY TECHNOLOGY (GEOLOGY AND MINING TECHNIQUES).

NOVEMBER, 2025

CERTIFICATION

This is to certify that this thesis **HYDROLOGICAL INVESTIGATION OF A MUNICIPAL SOLID WASTE DUMPSITE IN IYOWA, BENIN CITY, EDO STATE** was carried out by **Glory Onyekachukwu BOI (Miss)** with Matriculation Number LSC2009943 of the Department of Science Laboratory Technology (Geology and Mining Techniques), Faculty of Life Sciences, University of Benin, Benin-City, under the supervision of **Dr (Mrs.) A. Obayaju**.

Dr (Mrs.) A. Obayaju **Supervisor**	**Date**
Dr. P. O. Alonge **Project Coordinator**	**Date**
Prof. J. O. Osarumwense **Head of Department**	**Date**
External Examiner	**Date**

DEDICATION

This project is dedicated to God for his guidance, protection and provision throughout my academic journey.

I want to extend my heartfelt appreciation to my parents, Mr. and Mrs. Joseph Boi, for their unwavering love, care and support.

I am also grateful to everyone who contributed to my growth and success in one way or the other. Your kindness and encouragement have made a significant impact in shaping my academic pursuit, and this achievement stands as a testament to their unwavering belief in me.

ACKNOWLEDGEMENTS

With profound gratitude, I want to express my deep sense of acknowledgement to God Almighty for his grace, mercy, strength and guidance through my academic journey. His favor and wisdom has been my great anchor in overcoming challenges and successfully completing this project.

I extend my heartfelt appreciation to my project supervisor, Mrs. Andre Obayaju, for her patience, invaluable guidance, and constructive feedback, which contributed immensely to the success of this work. Her encouragement and commitment to excellence inspired me to push forward despite difficulties. I am grateful to my Head of Department, Prof. J. O. Osarumwense, for his leadership provided for academic and personal growth, fostering a culture of excellence within the department.

A special appreciation goes to Dr. P. O. Alonge, my project coordinator, for his unwavering support throughout this research. I also want to appreciate my esteem lecturers: Dr. Kenneth Ojeaga, Mr. Peter Bassey, Dr. John for their immensely contributions, mentorship and academic guidance, which have shaped my learning experience in the Department of Sciences Laboratory Technology(Geology and Mining Option),Faculty of Life Sciences, University of Benin. Their dedication to imparting knowledge and commitment to student's success are truly commendable.

Furthermore, I recognize the academic and non-academic staff of the department whose effort in creating a conducive learning environment made my studies smoother. And thankfully for their invaluable contributions.

I want to specially appreciate my loving parents, Mr. and Mrs. Joseph Boi for their unconditional love, financial sacrifices, prayers and moral support which has been my driving force. To my wonderful siblings, Favour and Grace, my twinnie thank you for always believing in me and standing by me throughout this journey. I want to sincerely appreciate my auntie, Mrs Joy Okweni, for her support, guidance, love and that has always stood by me all through.

To my friends, Joanita, Osarobo, Racheal, Sharon, Doris, for their support throughout my academic journey in the university.

I want to extend my gratitude to My Champion, Emmanuel Oritseseudede Fregene for his unwavering love, support, care, patience, guidance, affection, encouragement, leadership, and personal growth, through my academic journey. I am grateful for your kindness and how you played a significant impact in shaping my academic pursuit. Lastly I want to thank and appreciate myself for coming thus far in this journey.

TABLE OF CONTENTS

ABSTRACT

This study investigated the hydrogeological evaluation of borehole water contamination near a solid waste dumpsite in Iyowa, Benin City, Nigeria. The aim was to assess how dumpsite leachate affects groundwater quality by examining physicochemical, microbiological, and heavy metal parameters. Five borehole samples were collected at varying elevations and distances around the dumpsite (coordinates: 6°27′29″N–6°27′44″N, 5°36′10″E–5°36′37″E) using GPS mapping and WHO-recommended sampling procedures. Laboratory analyses covered pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, nitrate, sulphate, phosphate, and selected metals (Pb, Fe, Cr, Zn) determined by Atomic Absorption Spectrophotometry (AAS), alongside microbial tests for total coliforms and E. coli. The results (Tables 4.1–4.3, Figures 1–2) showed acidic groundwater (pH 5.19–6.14) below WHO limits (6.5–8.5), with low alkalinity (4–6 mg/L) and elevated metal concentrations: Pb (0.106–0.428 mg/L), Fe (2.98–7.51 mg/L), and Cr (0.37–3.87 mg/L), all exceeding the permissible limits of 0.01, 0.3, and 0.05 mg/L respectively. Potassium spiked at 55.8 mg/L in the borehole closest to the dumpsite (Sample 2), indicating direct leachate influence. Microbial tests showed absence of coliforms and E. coli, but minor heterotrophic bacteria (1 CFU/mL). Overall, the acidic and metal-enriched groundwater reveals significant leachate intrusion linked to dumpsite proximity, making the borehole water unsafe for domestic consumption without treatment. The findings highlight the need for controlled waste disposal, borehole siting regulation, and continuous groundwater monitoring in Iyowa.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Groundwater is a major source of drinking water for many urban and rural communities, especially in developing countries. In Nigeria, boreholes are commonly used to access groundwater due to unreliable surface water supply. These groundwater sources are often perceived as clean and safe. However, their quality can be compromised by human activities, especially when located near solid waste dumpsites (Abanyie *et al*., 2023). Waste materials deposited on land undergo decomposition and generate leachates liquid substances that percolate through the waste, carrying dissolved and suspended contaminants. These leachates can migrate through soil layers and reach the water table, introducing harmful substances into borehole water (Alao *et al*., 2023).

Iyowa, a rapidly growing settlement in Benin City, faces challenges related to poor waste management and unregulated siting of boreholes. In many parts of the community, boreholes are located close to open dumpsites, raising concerns about the potential for groundwater contamination. Leachates from these dumpsites may contain heavy metals, organic pollutants, pathogenic microorganisms, and other toxic substances. These contaminants pose significant health risks, including gastrointestinal infections, kidney damage, and developmental issues (Gunarathne *et al.,* 2024). Despite these risks, there is limited data on the hydrogeological characteristics of the area and the extent to which solid waste disposal affects groundwater quality in Iyowa.

This study focuses on the hydrogeological evaluation of borehole water contamination in the vicinity of solid waste dumpsites in Iyowa. It aims to assess the interaction between subsurface geological structures, groundwater movement, and the spread of pollutants from surface waste. Understanding the physical and chemical behavior of groundwater in relation to surrounding land use is essential for protecting public health and guiding future borehole development (Nlemolisa *et al.*, 2025). The study will provide evidence-based insight into the contamination levels and possible links between dumpsite proximity and groundwater quality, supporting recommendations for safer borehole placement and improved waste disposal practices.

1.2 STATEMENT OF THE PROBLEM

In many parts of Nigeria, including Iyowa in Benin City, the increasing dependence on borehole water has raised concerns about its long-term safety—especially in areas where solid waste dumpsites are poorly managed. Households and institutions often construct boreholes close to these waste disposal sites, without considering the potential impact on groundwater quality. Solid waste, as it decomposes, produces leachate containing heavy metals, organic matter, pathogens, and other harmful substances. If the underlying soil and rock formations are permeable or fractured, these pollutants can infiltrate the groundwater system (Gunarathne *et al*., 2024). Yet, there is limited hydrogeological data to show how fast or how far these contaminants travel underground in Iyowa. This leaves a serious knowledge gap about the safety of the water people drink daily.

Despite the widespread reliance on borehole water, routine water quality assessment is uncommon. Many users assume the water is clean simply because it looks clear and has no strong odour or taste. This assumption can be misleading. Water that appears safe can still contain invisible threats like E. coli, nitrates, lead, or cadmium (Omeire *et al*., 2015). The lack of local research on groundwater contamination near dumpsites in Iyowa makes it difficult to develop proper regulations or offer community guidance on where to safely drill boreholes. This study is being conducted to investigate the extent of borehole water contamination near dumpsites, analyze the subsurface conditions that affect contaminant transport, and offer scientific evidence that can inform safer water access and better waste management practices in the area.

1.3 SIGNIFICANCE OF THE STUDY

This study is important because it addresses a growing environmental and public health concern in many semi-urban communities like Iyowa, where poor land use planning has led to the close proximity of water sources and solid waste disposal sites. Groundwater from boreholes is widely used in the area for drinking, cooking, and other domestic purposes, yet many residents are unaware of the potential risks posed by leachate infiltration from nearby dumpsites (Alao *et al.*, 2023). This research provides a scientific basis for evaluating the safety of borehole water by examining its physical, chemical, and microbiological characteristics in relation to its distance from solid waste dumps. By doing so, the study will help identify the specific contaminants present, assess the degree of pollution, and highlight the influence of geological formations on contaminant migration. The findings will be useful to environmental health officers, urban planners, and water resource managers who need accurate data to make informed decisions about borehole siting, land zoning, and waste management. It will also serve as a practical guide for residents and local authorities on how to protect groundwater sources from pollution. In addition, this work contributes to the scientific understanding of groundwater vulnerability in the context of unengineered dumpsites, which are common in many parts of Nigeria. The study supports the development of regulatory standards for borehole construction, encourages regular water quality monitoring, and promotes awareness about the invisible risks of contaminated groundwater. Researchers and students working on related topics can also benefit from the methods, findings, and site-specific insights generated. In the long term, this research can help reduce the incidence of waterborne diseases, improve the quality of drinking water, and promote sustainable management of water resources in similar communities facing the same problem.

1.4 SCOPE OF THE WORK

This study was conducted within Iyowa community in Benin City, located approximately at latitude 6°27′35″N and longitude 5°36′25″E. The scope of the work involves assessing borehole water quality near a solid waste dumpsite by collecting and analyzing water samples from five existing boreholes situated at both higher and lower elevations around the dumpsite area. Sampling was carried out during a light drizzle, a condition which may influence leachate mobility and surface runoff into nearby boreholes. Coordinates and altitudes were recorded at each sampling point: Sample 1 – 6°27′29″N, 5°36′10″E, 307 ft; Sample 2 – 6°27′31″N, 5°36′37″E, 267 ft; Sample 3 – 6°27′03″N, 5°36′30″E, 295 ft; Sample 4 – 6°27′41″N, 5°36′10″E, 282 ft; and Sample 5 – 6°27′44″N, 5°36′13″E, 323 ft. Water samples were collected in clean plastic bottles and subjected to laboratory analysis covering physicochemical parameters (pH, electrical conductivity, turbidity, total dissolved solids), microbiological indicators (total coliforms, E. coli), and selected heavy metals (lead, cadmium, iron). The study did not include measurement of aquifer depth or soil permeability due to the fixed nature of the boreholes used. Instead, it focuses on evaluating contamination levels in real-use boreholes to provide baseline data on potential health and environmental risks.

1.5 AIM AND OBJECTIVES

Aim of the Study:

The aim of this study is to evaluate the impact of a solid waste dumpsite on the quality of borehole water in Iyowa, Benin City, through hydrogeological and laboratory-based assessment. The

Objectives of the Study:

Objectives set were to:

i. assess the physicochemical properties of borehole water samples collected near the dumpsite.
ii. determine the presence and concentration of microbiological contaminants such as total coliforms and Escherichia coli in the water samples.
iii. analyze the levels of selected heavy metals (e.g., lead, cadmium, iron) in the borehole water.
iv. compare the water quality results with standard guidelines provided by WHO and relevant national regulatory bodies.
v. examine the relationship between the location (elevation and proximity to the dumpsite) and the variation in water quality parameters.

1.6 LIMITATION OF THE STUDY

This study was limited by several factors that may have influenced the scope and depth of analysis. Borehole samples were collected from already existing installations, which restricted access to subsurface data such as aquifer depth and soil permeability. As a result, the study could not directly assess the geological controls on contaminant movement. The sampling was done during light rainfall, which may have temporarily altered surface runoff patterns and possibly affected water quality readings. Seasonal variation in groundwater quality was not captured, as sampling was conducted only once. In addition, constraints in logistics and laboratory access limited the number of boreholes sampled and the range of parameters tested. Despite these limitations, the study provides useful baseline data on water quality near a dumpsite and highlights the need for further hydrogeological investigations in the area.

CHAPTER TWO

LITERATURE REVIEW

2.1 CONCEPT OF GROUNDWATER AND HYDROGEOLOGY

Groundwater constitutes one of the most significant components of the Earth's freshwater system. It is defined as the water found beneath the Earth's surface within the pores, fractures, and voids of soil, sediment, and rock formations. Unlike surface water, which is directly exposed to atmospheric conditions, groundwater exists in the subsurface and is stored in geological formations known as aquifers. Aquifers serve as both storage and transmission media for groundwater, allowing it to be extracted through boreholes or wells for domestic, agricultural, and industrial purposes.

An aquifer is characterized by its ability to store and transmit water in quantities that are economically viable. The effectiveness of an aquifer depends on its porosity (the proportion of void spaces that can hold water) and permeability (the ability of the material to transmit water through interconnected pore spaces) (Salako and Adepelumi, 2018). Aquifers are generally classified into two major types:

Unconfined Aquifers: These are aquifers in which the water table is exposed to the atmosphere through permeable material. They are directly recharged by precipitation and are particularly vulnerable to surface contamination due to the absence of an overlying impermeable layer.

Confined Aquifers: These aquifers are bounded above and below by relatively impermeable strata such as clay or shale. The water in a confined aquifer is under pressure, which may cause it to rise above the top of the aquifer when tapped by a well.

In the context of hydrogeological evaluation, the nature and type of aquifer are critical in determining its vulnerability to pollution and its response to external stressors such as nearby waste disposal sites.

Basic Principles of Groundwater Movement

Groundwater movement is governed primarily by hydraulic gradients and the physical properties of the geologic medium through which it flows. Water in the saturated zone moves from areas of higher hydraulic head (pressure or elevation) to areas of lower head, a process described by Darcy's Law, which states that the flow rate of groundwater is directly proportional to the hydraulic gradient and the permeability of the material.

Key Principles Influencing Groundwater Movement

Hydraulic Gradient: This refers to the change in hydraulic head per unit distance in the direction of groundwater flow. A steeper gradient results in faster groundwater movement.

Permeability: This describes the ease with which fluids can pass through a porous medium. Coarse-grained materials like gravel have high permeability, while fine-grained materials like clay have low permeability.

Porosity: Porosity refers to the proportion of void space in a material. High porosity means more space for water storage, but not necessarily good water transmission unless the pores are well connected.

Aquifer Heterogeneity and Anisotropy: Natural aquifers are not uniform; they often contain layers with varying permeability and porosity. This affects the direction and rate of groundwater flow and complicates predictions of contaminant transport.

Groundwater typically moves at slow velocities—ranging from millimeters to meters per day—depending on the permeability of the subsurface materials. Because of this slow movement, contaminants introduced at the surface can remain in the subsurface for extended periods, potentially migrating long distances from their source over time.

Hydrogeological Settings and Factors Influencing Groundwater Quality

The hydrogeological setting of an area refers to the structural and lithological arrangement of subsurface materials and how they control groundwater occurrence, movement, recharge, and discharge (Wali *et al.*, 2024). These settings vary considerably and directly influence the quality and quantity of groundwater in a given location. In areas near dumpsites, understanding the hydrogeological context is essential for assessing the potential risk of groundwater contamination.

1. Permeability of Soil and Sediment

In sedimentary terrains like Iyowa, the permeability of the soil and underlying deposits strongly influences groundwater movement and contamination risk. Coarse-grained sediments such as sand and gravel permit faster infiltration and lateral migration of water and leachate from waste dumpsites. Conversely, fine-grained layers like silt and clay reduce vertical percolation, slowing down contaminant transport but allowing gradual accumulation over time. The presence of interbedded sandy horizons or weathered zones can create preferential flow paths, enabling contaminants to bypass low-permeability layers. Thus, in Iyowa, where boreholes are sited close to solid waste dumps, the sediment structure and stratification play a key role in determining how quickly and extensively leachate can reach the aquifer.

2. Depth to Groundwater Table (Aquifer Depth)

Shallow aquifers are typically more vulnerable to contamination due to the shorter distance between the surface and the water table. They are more likely to be impacted by surface activities such as waste dumping, leaking tanks, and agricultural runoff. Deeper aquifers, especially those separated by thick, impermeable layers, are generally better protected. However, they can still be vulnerable through poorly constructed boreholes or interconnected fractures. In this study, the depth of the aquifer was not measured due to reliance on existing boreholes. Nonetheless, the elevation data and topographic setting can help infer relative groundwater vulnerability.

3. Recharge Mechanisms and Rates

Recharge refers to the process by which surface water infiltrates the soil and replenishes groundwater. This process can be natural (from rainfall, river seepage) or artificial (injection wells, recharge basins). The rate and quality of recharge directly impact groundwater quality:

i. Fast recharge following heavy rainfall can flush surface pollutants, including leachate from waste dumps, into aquifers.

ii. In contrast, slow and filtered recharge through thick, fine-grained soil allows for natural attenuation of contaminants through filtration and adsorption.

iii. The day of sampling in Iyowa involved light rainfall, which may have contributed to the mobilization of leachate and its potential infiltration into the surrounding boreholes.

4. Topography and Drainage Patterns

Elevated areas typically serve as recharge zones, while low-lying areas may act as discharge zones or collection points for runoff and leachate. The relative elevation of boreholes with respect to the dumpsite can influence contaminant exposure. Boreholes located downslope or at lower elevations are more likely to receive polluted recharge. The selection of samples from both high and low elevations in this study provides a useful basis for analyzing the influence of topography on water quality.

5. Geochemical Interactions

Groundwater interacts chemically with the surrounding geologic materials, altering its quality. Some common interactions include:

i. Dissolution of minerals from rock, contributing to natural constituents like calcium, iron, and magnesium.

ii. Adsorption and desorption of metals on clay minerals, which can either remove or release contaminants.

iii. Changes in pH, redox potential, and microbial activity can influence the mobility and persistence of contaminants such as heavy metals.

iv. These geochemical factors often determine whether contaminants from waste dumps remain in the aquifer, degrade, or transform into more harmful compounds.

2.2 SOLID WASTE DUMPSITES AND LEACHATE GENERATION

Composition of Municipal Solid Waste

Municipal solid waste (MSW) refers to the daily waste generated from residential, commercial, institutional, and sometimes industrial sources (Ahsan *et al.*, 2015). The composition of MSW varies depending on location lifestyle, economic development, and regulations. In developing countries like Nigeria, the composition is often poorly sorted and predominantly organic.

Typical components of MSW include:

1. Biodegradable waste: food scraps, agricultural waste, and yard trimmings.
2. Recyclables: paper, plastics, glass, and metals.
3. Non-biodegradable waste: textiles, rubber, construction debris, and electronics.
4. Hazardous waste: batteries, expired drugs, hospital waste, and chemicals (often mixed with general waste due to poor segregation).

In unengineered dumpsites such as those common in urban fringe areas like Iyowa in Benin City, there is little to no control over what is deposited. This heterogeneity increases the complexity of environmental impact, especially in terms of water contamination.

The organic fraction of waste undergoes microbial degradation, which initiates chemical reactions that influence leachate composition. Inorganic and hazardous components may release heavy metals and toxic compounds, including:

i. Lead (Pb)
ii. Cadmium (Cd)
iii. Chromium (Cr)
iv. Mercury (Hg)
v. Arsenic (As)
vi. Nitrates and sulphates

Leachate Formation and Migration Mechanisms

Leachate is the liquid that drains or 'leaches' from a solid waste landfill. It results from:

i. Rainwater infiltration

ii. Decomposition of organic matter

iii. Moisture already present in the waste

Once water percolates through waste material, it becomes chemically enriched and can carry a wide range of pollutants. This includes:

i. Organic compounds (e.g., volatile fatty acids, phenols)

ii. Inorganic salts (e.g., chloride, ammonia)

iii. Heavy metals

iv. Microbial contaminants

Key mechanisms driving leachate formation and migration:

i. Infiltration: Precipitation and surface water seep into the waste pile.

ii. Percolation: Water moves downward through waste layers, dissolving soluble compounds.

iii. Saturation and Pressure: As leachate accumulates, pressure builds, causing lateral movement into surrounding soil and aquifers.

iv. Capillary rise: In unsaturated zones, leachate may also move upwards depending on the hydraulic gradient.

Leachate movement is affected by several physical and geological parameters:

1. Waste compaction and porosity
2. Soil permeability
3. Depth of the water table
4. Climatic conditions (temperature, rainfall)
5. Duration of waste deposition

If the base of the dumpsite lacks a proper liner (e.g., clay or synthetic barriers), contaminants easily reach the groundwater system. In such cases, borehole water near these dumpsites is at risk of contamination, especially when the water table is shallow.

Dumpsite Hydrology and Influence on Subsurface Water

The hydrology of a dumpsite describes how water enters, moves through, and exits the waste environment (Zulu, 2019). It is critical to understanding the risk of groundwater pollution. Dumpsites are open systems that interact with both surface and subsurface water.

Major hydrological processes include:

1. Precipitation input: Rainfall is the dominant source of water entering dumpsites.
2. Runoff: When infiltration capacity is exceeded, surface runoff occurs, possibly transporting leachate to nearby land or water bodies.
3. Infiltration and seepage: Water infiltrates waste and underlying soil, forming leachate that seeps downward.

iv. Evapotranspiration: Reduces moisture content at the surface but has limited effect on deeper layers.

Factors affecting dumpsite hydrology:

i. Topography: Slopes influence runoff and infiltration patterns.
ii. Waste depth and density: Affects water retention time and saturation.
iii. Hydraulic conductivity of soil: Determines the rate at which leachate can percolate through the subsurface.
iv. Depth to groundwater table: Shallow water tables are more susceptible to quick contamination.
v. Absence of engineered barriers: Most dumpsites in Nigeria are unlined and unmonitored.

Subsurface impact:

As leachate migrates through the vadose zone (unsaturated soil), it can reach the aquifer, especially if the soil is sandy or fractured. Groundwater can become contaminated with:

i. Pathogens (E. coli, total coliforms)
ii. Turbidity
iii. Elevated total dissolved solids (TDS)
iv. Heavy metals and inorganic ions

This poses significant risks to public health, especially when boreholes are used for domestic consumption without treatment. Contaminated borehole water can lead to:

i. Gastrointestinal diseases

ii. Bioaccumulation of toxic metals

iii. Long-term carcinogenic effects from persistent organic pollutants

2.3 CONTAMINANTS IN BOREHOLE WATER NEAR DUMPSITES

Borehole water located near solid waste dumpsites is often exposed to a wide range of contaminants originating from the decomposition and infiltration of waste materials. These contaminants vary in nature, but are typically grouped into three broad categories: physicochemical parameters, microbial agents, and heavy metals (Sackey *et al.,* 2024). Each of these groups presents distinct environmental and health concerns, particularly for communities that rely on such boreholes as a primary source of drinking water.

Physicochemical contaminants are commonly used as indicators of water quality and reflect the overall chemical characteristics of groundwater. Near dumpsites, the leachate generated from decomposing waste can alter these parameters significantly (Ančić *et al*., 2020). For instance, pH levels may fluctuate outside the safe drinking range of 6.5 to 8.5 due to the acidic or alkaline nature of infiltrating leachate. An acidic pH, which is often associated with the presence of organic acids from biodegradation of waste, can lead to pipe corrosion and the mobilization of toxic metals. Conversely, high pH values might result from ammonia accumulation or alkaline industrial waste. Total Dissolved Solids (TDS) is another crucial parameter, as elevated TDS levels may indicate the presence of inorganic salts and dissolved organic matter. TDS concentrations above 500 mg/L may affect the palatability of water and suggest poor water quality (Devesa and Dietrich, 2018). Nitrate contamination is particularly notable in boreholes located near dumpsites, especially where domestic waste is predominant. Nitrates originate primarily from decaying organic matter, human excreta, and fertilizers. Excessive nitrate intake is associated with methemoglobinemia, commonly known as "blue baby syndrome," and poses a serious risk to infants (Nlemolisa *et al.,* 2025). Turbidity, caused by suspended particles such as silt, microbial debris, and organic matter, is another parameter that reflects contamination. High turbidity reduces light penetration and may shield pathogens from disinfection processes, increasing the risk of waterborne diseases.

Microbial contamination is one of the most immediate and pressing concerns in borehole water near waste dumps. The infiltration of untreated leachate containing faecal matter, food waste, and decomposing organic material introduces a variety of pathogenic organisms into the groundwater system. Escherichia coli, total coliforms, and fecal streptococci are commonly used microbial indicators for faecal contamination. The presence of these organisms in borehole water signifies that the water has been compromised and may carry bacteria, viruses, or protozoa capable of causing gastrointestinal infections, dysentery, cholera, typhoid, and other illnesses. The vulnerability of shallow boreholes, especially those located downslope or in unconfined aquifers, increases significantly in the presence of nearby dumpsites. The health implications of consuming microbially contaminated water are profound, particularly for children, the elderly, and immunocompromised individuals. Additionally, microbial load in water is sensitive to seasonal changes (Alao *et al*., 2023). During the rainy season, increased runoff and percolation enhance the mobility of pathogens from the surface into the groundwater. In such conditions, even boreholes that were previously safe may become contaminated. Water that appears clean may still harbor microbial agents, making laboratory testing essential for safe water use.

Heavy metals are another group of contaminants with long-term health and ecological consequences. Unlike microbial contaminants, heavy metals do not degrade over time and tend to accumulate in the environment and living organisms. Lead (Pb), cadmium (Cd), and iron (Fe) are among the most commonly detected heavy metals in borehole water around dumpsites (Zulu, 2019). These metals originate from various sources including batteries, paints, electronics, plastics, and other solid waste components. Lead contamination in water is a major concern due to its neurotoxic effects, particularly in children, where it can impair cognitive development, reduce IQ, and lead to behavioral issues. Cadmium, often introduced through the degradation of plastic and battery waste, is toxic even at low concentrations (Devesa and Dietrich, 2018). Long-term exposure is linked to kidney damage, bone demineralization, and cancer. Iron, although an essential trace element, becomes problematic when present in excess. High levels of iron cause discoloration, metallic taste, and staining of plumbing fixtures. Excessive iron may also support the growth of iron bacteria, which produce biofilms that clog pipes and reduce borehole efficiency.

The mobility of these heavy metals in groundwater depends largely on the hydrogeological setting, including soil type, pH, redox potential, and organic matter content. Acidic conditions, for example, enhance the solubility of most metals, increasing their concentration in water (Ahsan *et al.*, 2015). Dumpsite leachates, often rich in organic acids and other reducing agents, facilitate the release of metals from soil particles into groundwater. The spatial proximity of boreholes to dumpsites is a critical determinant in contamination risk. Boreholes sited less than 50 meters from an active dumpsite face a higher risk of heavy metal infiltration, particularly in regions with high water tables and sandy or fractured geologic formations.

The combined effect of physicochemical, microbial, and heavy metal contaminants poses a significant threat to public health and water security. Most borehole users in peri-urban and rural areas lack access to routine water quality monitoring and are unaware of the risks associated with contaminated water (Devesa and Dietrich, 2018). The physical appearance of borehole water may remain unchanged even when contaminants are present, making it difficult for communities to detect problems without proper testing. Regulatory oversight is often limited, and in many cases, boreholes are sited without adequate hydrogeological assessments or environmental safeguards. The presence of multiple contaminants can also have synergistic effects. For instance, acidic water may increase the leaching of heavy metals, while high turbidity can shelter bacteria from chlorination. This interaction of contaminants amplifies the potential health hazards.

2.4 FACTORS INFLUENCING GROUNDWATER CONTAMINATION

Groundwater contamination near dumpsites is a function of multiple interacting environmental, geological, and anthropogenic factors. The mobility of contaminants from solid waste into aquifers depends on the surrounding hydrogeological conditions and site-specific characteristics. For boreholes located near dumpsites, these factors significantly affect water quality, posing potential health risks to users. The following subsections discuss key parameters that influence groundwater contamination in these environments.

Geological Structure and Soil Type

The geology and soil characteristics of an area directly affect the movement and filtration of contaminants from the surface into groundwater. Geological formations with low permeability, such as clay-rich soils, act as natural barriers that can slow or prevent the infiltration of pollutants. In contrast, sandy or gravelly soils allow faster percolation of leachate, enabling contaminants to reach the water table more quickly.

Fractured bedrock or unconsolidated materials can also create direct pathways for pollutant migration. In areas where the geology is dominated by porous sediment or weathered rock, the risk of contamination increases, especially if the unsaturated zone between the surface and aquifer is thin (Alao *et al*., 2023). Additionally, the presence of organic matter in soil can influence microbial activity and adsorption capacity, either helping to degrade contaminants or, conversely, promoting their movement depending on conditions.

In the context of boreholes near solid waste dumpsites, the soil type determines how efficiently leachate is filtered before reaching groundwater. A coarse-textured soil with minimal clay or organic content offers little protection, while a dense, fine-grained layer can act as a partial buffer. However, sustained waste exposure may eventually overcome this natural filtration capacity.

Topography and Elevation

Topographic conditions determine the direction of surface water flow, runoff patterns, and the general movement of subsurface water. Boreholes located at lower elevations compared to nearby dumpsites are particularly vulnerable, as gravity naturally drives water and leachate downslope toward these areas (Salako and Adepelumi, 2018).

Depressions or valleys may serve as collection zones for runoff, increasing the residence time of contaminated water and enhancing infiltration. On the other hand, elevated areas may have better drainage and reduced risk of infiltration from surface contaminants (Ahsan *et al.*, 2015). However, even these areas may be susceptible if the geological structure underneath facilitates lateral subsurface flow from contaminated zones.

The elevation difference between dumpsites and nearby boreholes is especially important during the rainy season. Rainfall can lead to surface runoff that follows natural slopes, transporting leachate from the waste accumulation site to lower-lying boreholes. In such cases, the topography effectively becomes a transport mechanism that amplifies contamination risk.

Proximity of Boreholes to Dumpsites

One of the most critical determinants of groundwater contamination is the distance between boreholes and the waste dumpsite. When boreholes are drilled too close to active or decomposing dumps, the probability of contaminant infiltration increases significantly. Leachate generated by the biodegradation of solid waste typically contains high concentrations of dissolved organic matter, heavy metals, and pathogenic microorganisms, which can seep into nearby groundwater systems.

Short distances between waste sites and water sources reduce the natural attenuation time and space for biological and chemical degradation of contaminants. The closer the borehole, the less opportunity for filtration, adsorption, and microbial breakdown to occur. In many cases, boreholes located within 50–100 meters of a dumpsite are at high risk of pollution, especially if hydrological gradients promote flow toward the water source (Salako and Adepelumi, 2018).

In areas where regulations regarding borehole placement are not enforced or are poorly understood, this proximity issue is exacerbated. Informal settlements and peri-urban areas often experience this problem, leading to widespread exposure to contaminated water despite the availability of boreholes.

Influence of Rainfall and Runoff

Rainfall intensity and frequency play major roles in the formation, dilution, and migration of leachate from dumpsites into groundwater systems. Heavy or sustained rainfall can saturate waste layers and promote the generation of leachate through percolation. As rainwater infiltrates the waste material, it dissolves soluble contaminants and carries them downward and laterally through the unsaturated zone.

Runoff generated during rainfall events can transport surface contaminants directly into recharge zones or areas with permeable soils. If boreholes are situated downslope of a dumpsite, runoff can accumulate around the borehole casing or percolate through surface fractures, introducing pollutants directly into the groundwater system (Ahsan *et al.*, 2015).

Furthermore, in tropical regions where seasonal rains are common, the volume of leachate can increase dramatically during wet months. This seasonal variation in contamination levels may not be captured in a single sampling event, leading to underestimation of the pollution risk. High rainfall also raises the local water table, potentially reducing the unsaturated zone thickness and bringing the aquifer closer to the contaminated surface, further increasing susceptibility to pollution.

2.5 METHODS FOR ASSESSING GROUNDWATER QUALITY

Water Sampling Techniques

The first step in assessing groundwater quality is proper sampling. The accuracy of any hydrogeochemical or microbiological assessment largely depends on the reliability of the samples collected. Groundwater sampling involves drawing water from boreholes or wells using pre-cleaned containers, ideally made of inert materials like high-density polyethylene. Sampling bottles are usually rinsed with the same water to be collected before the final sample is taken to avoid external contamination (Abanyie *et al.*, 2023). Samples meant for heavy metal analysis are often acidified with nitric acid to prevent precipitation and microbial growth before laboratory testing (APHA, 2017). For microbiological analysis, sterile bottles are used, and samples must be kept chilled and processed within six hours.

The sampling depth is another important consideration. Ideally, groundwater samples should be drawn after purging stagnant water from the borehole. In studies near dumpsites, where contamination is suspected, water is collected from both shallow and deep boreholes to detect vertical variation in contamination levels. However, in fixed borehole structures, as often encountered in community settings, sample collection may be limited to available outlet taps or preinstalled pumps. Moreover, documentation of sampling conditions, including weather (e.g., rainfall), time, and any nearby activities, helps in contextualizing the results. For instance, sampling during or shortly after rainfall may increase the presence of surface-derived contaminants.

Laboratory Analysis

Once collected, samples are analyzed in the laboratory using standard protocols to determine their quality. Physicochemical parameters commonly tested include pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, nitrates, sulphates, and hardness. These indicators help to assess water's usability and detect deviations that may signal contamination. For example, elevated nitrates may indicate leachate infiltration from waste decomposition, while abnormal pH may point to chemical waste intrusion (Gunarathne *et al.*, 2024).

Microbiological testing focuses on identifying disease-causing organisms, especially fecal coliforms like Escherichia coli, which are reliable indicators of recent contamination with human or animal waste. The presence of these organisms in groundwater suggests leakage of sewage or decomposed organic matter from solid waste (Alao *et al.*, 2023). Testing is typically done using membrane filtration or multiple tube fermentation techniques, depending on resources and objectives.

Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), iron (Fe), and zinc (Zn) are also evaluated due to their toxicity and tendency to accumulate in human organs. Atomic absorption spectroscopy (AAS) and inductively coupled plasma mass spectrometry (ICP-MS) are commonly used methods for detecting these metals. Elevated levels of these metals near dumpsites have been reported in several studies, linking them to industrial and domestic waste leachate (Gunarathne *et al*., 2024).

Use of GPS and Spatial Data in Environmental Studies

To accurately map and assess groundwater contamination patterns, geospatial data collection is vital. The use of Global Positioning System (GPS) tools allows researchers to record precise coordinates and elevation for each sampling location. This data is critical for spatial analysis using Geographic Information Systems (GIS), which helps to visualize the extent and direction of pollution spread. It also enables the correlation of water quality data with environmental variables such as proximity to dumpsites, slope, land use, and drainage patterns (Alao *et al*., 2023).

GIS mapping can reveal trends that might not be obvious from raw data alone, such as clustering of contaminated sites, influence of topography, or areas requiring urgent remediation. In recent years, spatial data integration has become standard practice in hydrogeological studies, especially for urban areas where multiple sources of pollution may exist. Combining chemical analysis with spatial mapping also aids policymakers in prioritizing intervention zones and planning sustainable waste disposal systems.

2.6 WATER QUALITY STANDARDS AND GUIDELINES

Groundwater quality is commonly assessed by comparing analytical results with established drinking water standards. The World Health Organization (WHO) provides international guideline values that define permissible limits for chemical, physical, and microbial parameters based on health risk assessments. In Nigeria, the Standards Organisation of Nigeria (SON) and the National Agency for Food and Drug Administration and Control (NAFDAC) adapt these global benchmarks for local application. These standards serve both as protective measures for public health and as regulatory tools for monitoring and managing water resources.

The recommended pH range for potable water is 6.5 to 8.5 according to both WHO and SON/NAFDAC. Total dissolved solids (TDS) should remain below 1000 mg/L under WHO guidelines, while SON prescribes 500 mg/L as the desirable limit and 1500 mg/L as the maximum permissible level. Turbidity is limited to 5 NTU by both frameworks, as higher values suggest suspended solids and can interfere with microbial detection. Nitrate concentrations are restricted to 50 mg/L by WHO, while SON specifies a slightly lower threshold of 45 mg/L, reflecting concerns about infant health risks such as methemoglobinemia. For microbial quality, both WHO and Nigerian standards mandate the complete absence of coliform bacteria, particularly *Escherichia coli*, in any 100 mL sample of drinking water. Heavy metal limits are also stringent: WHO prescribes 0.01 mg/L for lead, 0.003 mg/L for cadmium, and 0.3 mg/L for iron. SON adopts these limits but also emphasizes locally relevant parameters such as manganese at 0.2 mg/L and chromium at 0.05 mg/L.

Interpreting groundwater results against these standards highlights potential risks when parameters exceed the recommended limits. Deviations in pH influence the solubility and mobility of metals; acidic water promotes leaching of lead and cadmium from surrounding materials, while alkaline water reduces disinfection efficiency. Elevated turbidity indicates infiltration of suspended matter or organic material, often linked to surface runoff or poor filtration in sedimentary aquifers. Microbial contamination, even at trace levels, signifies recent fecal intrusion and is especially critical when accompanied by elevated nitrate and ammonia levels, which are typical indicators of leachate migration from dumpsites. Studies in Nigeria, such as Alao et al. (2023), have shown that boreholes located close to municipal waste sites tend to carry higher microbial loads, particularly after rainfall events that accelerate leachate percolation.

The presence of heavy metals above permissible limits also poses serious health concerns. Lead and cadmium are toxic even at very low concentrations, accumulating in human tissues and causing neurological and renal disorders. Their occurrence in groundwater often reflects leaching from batteries, paints, plastics, or metallic scraps in nearby waste dumps. Elevated concentrations of iron and manganese, though sometimes geogenic, degrade the taste, odor, and appearance of water, reducing its acceptability for domestic use. In Iyowa, where boreholes are located in sediment terrains close to solid waste dumpsites, these risks are heightened by the permeability and stratification of the sediments, which can facilitate contaminant transport.

Applying both WHO and Nigerian standards provides a comprehensive framework for evaluating groundwater safety. By comparing test results with permissible limits, researchers and policymakers can identify health risks, trace contamination pathways, and recommend mitigation measures. In areas like Iyowa, this interpretation is essential for guiding borehole siting, prioritizing water treatment options, and shaping waste management policies to protect community health.

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 Apparatus / Instruments

i. GPS device (for georeferencing boreholes)
ii. Sterilized HDPE bottles (1 L) for physicochemical and heavy metals analysis
iii. Sterile glass bottles (250 mL) for microbiological analysis
iv. Ice-packed coolers (for preservation at 4 °C)
v. Oven (103–105 °C)
vi. Desiccator
vii. Steam bath
viii. Analytical balance (sensitivity ±0.01 mg)
ix. Conical flasks (150–250 mL capacity)
x. Titration flasks / burettes / pipettes
xi. Standard DO bottles
xii. Hanna Temperature Meter
xiii. Hanna pH Meter (calibrated)
xiv. Hanna multiparameter instrument (3-in-1 for EC, TDS, Salinity)
xv. HACH colorimeter (for turbidity)

xvi. Atomic Absorption Spectrophotometer (AAS)

xvii. UV–Vis spectrophotometer (410 nm, 420 nm, 880 nm)

xviii. Volumetric flasks (50 mL, 100 mL)

xix. Filtration setup (filter paper, funnel)

3.1.2 Reagents / Chemicals

i. Concentrated nitric acid (HNO_3, for acidification of samples)

ii. Magnesium sulfate ($MgSO_4 \cdot 5H_2O$)

iii. Alkaline iodide solution

iv. Sulphuric acid (H_2SO_4, 5 N)

v. Sodium thiosulphate ($Na_2S_2O_3 \cdot 5H_2O$, 0.0125 N)

vi. Starch indicator

vii. Phenolphthalein indicator

viii. Methyl orange indicator

ix. Hydrochloric acid (HCl, titration standard)

x. Potassium chromate indicator (K_2CrO_4)

xi. Silver nitrate ($AgNO_3$, 0.014 N)

xii. Buffer solution (for hardness test)

xiii. Eriochrome Black T indicator

xiv. EDTA solution (0.01 N)

xv. Potassium hydroxide (KOH, 8 N)

xvi. Calcium indicator

xvii. Barium chloride crystals ($BaCl_2$, for sulphate determination)

xviii. Conditioning reagent (sulphate analysis)

xix. Phenoldisulphonic acid (for nitrate determination)

xx. Ammonium hydroxide (NH_4OH, for nitrate colour development)

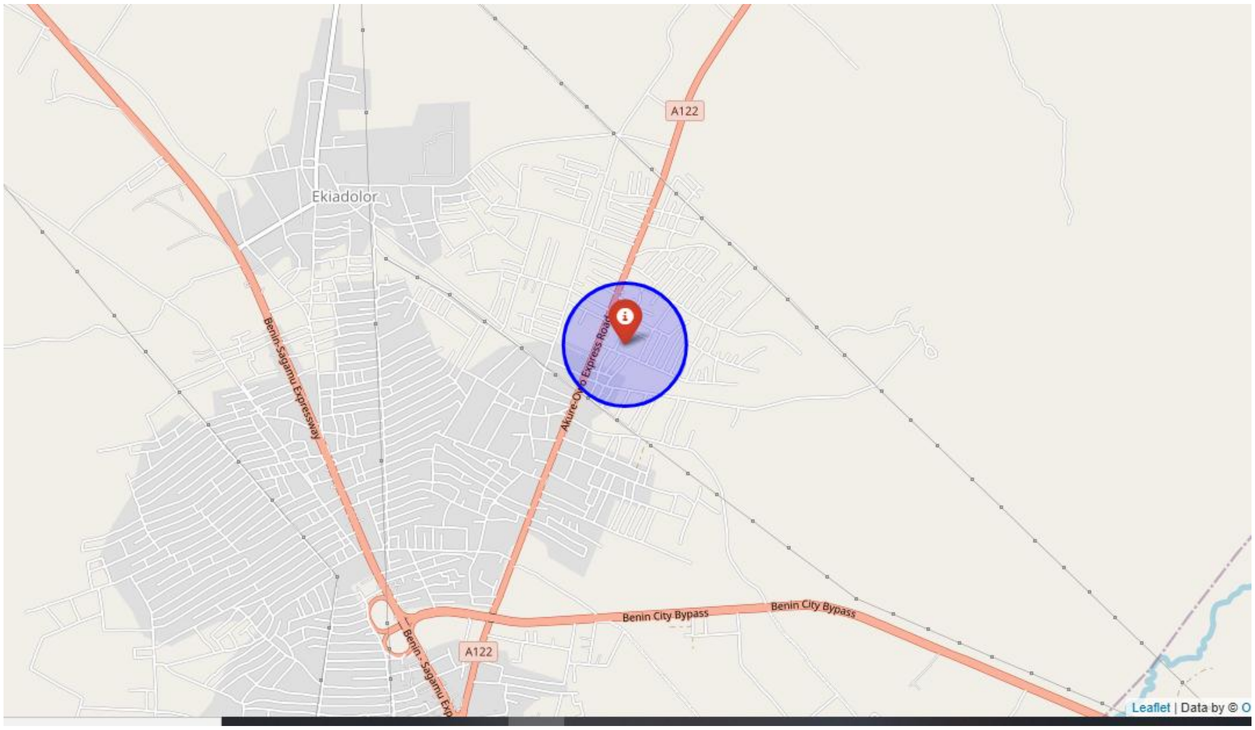
xxi. Antimony molybdate solution (for phosphate analysis)

xxii. Ascorbic acid solution (for phosphate analysis)

xxiii. Distilled/deionized water (all dilutions, blanks, washing)

3.2 METHODOLOGY

3.2.1 STUDY AREA



Iyowa lies in Ovia North-East LGA of Edo State, within the Benin City metropolitan zone. The approximate coordinates place it within the broader tropical savanna / wet environment of southern Nigeria. The area falls inside the geologic domain popularly termed **the** Benin Formation, which underlies much of Benin City and environs.

The surface soils are characterized by reddish, ferruginized or lateritic clay-sand mixtures, locally known as the “top reddish earth,” developed through intense chemical weathering under humid tropical conditions. This weathered zone lie coarse loose sands, pebbly sands, occasional clay lenses, and minor shale interbeds. Sediments are poorly to moderately sorted, often cross-bedded, with colors varying from reddish brown at weathered zones to pinkish, yellowish, or whitish in fresh zones.

In this region, the Benin Formation is reported to reach thicknesses of several hundred meters beneath Benin City (locally ~800 m in many sectors) and is predominantly water-bearing. The sedimentary sequence is usually discontinuous, with clay or shale interbeds acting as semi-confining layers. The formation dips gently southward at low angles (2°–8°), consistent with regional Niger Delta basin trends.

Topographically, the local relief is relatively low (about 91 m in the region) and the area is part of a dissected coastal plains system. The drainage network in the Benin region is dominated by river systems like the Ikpoba, Ogba, and Onigie-Ogbovben, which influence local groundwater recharge and runoff patterns. Hydrologically, the region experiences two distinct seasons: a wet season from April to October and a dry season from November to March, with high rainfall intensity promoting vertical infiltration.

Within the Iyowa zone, the combination of permeable sand horizons and occasional clay lenses suggests that groundwater flow is likely anisotropic, with preferential flow horizontally through sandy zones and slower vertical percolation through clay barriers. The relatively shallow weathered layer may also act as a buffer against contaminants, but the interruptions by fractures or coarse sands can create fast pathways.

3.2.2 SAMPLING TECHNIQUE

Sampling Technique

Water samples were collected from five existing boreholes located at both higher and lower elevations around the dumpsite in Iyowa. Since the boreholes were already constructed, no measurements of aquifer depth or soil permeability were carried out. Instead, sampling focused on water quality assessment.

Each borehole was georeferenced using a handheld Global Positioning System (GPS) device to document the exact sampling locations. The coordinates and altitudes of the sampled boreholes are presented below:

i. **Sample 1:** 6°27′29″ N, 5°36′10″ S, Altitude 307 ft

ii. **Sample 2:** 6°27′31″ N, 5°36′37″ S, Altitude 267 ft

iii. **Sample 3:** 6°27′3″ N, 5°36′30″ S, Altitude 295 ft

iv. **Sample 4:** 6°27′41″ N, 5°36′10″ S, Altitude 282 ft

v. **Sample 5:** 6°27′44″ N, 5°36′13″ S, Altitude 323 ft

Samples were obtained directly from the borehole outlets after allowing the water to run for a few minutes to flush stagnant water from the pipes. Each sample was collected in pre-cleaned, sterilized plastic containers and preserved in accordance with standard water sampling protocols before being transported to the laboratory for analysis.

3.2.3 SAMPLE COLLECTION AND PRESERVATION

Water samples were collected in line with the World Health Organization (WHO, 2017) guidelines and the Nigerian Standard for Drinking Water Quality (NSDWQ, SON, 2007). Sterilized and pre-labeled containers were used to avoid cross-contamination. For physicochemical and heavy metal analysis, 1-liter high-density polyethylene (HDPE) bottles rinsed with the sample water were used, while sterile 250 mL glass bottles were employed for microbiological analysis. Samples for microbial analysis were left unpreserved but kept under strict aseptic conditions to ensure accurate microbial recovery. Immediately after collection, all samples were stored in ice-packed coolers at approximately 4 °C and transported to the laboratory within six hours, as required by WHO and NSDWQ protocols. These preservation and handling practices minimize changes in water chemistry and microbiology prior to analysis, thereby ensuring that laboratory results reflect in-situ groundwater quality conditions.

3.2.4 STANDARD OPERATING PROCEDURES (SOP)

Temperature (°C)

The temperatures were determined Using electrometric method. Hama Temperature Meter was used for the reading 50ml of water sample was poured into 100ml plastic beaker, the meter was powered-on and the probe of the meter with inserted into the sample for the reading

This was determined electrometrically using a calibrated Hanna pH Meter

Electrical Conductivity and Total Dissolved Solid (TDS)

These were determined using Hanna instrument (3-in-1) for EC, TDS and Salinity. The meter probe was dipped into the sample and left for about 3 minutes for equilibration before the reading was recorded Electrical conductivity was reported in µS/cm while TDS and salinity were reported in mg.

Dissolved Oxygen (DO) Determination

Dissolved oxygen was determined using Winkler method (Titrimetric) A standard DO bottle was used. The bottle was filled with water sample making sure that bubbles were not trapped 2ml of $MgSO_4$ $5H_2O$ was added and 2ml of alkaline-iodide solution was also added. It was thoroughly mixed by rotating and inverting the bottle several times. The precipitate was allowed to settle, then 1ml of sulphuric acid was added, and gently mixed. Then, 100ml of the sample solution was measured into the conical flask and 2ml of starch indicator was added, and titrated against 0.0125N of $NaS_20_3.5H_20$. The end point was carefully observed and recorded by colour change from straw yellow to colourless. Thus, it was calculated as:

$$\text{DO (mg)} = \frac{8.0\text{x Vol of titrant x } 0.0125 \text{ x } 1000}{\text{Vol of sample taken}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{Equation 1}$$

Turbidity (NTU)

This was determined using HACH colorimeter. The meter was switched on and allowed to warm-up for 30 minutes. The instrument was calibrated with known standards. Then the water sample was poured into the empty turbidity bottle, and inserted into the chamber of the instrument, and set the meter to read. The meter was allowed to stabilize, and record of the value was taken from the displayed.

Heavy Metals

Atomic absorption spectrophotometry (AAS) is an analytical technique used to measure a wide range of elements in materials such as metals, pottery, water, whole blood, cell, plant, glass etc. although it is a destructive techniques (unlike ED-XRF), the sample size needed is very small (typically about 10mg – i.e 100 of a gram) and its removal causes little damaged. If the sample is accurately weighed and then dissolved often using strong acid, the resulting solution is sprayed into the flame of the instrument and atomized. Light of a suitable wave length of a particular element is shone through the flame, and some of this light is absorbed by the atoms of the sample. The amount of light absorbed is proportional to the concentration of the element in the solution, and hence in the original object. Measurements are made separately for each element of interest in turn to achieve a complete analysis of an object, and thus the technique is relatively slow to use. However it is very sensitive and it can measure trace elements down to the part per million level as well as being able to measure elements present in minor and major amounts.

Carbonate/ Bicarbonate and Total Alkalinity (mg/l)

Titrimetric method was used by measuring 100ml of water sample into titration flask, and then 2-drops of phenolphthalein indicator was added, and titrated with 5 N H_2SO, until pink colour just disappeared. The volume of acid consumed was recorded. To the same solution, 2-3 drops of methyl orange indicator was added, and titrated further until colour changes from yellow to red. The additional volume of acid consumed was recorded. It was calculated as:

Bicarbonate alkalinity = (B-A) x 50 x 1000 mg/ 50 x 100

Bicarbonate ion Conc. (HCO_2) = Bicarbonate alkalinity x 1.22 (mg/l)

Salinity as Chloride (Cl)

100ml of water sample was quantitatively measured into a 250-ml of conical flask, followed by the addition of 1ml of K_2CrO_4 indicator, and titrated with 0.014N $AgNO_3$. The mixture was fitrated from yellow to reddish colour, the colour changes from yellow to reddish brown at the end-point was observed and recorded. Thus calculated as

$$\text{Chloride } (Cl^-) \quad \frac{35.5 \times C_b \times V_b \times 1000}{\text{Vol ample}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{Equation 2}$$

Where C_b, = Concentration of AgNO, (Normality)

V_b = Volume of AgNO, (Consumed)

Total Hardness

50ml of water sample was quantitatively measured into 150ml capacity conical flask, added were 2ml of buffer solution and 2-drops of Eriochrome Black T indicator after which the mixture was titrated with 0.01N EDTA from wine colour to blue end-point. Total hardness was calculated as follows:

$$\text{Total Hardness as } CaCO_3\text{, mg/l} = \frac{\text{ml of (EDTA) (0.01) 50 x 1000}}{\text{Vol of sample (ml)}} \quad \text{……………Equation 3}$$

Calcium Hardness

50ml of sample was measured into 150 ml conical flask followed by addition of 1ml of 8. O N KOH. 4-drops of calcium indicator, and titrated with 0.01N EDTA from wine colour to blue end-point. The calcium hardness was calculated as follows:

$$\text{Ca as CaCO, (mg/l)} = (\frac{\text{ml of EDTA) (0.01) 50 x 1000}}{\text{Vol of Sample}} \quad \text{………………… Equation 4}$$

Magnesium Hardness

Mg as CaCO, = Total Hardness - Calcium Hardness (mg/l)

Sulphate (mg/l)

This was determined by Turbidimetric Method. A filtered quantity of sample was measured into conical flask and made up to 100ml with distilled water.5ml of conditioning reagent was added and stirred. 0.5g of barium chloride crystal was then added and stirred again after one minute the absorbance was red at 420nm.

Nitrate (mg/1)

50.0ml of filtered water sample was measured into an evaporating dish and evaporated to dryness, after cooling, 1ml phenoidisulphonic acid was added. The content of the evaporating dish was transferred into 50ml volumetric flask with 25- 35ml of distilled water. 4ml of ammonium hydroxide was added to develop the colour and diluted to a volume with distilled water. The blank was also carried out. The nitrate content in the sample was measured at 410 nm using the UV Vis spectrophotometer.

Total Suspended Solid (TSS)

A clean dish of suitable size was dried in an oven at 103–105 °C until a constant weight was obtained. It was then cooled to room temperature in a desiccator, and the weight was recorded. After thorough mixing, 100 mL of the water sample was accurately pipetted into the dish and evaporated to dryness on a steam bath. The outside of the dish was wiped, and the residue was dried in an oven for about one hour at 103–105 °C. The dish was then transferred quickly to a desiccator, cooled to room temperature, and weighed. Drying was repeated for an additional 10–20 minutes, followed by cooling and reweighing, until the weight of the dish and residue was constant within 0.05 mg. The weight of the empty dish was subtracted to obtain the total solids content.

Phosphate (PO) APHA 425C

A 40 mL portion of the sample was measured, after which 5 mL of antimony molybdate solution was added, followed by 2 mL of ascorbic acid. A blank solution was prepared and treated in the same manner as the sample. After standing for about 10–20 minutes, the absorbance of both the sample and the blank was measured using a UV–Vis spectrophotometer at a wavelength of 880 nm.

CHAPTER FOUR

RESULTS

The table 4.1 shows the physicochemical parameters of the groundwater samples, which help to assess general water quality, suitability for drinking, and potential contamination pathways.

Table 4.1: Result of Physico-Chemical Analysis

Parameter	**Units**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**WHO/NSDWQ Limit**
pH	–	5.19	6.14	5.88	5.27	5.21	6.5–8.5
EC	µS/cm	35	400	70	22	22	1000
TDS	mg/L	17	201	36	11	11	500
Alkalinity	mg/L	5	4	6	4	6	100–200
Turbidity	NTU	1	0	0	0	1	5
Nitrate	mg/L	0.83	0.52	0.69	0.59	0.68	50
Hardness	mg/L	6	5	4	5	7	150
Phosphate	mg/L	0.49	0.34	0.42	0.37	0.43	5
Sulphate	mg/L	2	1	2	1	2	100
Mg	mg/L	2.29	3.80	0.49	0.28	1.53	0.2
Na	mg/L	4.33	8.96	4.92	3.14	3.05	200
Ca	mg/L	8.20	7.50	8.27	8.53	5.23	75

K	mg/L	0.89	55.80	5.25	1.28	0.87	12

The groundwater quality around Iyowa revealed significant deviations from acceptable drinking water standards, particularly in acidity and heavy metal contamination.

pH values ranged between 5.19 and 6.14, which are consistently below the WHO and SON guideline of 6.5–8.5 for potable water. Acidic groundwater is problematic because it accelerates the dissolution of heavy metals, leading to elevated concentrations of Pb, Fe, and Cr. This acidity is most likely driven by organic acid leachates produced during waste decomposition at the dumpsite. Similar acidic trends have been documented in groundwater near open dumpsites, reinforcing the role of waste-derived leachates in lowering pH.

Electrical conductivity (EC) varied widely (22–400 µS/cm), but all values were below the WHO limit of 1000 µS/cm. The same pattern was observed for total dissolved solids (TDS) (11–201 mg/L), which fell below the 500 mg/L threshold. Despite compliance with standards, the wide fluctuations highlight uneven contaminant loading across boreholes. The borehole closest to the dumpsite (S2) recorded the highest EC (400 µS/cm) and TDS (201 mg/L), indicating direct impact from leachate percolation. This suggests that while average ionic content remains within safe limits, localized contamination is a serious risk.

Nitrate (0.52–0.83 mg/L) and phosphate (0.34–0.49 mg/L) concentrations were much lower than WHO standards (50 mg/L for nitrate, 5 mg/L for phosphate), pointing to minimal nutrient contamination. However, the persistence of organic decomposition around the dumpsite could still contribute to oxygen depletion in groundwater, a factor not directly measured here but inferred from the conditions.

Alkalinity was very low (4–6 mg/L) compared to the recommended 100–200 mg/L range. Low alkalinity means the water has poor buffering capacity against further acidification, leaving it highly vulnerable to shifts in pH. This is particularly concerning given the already acidic nature of the groundwater.

An important anomaly was noted in potassium (K). One borehole (S2) showed an elevated concentration of 55.8 mg/L, which is far above the 12 mg/L WHO limit. Such extreme levels strongly indicate localized leachate infiltration, likely from potash-rich waste materials such as ash, fertilizers, or food waste disposed in the dumpsite. This spike makes S2 groundwater unsuitable for domestic consumption without treatment.

Magnesium (0.28–3.8 mg/L) exceeded the WHO recommended value of 0.2 mg/L in most boreholes. Although magnesium is essential in trace amounts, excessive intake can cause laxative effects and contribute to hardness-related scaling.

Calcium (5.23–8.53 mg/L), sodium (3.05–8.96 mg/L), and sulphate (1–2 mg/L) remained well below guideline limits (100 mg/L for Ca, 200 mg/L for Na, 250 mg/L for sulphate). However, their consistent detection across boreholes suggests slow but steady mineral dissolution and leachate intrusion. This aligns with the acidic and poorly buffered nature of the aquifer, which favors the mobilization of these ions.

Overall, the results demonstrate that groundwater in Iyowa is acidic, poorly buffered, and variably impacted by waste leachate. Borehole Sample 2, due to its proximity to the dumpsite, exhibited the highest contamination signatures (low pH, high EC, elevated K and Mg). The combination of low pH, low alkalinity, and heavy metal risk makes the water unsafe for direct consumption.

The table 4.2 presents the concentrations of selected heavy metals (Pb, Zn, Fe, and Cr) in groundwater samples collected from boreholes around the Iyowa dumpsite. Heavy metals are a major concern in groundwater quality assessment due to their persistence, toxicity, and potential health risks.

Table 4.2: Report of Metal Analysis Using AAS

Sample	**Pb (mg/L)**	**Zn (mg/L)**	**Fe (mg/L)**	**Cr (mg/L)**
1	0.427	0.35	7.10	3.87
2	0.241	0.32	7.51	2.86
3	0.163	0.26	5.72	0.88
4	0.428	0.28	2.98	0.56
5	0.106	0.36	3.55	0.37
WHO	0.01	3.00	0.30	0.05
NSDWQ	0.01	3.00	0.30	0.05

Lead (Pb) concentrations ranged from 0.106–0.428 mg/L, far above the WHO and NSDWQ limit of 0.01 mg/L. This makes the water unsuitable for drinking. Pb likely originates from discarded batteries, plastics, and paint materials in the dumpsite. Long-term consumption of this water poses risks of neurological damage, hypertension, and kidney failure. Similar exceedances were reported in dumpsite-influenced groundwater in Lagos and Port Harcourt, showing a consistent pattern of Pb leaching. Iron (Fe) levels were extremely high (2.98–7.51 mg/L) compared to the permissible 0.3 mg/L. Excess Fe causes reddish coloration, metallic taste, and staining of pipes. Such high concentrations indicate leachate enrichment, possibly from decomposing metals and organic matter. Chromium (Cr) concentrations (0.37–3.87 mg/L) also exceeded the 0.05 mg/L guideline, posing carcinogenic and mutagenic risks. Its presence suggests leachate infiltration from waste materials containing dyes, plastics, and electroplated parts. Zinc (Zn) levels (0.26–0.36 mg/L) were within the acceptable range (≤3.0 mg/L). While not immediately harmful, Zn concentrations can rise with continuous leachate accumulation. Overall, the heavy metal results confirm significant groundwater contamination, with Pb, Fe, and Cr far beyond safe thresholds.

The table 4.3 summarizes the microbial quality of the groundwater samples, focusing on bacterial, coliform, *E. coli*, *Staphylococcus*, and fungal counts. Microbiological testing is critical since the presence of pathogens directly threatens human health.

Table 4.3: Result of Microbial Analysis

Sample	**Units (CFU/mL)**	**Total Bacteria Count (NA)**	**Total Coliform Count (MA)**	**Total *E. coli* Count (EMB)**	**Total *Staph* Count (MSA)**	**Total Fungi Count (PDA)**
1	CFU/mL	1	0	0	0	0
2	CFU/mL	0	0	0	0	0
3	CFU/mL	0	0	0	0	0
4	CFU/mL	1	0	0	0	0
5	CFU/mL	1	0	0	0	0

The microbial results indicate very low bacterial counts, with only total heterotrophic bacteria detected in samples 1, 4, and 5 (1 CFU/mL each). No coliforms, *E. coli*, *Staphylococcus aureus*, or fungi were detected in any of the samples. According to WHO and NSDWQ standards, drinking water must contain zero coliforms per 100 mL, and the complete absence of *E. coli* is mandatory. Since none of the samples showed coliforms or *E. coli*, the groundwater meets microbial safety standards.

The presence of heterotrophic bacteria, however, still indicates organic input into the aquifer. Such organisms thrive in nutrient-enriched environments and may act as precursors to further microbial proliferation if waste intrusion increases. Other Nigerian studies around dumpsites reported much higher bacterial counts, suggesting that Iyowa groundwater may still be in the early stages of microbial degradation. Nonetheless, the coexistence of low pH and high heavy metals with detectable bacteria highlights potential health risks, as even minimal microbial contamination may compromise immunocompromised individuals.

Overall Interpretation

The results show that borehole water near the Iyowa dumpsite is compromised by acidic pH, excessive Pb, Fe, and Cr, localized spikes in K and Mg, and the absence of bacteria. While TDS, EC, and nutrient concentrations were generally within limits, the exceedance of toxic metals and acidity makes the water unsafe for direct human consumption.

Compared to other studies in Nigeria, these findings are consistent with dumpsite-linked groundwater contamination, though the microbial load here was lower than typically reported.

From an environmental health perspective, continuous consumption of this water may lead to neurological, carcinogenic, and gastrointestinal health effects. The data strongly indicate leachate infiltration into the groundwater system and highlight the need for urgent monitoring, treatment, and regulation of waste disposal practices in Iyowa.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of findings

This study assessed groundwater contamination from five boreholes around the Iyowa dumpsite. Key findings are: pH was acidic across samples (5.19–6.14), below the WHO/NSDWQ range of 6.5–8.5. Lead (Pb) was high in all samples (0.106–0.428 mg/L), exceeding the WHO/NSDWQ limit of 0.01 mg/L. Iron (Fe) ranged from 2.98–7.51 mg/L, well above the 0.3 mg/L guideline. Chromium (Cr) also exceeded the guideline (0.37–3.87 mg/L vs WHO 0.05 mg/L). Zinc (Zn) remained within acceptable values (0.26–0.36 mg/L). TDS, EC and most nutrients (nitrate, phosphate, sulphate) were within common guideline limits, although sample S2 showed higher ionic load (EC 400 µS/cm; TDS 201 mg/L). Potassium in S2 was unusually high (55.8 mg/L). Microbial results showed only low heterotrophic bacteria in samples 1, 4 and 5 (1 CFU noted); no coliforms or *E. coli* were detected.

5.2 Conclusion

The data show that the Iyowa dumpsite has impacted shallow groundwater quality. Acidic groundwater has increased the mobility of toxic metals. The exceedance of Pb, Fe and Cr represents a clear public-health concern for anyone consuming untreated borehole water. Although microbial indicators were low at the sampling time, the chemical contamination profile and the site setting (unlined dumpsite over permeable sediment) point to ongoing leachate influence and a high vulnerability of local wells to future contamination. In short: the borehole water sampled near the dumpsite is not safe for direct human consumption without treatment targeted at metals and acidity control.

5.3 Recommendations

Immediate actions for households and community health

Do not drink borehole water from the sampled wells. Boiling will kill microbes but will not remove dissolved heavy metals. If you rely on a contaminated well for drinking, switch immediately to a safe alternative: bottled water, a verified treated supply, or a community communal source that is certified safe. Households with pregnant women and young children should seek medical screening for lead exposure through local health services if exposure is suspected.

Short-term technical measures (weeks–months)

Test the most affected wells again in the next wet season. For households who must use local borehole water temporarily, point-of-use treatment that removes dissolved metals is required. Reverse osmosis (RO) systems remove Pb, Cr and much Fe, but they need pre-treatment for high iron and periodic maintenance. Ion exchange or commercially available media designed for lead/chromium removal can work at point-of-use, but performance must be verified. For iron removal specifically, oxidize (air or low-dose chlorine) and filter out precipitated iron before other treatment steps.

Medium-term site-level measures

Install a regular water-quality monitoring program covering both wet and dry seasons. Begin with monthly sampling for three months to capture short-term variability, then move to quarterly sampling for at least 12 months. Tests must include pH, EC, TDS, major ions, Pb, Fe, Cr, Zn and microbial indicators. Mark and fence off high-risk wells. Provide a community water kiosk fed by a treated source (centralized RO or a combined aeration–filtration + adsorption system) while longer-term fixes proceed.

Long-term management and remediation

Relocate or properly upgrade the dumpsite to a lined, engineered landfill with leachate collection and treatment. If relocation is not immediately possible, cap the existing dumpsite, install a leachate collection trench and divert surface runoff away from the site. For groundwater remediation, pilot a permeable reactive barrier (PRB) or constructed wetland downgradient of the dumpsite. A PRB using suitable reactive media (e.g., zero-valent iron for chromium reduction and adsorption media for lead) can reduce metal flux into the aquifer. Conduct a cost–benefit assessment before full-scale remediation.

Monitoring and institutional recommendations

Set up a local monitoring plan delivered by the local government or water agency. Monitoring should: (a) sample multiple boreholes at set intervals; (b) compare results to WHO and NSDWQ limits; (c) publish results for the community. Require that any new borehole sited near waste disposal areas have a sanitary seal and a setback distance from dumpsites consistent with national guidance.

Research needs and data gaps

We did not measure aquifer depth or soil permeability during this study. Those data are necessary to model contaminant transport. I recommend: (1) a hydrogeological survey to determine water-table depths and hydraulic conductivity; (2) seasonal sampling for at least one full year to capture wet/dry variability; (3) chromium speciation to confirm hexavalent vs trivalent forms; (4) source-tracking studies (isotope or trace-element fingerprinting) to confirm the dumpsite as the dominant source; and (5) an exposure assessment focused on children and pregnant women in the immediate neighborhood.

Public-health and policy recommendations

Local authorities should prioritize siting engineered landfills outside high-density settlements and enforce buffer zones between dumpsites and water sources. Introduce waste segregation and recycling to reduce hazardous wastes reaching the dumpsite (batteries, electronics, paints). Provide periodic health education to residents on the limits of household treatments (boiling does not remove metals) and on safe water storage.

5.4 Final statement

These data show a hazardous mix: acidic groundwater and toxic metal levels at concentrations that exceed drinking-water guidelines. Addressing this will require combined actions: stop using contaminated wells for drinking, deploy treatment for affected users, institute systematic monitoring, and upgrade waste management at the dumpsite. Acting now will reduce long-term health risks to the Iyowa community.

REFERENCES

Abanyie, S. K., Apea, O. B., Abagale, S. A. and Amuah, E. E. Y. (2023). Sources and factors influencing groundwater quality and associated health implications: A review. *Emerging Contaminants* **9**(2): 100-207.

Ahsan, A., Alamgir, M., Imteaz, M. A., Shams, S., Rowshon, M. D. K., Aziz, M. G. and Syazwani Idrus. (2015). Municipal solid waste generation, composition and management: issues and challenges: a case study. *Environment Protection Engineering* **41**(3): 43-45.

Alao, J. O., Fahad, A., Abdo, H. G., Ayejoto, D. A., Almohamad, H., Ahmad, M. S., Nur, M. S., Danjuma, T. T., Yusuf, M. A., Francis, O. and Joy, A. O. (2023). Effects of dumpsite leachate plumes on surface and groundwater and the possible public health risks. *Science of the Total Environment* **897**: 165469–165469.

Ančić, M., Huđek, A., Rihtarić, I., Cazar, M., Bačun-Družina, V., Kopjar, N. and Durgo, K. (2020). Physico-chemical properties and toxicological effect of landfill groundwaters and leachates. *Chemosphere* **238**: 124574.

Devesa, R. and Dietrich, A. M. (2018). Guidance for optimizing drinking water taste by adjusting mineralization as measured by total dissolved solids (TDS). *Desalination* **439**: 147–154.

Edokpayi, J. N., Enitan, A. M., Mutileni, N. and Odiyo, J. O. (2018). Evaluation of water quality and human risk assessment due to heavy metals in groundwater around Muledane area of Vhembe District, Limpopo Province, South Africa. *Chemistry Central Journal* **12**(1): 12-14.

Egbinola, C. N. and Amanambu, A. C. (2014). Groundwater contamination in Ibadan, South-West Nigeria. *SpringerPlus* **3**(1): 34-56.

Falaiye, A. O. and Aweda, O. F. (2018). *Mineralogical characteristics of harmattan dust across Jos North Central and Potiskum North Eastern Cities of Nigeria*.

Ferreira, C. S. S., Adama-Ajonye, O., Ikenna, A. E. and Kalantari, Z. (2023). Groundwater quality in the vicinity of a dumpsite in Lagos metropolis, Nigeria. *Geography and Sustainability* **4**(4): 379–390.

Gunarathne, V., Phillips, A. J., Zanoletti, A., Rajapaksha, A. U., Vithanage, M., Di Maria, F., Pivato, A., Korzeniewska, E. and Bontempi, E. (2024). Environmental pitfalls and associated human health risks and ecological impacts from landfill leachate contaminants: Current evidence, recommended interventions and future directions. *Science of the Total Environment* **912**: 169-172.

Ige, O. O., Ameh, H. O. and Olaleye, I. M. (2021). Borehole inventory, groundwater potential and water quality studies in Ayede Ekiti, Southwestern Nigeria. *Discover Water* **1**(1): 23-34.

Igelle, E. I., Phil-Eze, P. O., Obeta, M. C., Abdelrahman, K., Andráš, P., Ekwok, S. E. and Eldosuoky, A. M. (2024). Predicting heavy metal transport in groundwater around Lemna dumpsite: implications for residence utilizing borehole water in Cross River State, Nigeria. *Applied Water Science* **14**(8): 17-20.

Isah, A., Akinbiyi, O. A., Ugwoke, J. L., Ayajuru, N. C. and Oyelola, R. O. (2022). Detection of groundwater level and heavy metal contamination: A case study of Olubunku dumpsite and environs, Ede North, Southwestern Nigeria. *Journal of African Earth Sciences* **197**: 104-140.

Isah, A., Bassey, E. N., Akinbiyi, O. A., Azeez, R. A., Oji, A. S. and El-Badawy, T. (2024). Characterizing groundwater contamination flow-paths and heavy metal mobilization near a waste site in Southwestern Nigeria. *Journal of African Earth Sciences* **221**(1): 105460.

Mshelia, Y. M. and Arhyel, M. (2024). Assessment of heavy metal contamination and health risk associated with selected borehole water proximal to a dumpsite in Giwo, Bauchi State. *FUDMA Journal of Sciences* ***8***(3): 66–70.

Nlemolisa, O. R., Ogbulie, J. N., Orji, J. C., Nweke, C. O., Kemka, U. N., Gaius-Mbalisi, V. K. and Ihenetu, F. C. (2025). Groundwater contamination and health risks near waste dumps and mechanic workshops: A seasonal perspective. *Cleaner Water* **4**: 100-109.

Ojekunle, Z. O., Adeyemi, A. A., Taiwo, A. M., Ganiyu, S. A. and Balogun, M. A. (2020). Assessment of physicochemical characteristics of groundwater within selected industrial areas in Ogun State, Nigeria. *Environmental Pollutants and Bioavailability* **32**(1): 100–113.

Okoro, B. C., Uzoukwu, R. A. and Ademe, C. K. (2016). Quality assessment of groundwater sources of potable water in Owerri, Imo State, Nigeria. *OALib* **3**(3): 1–6.

Omeire, G., Chinwendu, O. D., Chioma, E. and Peter-Ikechukwu, A. (2015). Assessment of the Quality of Borehole Water Sample in Federal Housing Estate and Sites and Services Areas... *ResearchGate* **42**: 5–12.

Owuna, B. D. and Austin, E. E. (2023). Contributions of heavy metals on Underground Water quality of Dumpsite in Rukpokwu, Rivers State, Nigeria. *Scholars Journal of Engineering and Technology* **11**(10): 261–267.

Sackey, L. N. A., Kwablah, R. and Agyemang, L. S. Y. (2024). The Impact of Landfill Operations on Borehole Water Quality. *The Scientific World Journal* **2024**(1): 34-38.

Saini, S. and Dhania, G. (2019). Cadmium as an environmental pollutant: Ecotoxicological effects, health hazards, and bioremediation approaches for its detoxification from contaminated sites. *Bioremediation of Industrial Waste for Environmental Safety* 23: 357–387.

Salako, A. O. and Adepelumi, A. A. (2018). Aquifer, Classification and Characterization. *Aquifers - Matrix and Fluids*.

Sanders, T., Liu, Y., Buchner, V. and Tchounwou, P. B. (2009). Neurotoxic effects and biomarkers of lead exposure: a review. *Reviews on Environmental Health*, **24**(1): 15–45.

Stuart, A. and Hitchman, S. P. (1986). Borehole sampling techniques and field analysis of groundwater in landfill pollution studies. *Geological Society, London, Engineering Geology Special Publications* **3**(1): 225–246.

Sunitha, V. (2013). *Nitrates in Groundwater: Health Hazards and Remedial Measures*. *Indian Journal of Advances in Chemical Science* **1**(3): 164-170

Thombre, N. V. (2023). Drinking water, iron, and manganese removal in groundwater purification. *Handbook of water and used water purification*, Cham. Springer. pp. 174–181.

Wali, S. U., Usman, A. A., Usman, A. B., Abdullahi, U., Mohammed, I. U., andHayatu, J. M. (2024). Impact of geology on hydrogeological and hydrochemical characteristics of groundwater in tropical environments: a narrative review. *International Journal of Hydrology* **8**(6): 202–221.

Yahaya, T. O., Oladele, E. O., Fatodu, I. A., Abdulazeez, A. and Yeldu, Y. I. (2021). *The concentration and health risk assessment of heavy metals and microorganisms in the groundwater of Lagos, Southwest Nigeria*. 17p

Yahaya, T., Abdulganiyu, Y., Gulumbe, B. H., Oladele, E., Anyebe, D. and Shemishere, U. (2022). Heavy metals and microorganisms in borehole water around the Olusosun dumpsite in Lagos, Nigeria: Occurrence and health risk assessment. *Avicenna Journal of Environmental Health Engineering* **9**(2): 69–74.

Zulu, K. (2019). Groundwater Contamination: Sources, Health Risks and Future Prospects. *Environmental Analysis* and *Ecology Studies* **5**(5): 1–5.