ASSESSMENT OF PORTABLE WATER SUPPLY SOURCES IN IKKHENIRO COMMUNITY, BENIN CITY, EDO STATE, NIGERIA.

BY

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CERTIFICATION

This is to certify that this work was carried out by **OBIKORU MERCY** with Matriculation Number **ENG2006194** of the **Department of Civil Engineering, Faculty of Engineering, University of Benin** Benin City, Edo State, Nigeria.

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DEDICATION

This work is dedicated to the Almighty God, for the numerous things He has done for me throughout the period of study, and also to the entire family of MR and MRS Benjamin Obikoru for their endless love and support.

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ABSTRACT

This study examined the comparative quality of borehole water, sachet water, and bottled water consumed in Ikhueniro Community, Benin City, Edo State, Nigeria. The research adopted an investigative and analytical approach to evaluate the safety and suitability of the major drinking water sources used by residents. In response to increasing public health concerns associated with waterborne diseases and the widespread availability of inadequately regulated water sources, the study provided a scientific basis for water quality assessment and proposed recommendations for enhanced water safety and regulatory control.

The primary objective of the study was to compare the microbiological and physicochemical quality of borehole, sachet, and bottled water and to determine their compliance with established drinking water standards. Specifically, the study assessed the physical, chemical, and microbiological parameters of the three water sources; evaluated their quality using national and international guidelines provided by the World Health Organization (WHO), National Agency for Food and Drug Administration and Control (NAFDAC), Standards Organisation of Nigeria (SON), and Nigerian Standard for Drinking Water Quality (NSDWQ); computed the Water Quality Index (WQI) for each source to facilitate interpretation; and identified potential contaminants as well as the effectiveness of treatment and purification methods.

Both field and laboratory methods were employed in the study. Physicochemical parameters analyzed included pH, electrical conductivity, total dissolved solids, total alkalinity, temperature, and concentrations of selected heavy metals such as lead, iron, magnesium, and cadmium.

Microbiological analysis was conducted using presumptive coliform tests through the multiple-tube fermentation method to detect total coliforms and the possible presence of *Escherichia coli*.

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ABREVIATIONS AND KEYWORDS

WHO	World Health Organisation
NAFDAC	National Agency for Food and Drug Administration and Control
FEPA	Federal Environmental Protection Agency
SON	Standards Organisation of Nigeria
EU	European Union
TDS	Total Dissolved Solids
EC	Electrical conductivity
NSDWQ	National Standard for Drinking Water Quality
APHA	American Public Health Association
WQI	Water Quality Index

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WWAP	World Water Assessment Programme
MAR	Managed Aquifer Recharge
SODIS	Solar Disinfection
UV	Ultra Violent
FDA	Food and Drug Administration
EFSA	European Food Safety Authority
RO	Reverse osmosis
NRDC	Natural Resources Defense Council
BPA	Bisphenol-A
E. Coli	Escherichia coli
WSP	Water Safety Plan
HACCP	Hazard Analysis and Critical Control Points
QA/QC	Quality Assurance and Quality Control
SOPs	standard operating procedures

GIS	Geographic Information Systems
MTFT	Multiple-Tube Fermentation Technique
MPN	Most Probable Number
MTF	multiple-tube fermentation
NTU	nephelometric turbidity unit
FAAS	Flame atomic absorption spectrophotometer
BGLB	Brilliant Green Lactose Bile
EMB	Eosin Methylene Blue

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF STUDY

Water is an essential element for the survival of all living organisms. In humans, it is shown to make up about 70% of the body mass (Eldon, 2004). As the human population increases, as people express their desire for a better standard living, and as economic activities continue to expand in scale and diversity, the demands on fresh water resources continues to grow. The human psychological activities are thereof dependent on water availability. Many infectious diseases in developing countries are associated with contaminated water (Tar et al., 2019). Thus good drinking water is a luxury but one of the most essential requirements of life (Ajewole, 2005).

While there has been an increase in the number of boreholes in Nigeria, access to safe drinking water and sanitation is still a concern. Studies have shown that over one billion people in the world lack access to safe drinking water and 2.5 billion people do not have access to adequate sanitation services (Tar et al., 2019). As a consequence, governmental and non-governmental organizations made efforts to construct improved sources to provide access to safe and portable drinking water. Unregulated borehole production, sachet water production and bottled water production are public health issues requiring attention because of their effects on general health and productivity of those affected (Amaechi, 2016; Emenike et al; 2017).

Water quality concerns are often the most important component for measuring access to improved water sources. Acceptable quality shows the safety of drinking water in terms of its physical, chemical and bacteriological parameters (WHO, 2004). Consumer perceptions and aesthetic criteria need to be considered when assessing drinking water supplies even though they may not adversely affect human health (WHO, 2004).

The water quality can be determined by specific analysis called Water Quality Index (WQI) using specific parameters. The water quality index (WQI) is commonly used for the detection and evaluation of water pollution and may be defined as 'a rating reflecting the composite influence of different parameters on the overall quality of water' (Mishra, 2005). It is highly recommended that our water supply must be checked and tested continuously to make sure its quality follows the required and standard level of quality.

Despite the aim to provide safe drinking water through borehole, bottled water and sachet water production, there are many people without safe drinking water in Nigeria (Wright, Dzodzomenyo and Wardrop, 2016). Before water can be described as potable, it has to comply with certain physical, chemical, and microbiological standards which are designed to ensure that the water is potable, safe for drinking, thus studies will be conducted to ascertain these parameters in varying drinking water sources.

One of the most effective ways to communicate information on water quality trends is with indices. Physicochemical indices are based on the values of various physicochemical qualities in water sample. These are vital for water quality monitoring (APHA, 1998). A number of scientific procedures and tools have been developed to assess the water contaminants (Dissmeyer, 2000). These procedures include the analysis of different parameters such as PH, turbidity, total suspended solids, dissolved oxygen, alkalinity amongst others. These parameters can affect the drinking water quality, if their values are in higher concentration than the safe limits by WHO and other bodies (WHO, 2011).

Biological (bacteriological) indices are determined using the species composition of the sample, the diversity as well as the distribution pattern, the presence or absence of the indicator species or groups (Trivedy, 1984). Bacteria contamination of drinking water is a major public health problem worldwide, as the water can be an important carrier of diarrhea diseases; thus the need to evaluate the bacteria quality (Suthar, 2009). Monitoring the bacteria quality of drinking water is done through laboratory testing for coliform groups, which include E coli. Streptococcus, Enterobacter etc.

A borehole water is referred to as groundwater extracted from a borehole, well drilled into an underground aquifer (WHO, 2017). They can be used for various purposes, including drinking water supply, irrigation, and industrial applications. Each so Borehole water is a widespread alternative in areas lacking municipal water supply. While it is relatively inexpensive and naturally occurring, its quality is highly dependent on environmental and geological factors, as well as proximity to pollution sources such as septic tanks and waste dumps. Sachet water is a commercially packaged water bagged in sealed 250ml polyethylene bags, for human consumption. They are often purified or treated water distributed for drinking purposes. It came into the Nigerian retail market in 1990 (Stephen, 2015). Sachet water is a popular low-cost option, particularly in Nigeria. It is widely consumed in both urban and rural settings due to its affordability and accessibility. However, despite regulatory oversight by agencies such as NAFDAC, sachet water production is frequently carried out by small-scale operators, some of whom lack the proper facilities or licenses to ensure adequate treatment and hygiene standards. Bottled water refers to water packaged in bottles, typically made of plastic or glass, for human consumption. They can be sourced from different sources like springs or wells and they undergo purification processes. Each source has its own perceived advantages and limitations. Bottled water is generally marketed as a premium product. It is perceived as cleaner, safer, and of higher quality than sachet or borehole water. It typically undergoes various stages of filtration and purification and is often regulated by national standards. Nonetheless, bottled water is not immune to quality concerns, particularly when subjected to improper storage conditions, exposure to sunlight, or contamination from the plastic materials used in packaging.

1.2 PROBLEM STATEMENT

The process of accessing safe drinking water by consumers in Nigeria needs to be studied, as there is an increasing understanding that contaminated water consumption is responsible for most health-related issues such as diarrhea and typhoid fever. Contaminated water can lead to a variety of waterborne diseases such as cholera, typhoid fever, dysentery, and diarrhea, which continue to be leading causes of morbidity and mortality in many parts of the developing world, especially among children and the elderly.

Most of the sachet water and bottled water produced in Nigeria, may be sold without sufficient purification, treatment and monitoring, and may not be free from physicochemical and bacteriological contamination. In some cases, the storage tanks and pipes used by most sachet water and bottled water companies are not well maintained to ensure good quality and safe water for consumption.

Understanding the potential risks associated with these water sources is essential for both producers and consumers. Despite regulatory standards, there is growing concern regarding the adequacy of treatment, monitoring, and storage of these water sources, which can lead to contamination and compromise public health.

1.3 AIM AND OBJECTIVES

The main aim of this study is to examine and compare the quality of borehole, sachet and bottled water in Ikhueniro community, Benin city Edo state, to check if they conform to the standards set by the regulatory body.

The specific objectives are to:

1. Assess the quality of water samples by Carrying out physicochemical and bacteriological tests on samples.
2. Compare the results with water quality standards and to determine the water quality indices.
3. Identify potential contaminants and to evaluate treatment and purification methods.

1.4 SCOPE OF STUDY

The scope of this work covers the quality analysis of water samples obtained from five (5) different borehole sources in ikhueniro community, and five (5) different packaged water sold in the community. However, the choice of 5 to 5 to 5 samples of borehole to sachet to bottle water is for ease of calculation and also the higher the sample size the better the representation of each brand in the actual population. The water quality index test (WQI) will be carried out in the laboratory to this regard.

The Water Quality Index (WQI) is calculated based on various physical, chemical, and biological tests. Some common parameters include temperature, PH, turbidity, dissolved oxygen, chemical oxygen demand (COD), fecal coliforms, nitrates, phosphates, total dissolved solids (TDS), and the presence of bacteria, viruses, and parasites.

The tools to be employed in this analysis includes pH meter, turbidimeter, TDS meter, microscope, autoclave, incubator, spectrophotometer, pipettes, sterile sampling bottle, micropipettes, and gloves. The software to be used are Microsoft excel and google sheets.

1.5 JUSTIFICATION OF STUDY

This study is justified by the urgent need to ensure public health through access to safe drinking water. In urban and semi-urban areas, the population relies on diverse sources of drinking water, notably borehole water, sachet water, and bottled water. Each of these sources varies significantly in terms of quality control, treatment processes, packaging, and storage practices. While borehole water is often perceived as natural and affordable, it is prone to contamination from nearby septic systems, agricultural runoff, and industrial waste. Sachet water, popularly known as “pure water,” is widely consumed due to its affordability and convenience, but several reports have raised concerns about inadequate quality control during production and distribution.

Bottled water, although considered premium and often presumed to be safe, may also contain harmful contaminants due to leaching from plastic containers or poor storage conditions.

The relevance of this study in this community and generally is that it identifies potential health risks associated with the different types of water consumed. It also informs policy decisions and interventions to improve water quality, and raises consumer awareness about the quality of different water sources.

The findings of this study can also contribute to enhancing water treatment and management practices, minimizing the risk of waterborne diseases, and promoting trust in water sources and treatment processes.

In summary, this study not only bridges knowledge gaps but also serves as a catalyst for improved water safety practices, regulatory enforcement, and consumer protection.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

Water is an essential component of life, fundamental for human health, agricultural production, and industrial processes. The increasing demand for safe drinking water has led to the proliferation of multiple water sources and packaging methods, notably borehole water**,** sachet water**,** and bottled water, particularly in developing countries. Assessing the quality of these water types is crucial for public health safety, environmental management, and regulatory policies.

In many developing countries, water sources include borehole water (groundwater), sachet water (packaged in small plastic bags), and bottled water (commercially purified and sealed). The proliferation of these sources necessitates a comparative assessment of their quality in terms of physical, chemical, and microbiological properties. This review synthesizes findings from previous studies to assess the relative safety and quality of these three water types.

2.2 SOURCES OF WATER

Water exists in various forms and originates from different parts of the Earth's hydrological (water) cycle. All water sources fall into two main categories; Surface Water**,** and Groundwater.

In addition, atmospheric water and desalinated water are emerging or supplementary sources in some areas.

2.2.1 Surface Water

Surface water is the water that collects on the Earth's surface in natural and man-made formations such as rivers, lakes, reservoirs, ponds, wetlands, and streams. It originates from precipitation, glacial melt, and runoff from surrounding land, and plays a significant role in the hydrologic cycle by supporting ecosystems and human activities alike (EPA, 2020). Surface water is typically divided into lentic systems (still waters like lakes and ponds) and lotic systems (flowing waters like rivers and streams), each of which supports distinct ecological functions and biodiversity.

Surface water is more accessible than groundwater, making it a primary source for municipal water supply, irrigation, recreation, and hydropower generation. It is also critical for maintaining habitats for aquatic life, regulating temperature, and supporting biodiversity. However, surface water is more susceptible to pollution, given its direct exposure to human activities. Runoff from agricultural fields can introduce excess nutrients such as nitrogen and phosphorus, leading to eutrophication—a condition where water bodies become overly enriched with nutrients, causing harmful algal blooms and oxygen depletion (Gleick, 2014).

Additionally, industrial discharges, urban wastewater, and plastic pollution pose major threats to surface water quality. Climate change further exacerbates these issues, contributing to altered rainfall patterns, droughts, and flooding, which can disrupt the balance of surface water systems (EPA, 2020). Effective watershed management and pollution control strategies are crucial for maintaining the quantity and quality of surface water.

Advantages

Surface water is readily accessible and relatively easy to collect for human use. Rivers, lakes, and reservoirs are visible and can be tapped into with minimal infrastructure compared to groundwater, which requires drilling and pumping. Surface water sources are often located near population centers and are capable of providing large volumes of water, making them ideal for municipal water supplies, agriculture, hydropower generation, and recreation (EPA, 2020). In many developing countries, surface water bodies support economic activities such as fishing, transportation, and tourism. Additionally, surface water plays a crucial role in supporting ecosystems, maintaining wetlands, and providing habitats for a wide variety of plant and animal species (Gleick, 2014).

Concerns and Limitations

Despite its benefits, surface water is highly vulnerable to pollution due to its exposure to the environment and human activities. Runoff from agricultural fields can introduce fertilizers, pesticides, and animal waste, leading to nutrient enrichment and eutrophication. Urban runoff may contain oil, metals, and household waste, while industrial discharges can introduce toxic chemicals into surface water bodies (UNEP, 2021). Surface water also faces threats from sewage dumping, plastic waste, and mining effluents, which can make the water unsafe for consumption without extensive treatment.

Another limitation is that surface water is seasonally variable. In arid and semi-arid regions, rivers and lakes may dry up during dry seasons or droughts, leading to water shortages. Climate change has further increased the frequency and severity of extreme weather events, including floods and droughts, which can disrupt the reliability of surface water supply (WWAP, 2022). Furthermore, heavy evaporation in hot climates reduces water availability in open reservoirs and lakes, which may cause water quality issues such as increased salinity.

Water Quality Issues

Contaminants: Pathogens, pesticides, heavy metals. Algal blooms: Caused by excessive nutrients (eutrophication). Siltation: From deforestation and soil erosion.

2.2.2 Groundwater

Groundwater refers to the water that resides beneath the Earth's surface, occupying the spaces between soil particles and within cracks in rock formations. It is formed when precipitation—such as rain or snow—seeps into the ground, passing through the soil and permeable rock layers in a process known as infiltration. Eventually, this water accumulates in aquifers, which are underground layers of water-bearing rock or materials like gravel, sand, or silt (Todd & Mays, 2005). These aquifers can be unconfined, where water seeps directly from the surface above, or confined, where the water is trapped between impermeable layers of rock or clay, offering protection from surface contaminants.

Groundwater is a vital resource globally, providing water for drinking, irrigation, and industrial use. According to the United Nations, nearly 50% of the global population relies on groundwater for their domestic needs (UNESCO, 2022). One of the advantages of groundwater is that it is often naturally filtered as it passes through soil and rock, which can make it cleaner and safer for consumption compared to surface water. However, it is not without challenges. Groundwater is increasingly threatened by over-extraction, especially in agriculture-dominated regions, leading to depletion of aquifers and lowering of water tables. Additionally, contamination from leaching pesticides, industrial waste, and poorly managed landfills can render groundwater unsafe for use (USGS, 2022).

In coastal regions, excessive withdrawal of groundwater can result in saltwater intrusion, where seawater encroaches into freshwater aquifers, compromising water quality. Because the natural recharge of aquifers is a slow process, especially in arid regions, careful management is essential to ensure the sustainability of this hidden but crucial water source (Todd & Mays, 2005).

Groundwater quality comprises the physical, chemical, and biological qualities of ground water. Temperature, turbidity, color, taste, and odor make up the list of physical water quality parameters. Since most ground water is colorless, odorless, and without specific taste, we are typically most concerned with its chemical and biological qualities. Although spring water or groundwater products are often sold as “pure,” their water quality is different from that of pure water. Naturally, ground water contains mineral ions. These ions slowly dissolve from soil particles, sediments, and rocks as the water travels along mineral surfaces in the pores or fractures of the unsaturated zone and the aquifer. They are referred to as dissolved solids. Some dissolved solids may have originated in the precipitation water or river water that recharges the aquifer. The total mass of dissolved constituents is referred to as the total dissolved solids (TDS) concentration. In water, all of the dissolved solids are either positively charged ions (cations) or negatively charged ions (anions). The total negative charge of the anions always equals the total positive charge of the cations.

Advantages

Groundwater is often regarded as a cleaner and more reliable source of water than surface water, especially in areas where surface sources are polluted or intermittent. Because it is stored underground in aquifers, groundwater is naturally filtered through layers of soil, sand, and rock, which helps remove many microorganisms and suspended particles (Todd & Mays, 2005). This makes it suitable for drinking, domestic, and industrial use with minimal treatment. Groundwater is also less susceptible to seasonal changes, as aquifers can store water for long periods, making it a more dependable supply during dry seasons or droughts.

Another major advantage is that groundwater systems are often decentralized, allowing individual households, farms, or institutions to develop private wells or boreholes, especially in remote areas where piped infrastructure is absent. This can enhance water security and resilience for small communities (UNESCO, 2022).

Concerns and Limitations

One of the main concerns with groundwater is the risk of over-extraction. When groundwater is withdrawn faster than it is naturally recharged, it leads to declining water tables, dry wells, and aquifer depletion. This can have far-reaching consequences, including land subsidence, which damages infrastructure and ecosystems, and saltwater intrusion in coastal areas, which makes freshwater aquifers saline and unusable (USGS, 2022).

Groundwater is also vulnerable to contamination, although it often appears less immediate due to its concealed nature. Improper disposal of industrial waste, landfill leachate, septic system leakage, and agricultural chemicals can infiltrate aquifers and introduce pollutants such as nitrates, arsenic, fluoride, or pathogens. Because aquifers have slow turnover rates, contaminated groundwater can remain unsafe for decades without costly remediation.

Another limitation is that drilling wells and installing pumping systems require technical expertise and capital investment, which may not be readily available in impoverished or remote areas. Moreover, unregulated and unmonitored extraction makes groundwater difficult to manage sustainably at a national or regional level (MacDonald et al., 2012).

Groundwater Recharge

Groundwater recharge refers to the process by which water enters an aquifer from the surface. This occurs when precipitation, snowmelt, or surface water infiltrates the soil and percolates downward to the saturated zone. Recharge can occur naturally, through rainfall and river seepage, or artificially, through human-made methods designed to enhance aquifer replenishment.

Natural Recharge

Natural recharge is primarily driven by climatic and geological factors. Regions with porous soils, sufficient rainfall, and vegetative cover tend to have higher recharge rates. However, in arid and semi-arid areas, the rate of natural recharge is often very low due to limited rainfall and high evaporation rates. Deforestation, urbanization, and land degradation further reduce recharge by sealing the soil surface and increasing runoff.

Artificial Recharge

To combat groundwater depletion, many regions have adopted artificial recharge techniques, including: recharge basins or ponds that allow water to slowly infiltrate into the ground, injection wells that pump treated surface water directly into aquifers, rainwater harvesting systems that collect and direct rainwater into the ground, check dams and percolation tanks that slow down river flow and encourage infiltration (CGWB, 2021).

Artificial recharge is particularly important in areas experiencing groundwater stress, where extraction rates exceed recharge. Managed aquifer recharge (MAR) is a growing field that integrates hydrogeology, engineering, and policy to promote sustainable groundwater use.

Importance of Groundwater Recharge

Groundwater recharge ensures the long-term sustainability of aquifers and maintains base flow in rivers and wetlands. Without sufficient recharge, aquifers become depleted, affecting both human water supply and ecosystem health. Enhancing recharge also reduces flood risk, improves water quality, and supports climate change resilience by storing water during wet seasons for use during droughts.

However, for recharge to be effective, it must be carefully managed. Artificial recharge can lead to contamination if poor-quality water is used, and excessive recharge in some geological settings can trigger land instability or raise water tables to problematic levels. Therefore, understanding local hydrogeology is critical before implementing recharge projects (Dillon et al., 2009).

2.3 BOREHOLE WATER

Borehole water refers to water extracted from underground aquifers using a drilled, narrow shaft or well—called a borehole—which taps into the groundwater system beneath the Earth’s surface.

Groundwater is stored in porous geological formations known as aquifers, which may be composed of sand, gravel, or fractured rock. This water is often stored under pressure in confined or unconfined aquifers and is retrieved through pumping systems installed in the borehole. These aquifers are recharged over time through the infiltration of rainwater, surface water seepage, or snowmelt that percolates through the soil layers (Todd & Mays, 2005). Boreholes are especially vital in areas where access to surface water is limited, unreliable, or heavily polluted, making them an essential water source in many parts of Africa, Asia, and rural communities globally (UNESCO, 2022). Borehole systems are commonly used in rural and peri-urban areas where access to centralized water supply infrastructure is limited or unreliable (WHO, 2017). In many parts of Africa and Asia, boreholes serve as the primary source of drinking water, agricultural irrigation, and small-scale industrial use.

Source and Extraction Mode

The **source** of borehole water is typically confined or unconfined aquifers located at varying depths beneath the ground. Unconfined aquifers lie closer to the surface and are directly recharged by rainfall, while confined aquifers are trapped between impermeable layers of rock or clay and are often under greater pressure. Because of this natural pressure, confined aquifers can yield cleaner water, but they require deeper drilling to access (MacDonald et al., 2012).

To extract borehole water, specialized rotary drilling machines are used to drill vertically into the earth until the aquifer is reached. Once the aquifer is accessed, a casing is installed to line the borehole and prevent collapse or contamination. A submersible pump or hand pump is then fitted to bring the water to the surface. In areas with electricity, electric pumps are preferred due to their efficiency, while manual pumps are common in low-income or off-grid regions. The depth of boreholes can vary significantly—from 20 meters in shallow aquifers to over 300 meters for deep groundwater extraction (CGWB, 2021).

Water Quality Concerns

Although borehole water is generally considered to be cleaner than surface water due to natural filtration, it is not immune to contamination. Several water quality concerns are associated with borehole use. While it is often considered safer than surface water due to natural filtration through soil layers, it is still susceptible to contamination from septic systems, agricultural runoff, and industrial waste (Awofolu et al., 2005). One major issue is microbial contamination, which can occur if the borehole is poorly constructed or if surface pollutants enter the aquifer through cracks or improper sealing. This can result in the presence of E. coli, total coliforms, or other pathogens that pose significant health risks (Adekunle et al., 2007).

The quality of borehole water depends significantly on the geological formations it passes through and the depth of the borehole. Deep boreholes typically yield cleaner water as it has undergone natural filtration through layers of sand, gravel, and rock, which can remove many contaminants. However, borehole water is not immune to pollution. In areas with high agricultural activity, fertilizers and pesticides can seep into the ground and contaminate aquifers. Additionally, poorly constructed or maintained boreholes can introduce pathogens or heavy metals such as arsenic and lead into the water supply (Adekunle et al., 2007). For this reason, the World Health Organization (WHO) recommends regular testing and treatment of borehole water to ensure it meets potable water standards (WHO, 2017).

Another concern is over-extraction, especially in rapidly growing urban areas where demand for groundwater exceeds natural recharge rates. This can lead to a decline in the water table, making borehole water more expensive and energy-intensive to extract. Despite these concerns, boreholes remain a crucial water source in developing regions due to their reliability and relatively low operational costs compared to other water systems (MacDonald et al., 2012).

Another concern is chemical contamination, particularly from natural geological sources. For instance, arsenic, fluoride, and iron are commonly found in groundwater in many regions and can cause chronic health conditions such as fluorosis or arsenicosis if consumed over long periods (WHO, 2017). Additionally, nitrate contamination from agricultural fertilizers and pesticide infiltration are major threats, especially in rural farming communities. Industrial pollution and leachate from landfills and septic tanks can also seep into groundwater sources over time.

Treatment Processes

Due to the potential for contamination, treatment of borehole water is essential before consumption, especially for domestic use. The level and type of treatment required depend on the specific contaminants present in the water, which are usually identified through regular water quality testing.

1. Filtration is used to remove suspended solids, sediments, and particulates. This is often the first step in borehole water treatment.
2. Disinfection is critical for eliminating microbial pathogens. Common methods include chlorination, ultraviolet (UV) treatment, and ozonation.
3. Iron and Manganese Removal systems, such as aeration and oxidation filtration, are used in areas where these elements occur naturally in high concentrations.

4. Reverse Osmosis (RO) or activated carbon filtration may be used for removing dissolved salts, heavy metals, and organic pollutants, particularly where water quality is severely compromised.
5. pH adjustment may be necessary in acidic groundwater to protect plumbing systems and improve taste.

In rural settings, simple technologies like biosand filters, solar disinfection (SODIS), or boiling may also be employed to make borehole water safe for consumption in the absence of centralized treatment systems (WHO, 2017).

Other Key Concepts and Considerations

A few other critical considerations are tied to borehole water development:

1. Sustainability: Over-extraction of groundwater from boreholes can lead to a rapid decline in the water table, especially when recharge rates are low or nonexistent. Sustainable management practices, including controlled pumping and periodic monitoring, are vital to prevent aquifer depletion (USGS, 2022).
2. Borehole Maintenance: Regular maintenance of the borehole, pump, and surrounding sanitary seal is essential to prevent contamination. Boreholes should be periodically disinfected and tested to ensure consistent water quality.
3. Water Rights and Access: In many countries, boreholes are privately owned, which can raise issues of inequitable water access, especially in water-scarce regions. National water policies increasingly promote community boreholes to ensure shared, equitable access.

4. Groundwater Recharge: In water-stressed regions, artificial groundwater recharge techniques—such as constructing recharge pits or using rainwater harvesting systems—are being adopted to help maintain aquifer levels and ensure the long-term sustainability of borehole sources (Dillon et al., 2009).

2.4 SACHET WATER

Sachet water refers to potable water packaged in small plastic bags, usually containing 500 milliliters per sachet, and sold commercially at affordable prices. It is widely consumed in many developing countries, especially in West Africa, due to its low cost and convenience. Sachet water production typically involves drawing water from municipal taps, boreholes, or surface sources, which is then treated—often through filtration, UV sterilization, or reverse osmosis—and packaged using automatic sealing machines (Kwakye-Nuako et al., 2007). In urban and semi-urban areas where piped water supply is intermittent or unreliable, sachet water has become a widely accepted alternative.

The source of sachet water varies. It can be drawn from municipal tap water, borehole water, wells, or surface water sources like rivers and streams. However, the quality of the source water greatly influences the final product and its safety. Where municipal water is treated and piped intermittently, producers may opt for private boreholes to ensure consistency (Oyedeji et al., 2010).

Production and Treatment Processes

Sachet water production involves a multistage process:

1. Water extraction (from boreholes or taps),

2. Pre-treatment (sand filtration or sedimentation to remove suspended solids),
3. Main treatment, which may include microfiltration, UV disinfection, reverse osmosis, or chlorination, and
4. Packaging, using automated machines that fill and heat-seal polyethylene sachets.

The efficacy of treatment depends largely on the equipment used and the adherence to standard operating procedures. Larger, registered producers often use advanced filtration and sterilization technologies, while informal producers may cut corners, increasing the risk of microbial contamination (Oyedeji et al., 2010; Adekunle et al., 2007).

Water Quality Concerns

While sachet water is a critical component of urban water supply systems, especially in low-income communities, its safety and quality vary widely depending on the producer. Studies have shown that sachet water from registered and regulated producers tends to meet acceptable water quality standards, whereas those from unregulated or informal producers may contain high levels of microbial contaminants such as *Escherichia coli*, coliform bacteria, or even chemical residues (Oyedeji et al., 2010). In Nigeria, the National Agency for Food and Drug Administration and Control (NAFDAC) is responsible for regulating the production and sale of sachet water, but enforcement remains inconsistent due to the proliferation of informal vendors.

Environmental concerns also surround the widespread use of sachet water. The single-use plastic packaging is a significant source of environmental pollution, particularly in urban drainage systems and waterways. These plastics are often not biodegradable and contribute to urban flooding and water contamination (Adekunle et al., 2015). Despite these drawbacks, sachet water remains a vital water source for millions of people who lack access to treated piped water.

Water quality studies have shown inconsistencies in microbiological and chemical safety, especially from unregistered producers. Common concerns include: Presence of coliform bacteria or E. coli, indicating fecal contamination, Low free chlorine levels, resulting in inadequate disinfection, Leaching of chemicals from poor-quality plastic during hot storage conditions.

According to a study in Ghana, over 25% of sachet water samples were contaminated with enteric protozoan parasites, posing a risk of gastrointestinal infections (Kwakye-Nuako et al., 2007). Environmental issues also arise from plastic waste, as discarded sachets contribute to urban flooding and drainage blockages (Adekunle et al., 2015).

Regulatory Framework

In countries like Nigeria, sachet water production is regulated by the National Agency for Food and Drug Administration and Control (NAFDAC) and the Standards Organisation of Nigeria (SON). NAFDAC requires registration, routine inspection, and labeling of production details on sachets (NAFDAC, 2020). However, due to the informal nature of the industry and weak enforcement mechanisms, many producers operate without licenses, compromising quality assurance.

The World Health Organization (WHO) also provides global guidelines for packaged drinking water, including limits on microbial content, total dissolved solids (TDS), and heavy metals (WHO, 2017). However, local adaptation and enforcement remain key challenges in many low-income settings.

Issues with Sachet Water:

1. Lack of regulation: Many sachet water producers operate informally and are not registered with regulatory bodies.
2. Storage problems: Exposure to sunlight and high temperatures can degrade water quality and promote microbial growth.
3. Packaging concerns: Low-quality polyethylene bags can leach chemicals into the water or harbor bacteria on the outer surface.

2.5 BOTTLED WATER

Bottled water refers to water that is processed, packaged in plastic or glass bottles, and sold commercially for human consumption. It includes various categories such as natural spring water, purified water, distilled water, and mineral water. Bottled water is usually subjected to rigorous filtration, treatment, and quality testing procedures to meet local and international safety standards. For example, in the United States, bottled water is regulated by the Food and Drug Administration (FDA), while in the European Union, it falls under the jurisdiction of the European Food Safety Authority (EFSA) (Gleick, 2010).

Bottled water is typically produced and packaged by licensed companies under strict regulatory standards. It often undergoes multiple purification processes such as reverse osmosis, ozonation, or ultraviolet sterilization (Ugochukwu et al., 2013).

Bottled water is commercially produced drinking water, typically sealed in plastic or glass bottles of varying sizes (from 330 mL to 1.5 L or more). It is considered the most controlled and standardized form of packaged water.

The sources of bottled water vary widely and may include municipal tap water, underground wells, or natural springs. Premium bottled water brands often emphasize their sources, especially when drawn from pristine springs or mountains, claiming superior taste and mineral composition. However, a significant proportion of bottled water globally is simply treated municipal water that has been rebranded and packaged for commercial distribution (NRDC, 1999; WHO 2017). In countries with inconsistent or poor water infrastructure, such as Nigeria or India, bottled water is often perceived as a safer and more reliable alternative to tap or borehole water.

Moreover, the high cost of bottled water compared to tap or sachet water raises questions about affordability and equity, particularly in developing countries where access to clean water is already limited. Nonetheless, bottled water remains a popular choice among middle- and upper-income consumers, especially in urban settings and areas lacking consistent public water supply.

Production and Treatment Processes

The production of bottled water follows several stages to ensure safety, clarity, and shelf stability:

1. Water sourcing: Water is drawn from a designated source—either municipal, spring, or well—and transported to the bottling facility or processed onsite.
2. Filtration and treatment: This may include multiple techniques such as: microfiltration and carbon filtration to remove sediments and organic matter, reverse osmosis (RO) to remove dissolved solids and contaminants, ultraviolet (UV) irradiation and ozonation for microbial disinfection, distillation to separate pure water from impurities through boiling and condensation.

3. Bottling and packaging: After treatment, the water is filled into sterilized bottles using automated, hygienic equipment in controlled environments. Bottles are then sealed, labeled, and batch-coded for traceability.

Mineral and spring water products may retain naturally occurring dissolved minerals, which are sometimes listed on the bottle for marketing purposes (Semerjian, 2011). In contrast, distilled and purified waters may undergo deionization, resulting in very low mineral content.

Water Quality Concerns

From a health perspective, bottled water is generally safe for consumption, provided it is produced and stored under hygienic conditions. Studies have shown that contamination in bottled water is rare in regulated markets, although incidents of microbial or chemical contamination have occurred, especially with improperly stored or counterfeit products (Semerjian, 2011). Despite its safety advantages, bottled water faces criticism for its environmental impact. The plastic bottles contribute to solid waste problems and, when improperly disposed of, pollute land and marine ecosystems. The production and transportation of bottled water also consume significant energy, raising concerns about its carbon footprint (Gleick & Cooley, 2009). The following are notable concerns:

1. Microbial contamination can occur if bottling equipment is improperly sanitized or if bottles are stored in hot or humid conditions. Some studies have found heterotrophic bacteria in improperly stored bottled water (WHO, 2017).

2. Chemical leaching from plastic bottles, especially when exposed to heat or sunlight, may introduce substances like antimony, bisphenol-A (BPA), and phthalates into the water, though levels are usually below toxic thresholds (Shotyk & Krachler, 2007).

3. Bottled water can sometimes contain microplastics, as shown by recent studies which found plastic particles in over 90% of popular bottled water brands sampled globally (Mason et al., 2018).

Additionally, because some bottled waters are simply repackaged municipal water, consumers may be misled into believing they are drinking superior-quality water when in reality, the safety and taste are often comparable to or even lower than public tap water (NRDC, 1999).

Regulatory Framework

The regulation of bottled water varies by country but typically involves food safety and consumer protection agencies. In many parts of the world:

1. In the United States, bottled water is regulated by the Food and Drug Administration (FDA) under the Federal Food, Drug, and Cosmetic Act, which mandates labeling, treatment, and quality standards.
2. In the European Union, bottled water is overseen by the European Food Safety Authority (EFSA) and categorized into natural mineral water, spring water, and processed drinking water, each with specific quality and labeling requirements.
3. In Nigeria, bottled water is regulated by the National Agency for Food and Drug Administration and Control (NAFDAC), which sets standards for labeling, composition, production hygiene, and microbiological testing.

Bottled water producers must comply with guidelines issued by the World Health Organization (WHO), which outline acceptable limits for microbiological and chemical contaminants (WHO, 2017). International standards such as Codex Alimentarius also provide a regulatory framework for bottled water classification and safety protocols.

Other Key Concepts and Issues

Environmental Concerns

One of the major criticisms of bottled water is its environmental footprint: The manufacturing of plastic bottles uses significant petroleum-based resources. The transportation of bottled water across countries or continents consumes fossil fuels and contributes to carbon emissions. Plastic pollution is a severe problem, especially in countries lacking effective waste management systems. Bottles often end up in oceans and rivers, posing risks to marine life and ecosystems (Gleick & Cooley, 2009).

In response to these challenges, there has been a global push for recyclable packaging, biodegradable alternatives, and refill stations to reduce dependency on single-use plastics.

Economic and Social Aspects

Bottled water is often significantly more expensive than tap or borehole water. While it may be seen as a luxury item in wealthier countries, in low- and middle-income countries it becomes a necessity due to the absence of safe public water supplies. This raises issues of water equity, where only those who can afford bottled water have access to safe drinking water (Gleick, 2010).

Additionally, the commodification of water through bottled water markets has sparked debate about human rights to water versus corporate profit. Some argue that prioritizing bottled water undermines investment in public water infrastructure, especially in countries where bottled water sales are booming.

2.6 CONCEPTUAL DEFINITIONS AND EXPLANATIONS

Understanding key terms and concepts is foundational to analyzing and interpreting water quality data effectively. The definitions below help clarify the nature of water sources, treatment processes, and quality determinants involved in this study.

2.6.1 Water Quality

Water quality is a multidimensional concept that refers to the suitability of water for its intended use, particularly drinking, based on a set of physical, chemical, and biological characteristics. High-quality drinking water should be free from disease-causing organisms, harmful chemicals, unpleasant taste, and odor, and should meet specific parameters defined by regulatory and health institutions. In the context of borehole water, sachet water, and bottled water, water quality is influenced by the source, environmental conditions, and the effectiveness of treatment and handling methods. Borehole water, for instance, may appear clear and clean due to its underground origin, yet it can contain naturally occurring contaminants like arsenic, fluoride, and iron that can pose long-term health risks if left untreated (Todd & Mays, 2005; MacDonald et al., 2012). Sachet water, commonly sold in low-income communities as an affordable source of drinking water, may originate from boreholes or municipal taps but is susceptible to contamination if produced under unhygienic conditions or stored improperly. Bottled water, often perceived as superior in quality due to strict branding and regulation, is usually sourced from springs, wells, or treated municipal water. However, its quality is not uniformly guaranteed, as instances of microbial contamination and chemical leaching from plastic containers have been reported (Mason et al., 2018). Therefore, evaluating water quality among these sources involves assessing both the treatment processes applied and the effectiveness of their implementation in maintaining microbiological and chemical safety.

2.6.2 Microbiological Quality

The microbiological quality of water is an essential determinant of its safety, particularly in preventing waterborne diseases. It refers to the presence or absence of pathogenic microorganisms such as bacteria, viruses, and protozoa in a water sample. Inadequate microbiological quality is one of the most common causes of diarrheal diseases globally, particularly in developing countries where regulatory oversight and infrastructure are limited. In borehole water, microbiological safety is generally expected if the borehole is properly constructed, protected from surface runoff, and located far from sources of fecal contamination. However, in many settings, shallow or poorly sealed boreholes become conduits for pathogens, especially where sanitation practices are weak (Adekunle et al., 2007). Sachet water is especially vulnerable due to its decentralized and often informal production systems. Research has shown that a significant percentage of sachet water samples fail microbiological tests due to insufficient treatment, contaminated equipment, or poor hygiene practices during packaging (Kwakye-Nuako et al., 2007; Oyedeji et al., 2010). Bottled water, produced in more controlled environments, tends to exhibit higher microbiological quality, yet contamination can still occur due to lapses in production hygiene or post-production handling (Mason et al., 2018). As such, microbiological quality serves as a critical benchmark for comparing these water types, not only because of the immediate health implications but also because it reflects the reliability of production and oversight systems in place.

2.6.3 Physical and Chemical Properties

The physical and chemical properties of water are important determinants of its acceptability and health implications. Physical properties such as color, taste, odor, and turbidity affect the aesthetic appeal of water, while chemical properties like pH, alkalinity, hardness, and concentrations of dissolved solids and metals influence both safety and palatability. For instance, high turbidity not only affects the appearance of water but can also shield harmful microbes from disinfectants, reducing the effectiveness of chlorination or UV treatment. Elevated levels of nitrates, often due to fertilizer runoff or human waste, can cause methemoglobinemia in infants—a potentially fatal condition. In borehole water, chemical properties are heavily influenced by local geology, and excessive levels of naturally occurring elements such as fluoride or iron are common in certain regions (Todd & Mays, 2005). In sachet and bottled water, these properties are expected to be controlled through filtration and treatment processes, but studies have shown that sachet water sometimes exceeds acceptable limits due to poor purification and lack of regulation (Semerjian, 2011). Chemical contamination can also result from the leaching of compounds from plastic packaging, particularly when water is stored under hot conditions. Thus, a detailed understanding of these properties is crucial for evaluating the overall safety and consumer acceptability of drinking water from different sources.

2.6.4 Microbial Contamination

Microbial contamination of drinking water remains one of the leading causes of infectious disease outbreaks, especially in regions with poor water infrastructure. It occurs when water becomes contaminated with microorganisms, particularly pathogenic bacteria**,** viruses**,** and protozoa that can cause illness. This contamination can result from a variety of factors including defective treatment processes, poor sanitation near water sources, inadequate storage systems, and improper handling during distribution. In borehole water systems, microbial contamination often arises when boreholes are dug too shallow or too close to septic tanks or pit latrines, allowing human waste to leach into the groundwater (Adekunle et al., 2007). Sachet water, though treated in theory, is particularly susceptible to microbial contamination due to substandard production environments, lack of monitoring, and poor hygiene practices during packaging and transportation (Kwakye-Nuako et al., 2007). Bottled water is less susceptible due to stricter regulatory oversight and controlled packaging environments, but it is not entirely immune (Mason et al., 2018). Although it is usually subject to stricter regulation and testing, it can also be compromised by lapses in factory hygiene or exposure to heat and light during storage, which can encourage microbial growth. This makes microbial contamination a major concern in any comparative analysis of drinking water sources, as it directly affects public health and reflects the efficacy of sanitation, treatment, and oversight measures.

2.6.5 Microbiological parameters

Microbiological parameters are standardized indicators used in water quality assessment to detect the presence of microbial contaminants that may pose health risks. The most widely used indicators include total coliforms, fecal coliforms, and Escherichia coli (E. coli), all of which suggest the possible presence of fecal material and therefore the potential for pathogenic microorganisms such as Salmonella, Shigella, or Vibrio cholerae. These parameters are vital in routine water monitoring because direct testing for every possible pathogen is impractical. In comparative studies of borehole, sachet, and bottled water, microbiological parameters help determine the safety and reliability of each water source. Borehole water that is properly constructed and sealed may show zero coliform count; however, proximity to latrines or agricultural activities often results in contamination. Sachet water, especially when unregulated, frequently exceeds acceptable limits for microbial indicators, making it a common source of gastrointestinal illnesses (Oyedeji et al., 2010). Bottled water generally fares better due to more advanced disinfection processes such as UV irradiation or ozonation, although it is not immune to contamination, especially post-packaging. Therefore, microbiological parameters remain the cornerstone of water safety assessment, providing a direct linkage between water quality and health outcomes.

2.6.6 Physicochemical Parameters

Physicochemical parameters are the measurable physical and chemical properties of water that influence both its aesthetic appeal and its safety for consumption. These parameters include temperature, pH, turbidity, electrical conductivity, total dissolved solids (TDS), hardness, and concentrations of various inorganic ions such as nitrate, fluoride, chloride, biological oxygen demand (BOD), chemical oxygen demand (COD) and heavy metals like lead, iron, and manganese. Each of these indicators provides insight into the source and condition of the water. For example, high turbidity levels may indicate the presence of suspended solids that can harbor microbial life, while elevated nitrate concentrations are typically linked to agricultural runoff or nearby sanitation systems. Borehole water, drawn from aquifers, often contains elevated levels of naturally occurring elements such as iron and manganese, which can stain plumbing and affect taste, and in some regions, geogenic fluoride or arsenic may reach toxic levels if not treated (MacDonald et al., 2012). In sachet and bottled water, these parameters should be within WHO-recommended limits, but discrepancies have been observed, particularly in sachet water where substandard filtration processes are used (Semerjian, 2011). Regular testing of these parameters is crucial not only for regulatory compliance but also for building consumer trust. Their significance in comparative water quality studies lies in their ability to reflect both natural influences and the effectiveness of purification systems applied to the different water types.

2.6.7 Water Treatment and Purification Processes

Water treatment and purification are critical processes aimed at making water safe for human consumption by removing physical, chemical, and biological contaminants. The nature of the treatment process depends on the source and initial quality of the water. Borehole water, while relatively free of microbial pathogens due to natural filtration, may require aeration, sand filtration, iron removal, or chlorination to address high mineral content or occasional microbial contamination. Sachet water producers may use filtration systems, activated carbon filters, and UV light or chlorine disinfection, although these treatments are often inconsistently applied in informal settings. Bottled water typically undergoes more rigorous purification such as reverse osmosis, distillation, or ozonation, which can effectively remove a wide range of contaminants, including microbes and dissolved solids (Semerjian, 2011). However, the efficacy of any water treatment system depends on proper operation, regular maintenance, and quality control. When these systems fail or are neglected, water that is packaged and sold can still pose significant health risks. Therefore, the presence, type, and reliability of purification processes must be assessed when comparing different water sources.

2.6.8 Water Safety Plans (WSPs)

A Water Safety Plan (WSP) is a comprehensive, proactive approach recommended by the World Health Organization to manage the safety of drinking water supplies. It encompasses a risk assessment and management framework that spans the entire water supply chain—from source to consumer. The core aim of WSPs is to prevent contamination rather than react to it. This involves identifying potential hazards, assessing the risk of those hazards, and implementing control measures to mitigate them. For borehole water, a WSP might include ensuring proper well construction, siting away from contamination sources, and regular microbial and chemical testing. In sachet and bottled water production, WSPs would involve maintaining hygiene in the production area, routine equipment sanitation, regular testing, and compliance with health standards. While larger bottled water companies may implement formal WSPs as part of broader quality management systems like HACCP (Hazard Analysis and Critical Control Points), many small-scale sachet producers lack the capacity or oversight to do so. Consequently, the absence of robust safety planning contributes to inconsistent water quality. In comparative water quality studies, the existence and enforcement of water safety plans serve as indicators of institutional readiness and long-term water safety management (WHO, 2017).

2.7 REVIEW OF RELATED STUDIES AND LITERATURE

Water quality studies conducted across various Nigerian regions offer vital insights into the microbial, physicochemical, and chemical safety of commonly consumed drinking water sources such as borehole, sachet, and bottled water. The existing body of literature reveals both patterns and disparities in water quality, highlighting the urgent need for standardized regulatory enforcement, improved treatment processes, and consumer education. The following subsections synthesize relevant empirical studies to provide a broad understanding of the water quality landscape in Nigeria.

2.7.1 Microbial Quality Comparison

Several studies have highlighted microbial contamination as a key challenge in drinking water safety, particularly in sachet and borehole water. Obi et al. (2002) found that sachet water samples collected in southeastern Nigeria had significantly higher microbial loads than borehole water, with many exceeding WHO permissible limits for *E. coli* and total coliforms. Adekunle et al. (2004) corroborated these findings by detecting fecal coliforms in both sachet and borehole water in southwestern Nigeria, indicating fecal contamination likely due to poor hygiene practices during production and unsafe borehole siting.

In Lagos, Egwari et al. (2005) analyzed both sachet and borehole water and found *E. coli* and *Pseudomonas* spp. in more than 30% of sachet samples, while borehole samples exhibited generally lower but still sporadic microbial presence. The authors recommended mandatory, routine microbiological surveillance by regulatory bodies such as NAFDAC and the State Water Boards to safeguard public health.

Studies focusing on bottled water have shown more promising results. Adegoke et al. (2012), in their study of bottled water brands in Ibadan, reported that over 90% of the samples met WHO microbial safety standards. However, some brands displayed elevated coliform counts, attributed to post-treatment contamination during storage. Similarly, Igbeneghu and Lamikanra (2014) examined bottled water sold in supermarkets and noted that while most brands were microbiologically compliant, a few exceeded safety thresholds, likely due to warm storage conditions. These findings underscore the importance of maintaining a cold supply chain, even for treated and sealed water.

2.7.2 Physicochemical Characteristics

Water quality is also defined by its physicochemical parameters, such as pH, turbidity, total dissolved solids (TDS), and hardness. Oloruntoba et al. (2011) conducted a comparative study in Lagos and discovered that borehole water frequently had higher TDS and hardness values, likely due to the dissolution of subsurface minerals. In contrast, bottled water consistently adhered to

WHO standards for pH (6.5–8.5), turbidity (<5 NTU), and TDS (<500 mg/L), making it the most stable and reliable option in terms of physicochemical safety.

Earlier work by Olayemi (1999) in Ilorin compared borehole, stream, and sachet water, revealing that stream water had the highest turbidity and microbial contamination. Sachet water exhibited wide variation in TDS, pH, and coloration, often influenced by inconsistent source water and treatment practices. Borehole samples frequently showed elevated iron and manganese levels, attributed to natural leaching from underground aquifers.

Umeh et al. (2005), in a study conducted in university hostels in Enugu, reported that sachet water had higher nitrate concentrations than borehole water. The nitrate levels were suspected to originate from sewage infiltration into municipal water sources that sachet producers often use. The same study noted excessive water hardness in borehole samples, recommending pre-consumption treatment such as sediment filtration or softening to reduce scale-forming potential.

Akpoveta et al. (2011), in their investigation of groundwater in Delta State, identified elevated concentrations of toxic metals—lead, cadmium, and arsenic—in certain boreholes. These chemical contaminants were traced to industrial discharges and improper waste management practices in nearby communities. The authors advocated for localized geochemical mapping and stringent groundwater quality monitoring to mitigate long-term health risks.

2.7.3 Comparative Studies of Bottled and Sachet Water

A number of comparative studies have been conducted to differentiate the quality of sachet and bottled water. Ugochukwu et al. (2013), in Anambra State, analyzed 10 sachet water brands and five bottled water brands. Their findings revealed uniformity in bottled water samples in terms of pH, TDS, and microbial load. However, sachet water samples exhibited significant inconsistencies—while some were sterile, others were contaminated with *Staphylococcus aureus* and *E. coli*. The study linked these disparities to unregistered and poorly regulated sachet producers.

Omalu et al. (2010) examined the microbiological safety of sachet water in Minna and found that water stored in direct sunlight for more than 24 hours showed significantly higher microbial loads. They also detected pathogenic bacteria like *Shigella* and *Salmonella*, emphasizing that inadequate packaging and exposure to heat can exacerbate contamination even after initial treatment. These studies illustrate that sachet water, although affordable and accessible, may pose greater health risks if regulatory standards and handling protocols are not rigorously enforced.

2.7.4 Chemical Contaminants and Heavy Metals

The issue of chemical contamination, especially in borehole water, has also attracted scholarly attention. Ogunbanjo and Awomeso (2014) assessed heavy metal content in borehole water samples from Ogun State and found elevated levels of iron, manganese, and lead. These contaminants were attributed either to geologic formations or leaching from corroded pipes. In contrast, sachet and bottled water samples analyzed in the same study exhibited significantly lower heavy metal concentrations, primarily due to industrial filtration methods like reverse osmosis and activated carbon treatment.

Onianwa et al. (2001) also analyzed bottled water brands in Ibadan and found trace levels of cadmium and lead within WHO limits. However, they noted that some samples had a pH below 6.5, suggesting mild acidity, likely caused by carbon dioxide dissolution during bottling. These findings suggest that although bottled water is generally safer, it is not entirely immune to chemical quality concerns, especially if manufacturing and storage protocols are compromised.

2.7.5 Regulatory Framework and Standards

Globally, the World Health Organization (WHO) provides comprehensive guidelines for drinking water safety, including thresholds for microbial and chemical contaminants. In Nigeria, NAFDAC is the primary agency regulating packaged water (sachet and bottled), while SON develops and enforces technical standards, such as allowable pH, turbidity, and microbial content. Despite these frameworks, enforcement remains weak, particularly among informal sachet water vendors operating without licenses or quality certifications. Egwari and Aboaba (2002) noted that poor inter-agency coordination and resource constraints have limited the effectiveness of regulatory oversight, allowing substandard water products to proliferate in low-income areas.

2.7.6 Consumer Perception and Usage

Consumer perception plays a key role in the selection of drinking water sources. Studies such as Ali et al. (2016) have shown that Nigerian consumers associate bottled water with higher quality and safety due to its professional packaging, branding, and perceived compliance with regulatory standards. However, the higher cost of bottled water renders it inaccessible to many low-income households, who often rely on borehole or sachet water instead. This economic disparity translates into differential exposure to waterborne diseases.

Oluduro and Aderiye (2007) conducted a study in Akure and observed that boreholes situated near farmlands often had dangerously high nitrate levels, likely due to fertilizer runoff. High nitrate ingestion can cause methemoglobinemia or "blue baby syndrome" in infants. The authors recommended locating boreholes at least 30 meters away from agricultural fields and ensuring proper casing during construction. These studies collectively suggest that while public perceptions align with actual safety rankings—bottled water generally being the safest—socioeconomic barriers force vulnerable populations to depend on less reliable sources, often at the cost of their health.

2.8 INSTITUTIONAL AND REGULATORY LITERATURE

The regulation of drinking water quality—particularly in low- and middle-income countries like Nigeria—relies on a network of international and national institutions responsible for setting standards, enforcing compliance, and protecting public health. At the global level, the World Health Organization (WHO) plays a pivotal role by providing universally accepted guidelines for drinking water safety. WHO's Guidelines for Drinking-Water Quality emphasize a risk-based management approach known as the Water Safety Plan (WSP), which spans the entire water supply chain from catchment to consumer. This framework encourages the identification of hazards, regular monitoring, preventive measures, and a multi-barrier approach to water protection (WHO, 2017). The WHO framework has become the reference point for national regulatory agencies worldwide, including those in Nigeria.

In the Nigerian context, the National Agency for Food and Drug Administration and Control (NAFDAC) is the primary institution charged with the regulation of packaged water, including sachet and bottled water. NAFDAC’s annual reports from 2015 to 2020 reveal persistent challenges in enforcing standards, particularly among informal sachet water producers. The agency has conducted periodic seizures of substandard water products across several states and has continually emphasized the need for greater inter-agency collaboration (NAFDAC, 2016; NAFDAC, 2018). The Standards Organisation of Nigeria (SON) also contributes by formulating specifications for water quality, packaging materials, and labeling requirements. SON's standards are meant to ensure uniformity and consumer protection, but enforcement remains inconsistent in the sachet water industry due to a high prevalence of unregistered producers and weak surveillance systems.

Environmental and groundwater protection also fall under the purview of state and federal Environmental Protection Agencies (EPAs). These agencies are tasked with monitoring pollution levels, protecting aquifers from industrial waste and sewage contamination, and ensuring that boreholes are drilled at safe distances from potential sources of contamination. However, borehole regulation in many rural and peri-urban communities remains largely informal or decentralized, leading to considerable variability in water quality and safety (MacDonald et al., 2012). The absence of robust inspection mechanisms often results in households relying on unprotected or shallow boreholes, thereby increasing vulnerability to microbial and chemical contamination.

The reviewed literature highlights a complex interplay between water source characteristics, treatment technologies, institutional oversight, and consumer behaviors. Bottled water generally achieves the highest ratings in terms of microbiological and physicochemical safety due to more stringent regulations, standardized industrial treatment, and stronger traceability measures. However, it remains less accessible to **low-**income populations due to its cost. Conversely, sachet water, although cheap and widely available, presents high variability in quality—largely due to the proliferation of unlicensed producers and inconsistent application of treatment protocols (Kwakye-Nuako et al., 2007; Oyedeji et al., 2010). Borehole water, often perceived as "natural," occupies a middle ground: while it may be free from industrial pollutants, it often lacks systematic treatment and is subject to geogenic and microbial risks, especially when protective infrastructure is inadequate (Adekunle et al., 2007).

As such, studies and regulatory reports converge on several key recommendations. There is a growing call for stricter enforcement of water quality standards, particularly in the sachet water industry. The literature also emphasizes the importance of community sensitization programs to educate consumers on hygiene, proper water storage, and the identification of safe water sources. Furthermore, the integration of low-cost, innovative technologies—such as solar disinfection, community chlorination kiosks, or ceramic filters—is encouraged to improve water quality in rural borehole systems. Lastly, the need for cross-sectoral coordination is paramount; collaboration between water, health, and environmental institutions is necessary to establish an effective, unified water safety management framework across all water types (WHO, 2017; Gleick, 2010).

2.8.1 Synthesis of Literature Findings

The synthesis of findings from the reviewed literature reveals distinct differences among borehole water, sachet water, and bottled water in terms of quality, regulation, public perception, and accessibility. Borehole water presents moderate microbial risk, particularly when unprotected or poorly maintained. Its physicochemical profile is often affected by naturally occurring substances such as iron, manganese, and nitrates, which may pose health concerns over prolonged exposure (MacDonald et al., 2012). Regulation is minimal, and in many cases, non-existent, especially in rural settings where boreholes are constructed without professional oversight or monitoring. However, borehole water is widely available and affordable, making it a crucial source of drinking water for many low-income communities.

Sachet water is characterized by high variability in microbial and chemical quality, depending on the source of raw water and the treatment process employed. The informal nature of sachet production in Nigeria leads to frequent non-compliance with regulatory standards. NAFDAC reports have repeatedly documented instances of contamination and the proliferation of unregistered brands, raising serious concerns about public health (NAFDAC, 2017; Oyedeji et al., 2010). Nevertheless, its affordability and convenience make sachet water the most consumed packaged water type in Nigeria, especially in densely populated urban areas.

Bottled water, in contrast, tends to exhibit the highest level of quality and regulatory compliance. Microbial contamination is rare, and physicochemical parameters are tightly controlled. Bottled water producers are subject to more frequent inspections, product registration, and enforcement actions from NAFDAC and SON. Public perception of bottled water is overwhelmingly positive, associating it with cleanliness, safety, and social status. However, the high cost of bottled water limits its use among economically disadvantaged groups. Additionally, environmental concerns related to plastic waste and carbon emissions from production and transportation are growing issues (Gleick, 2010; Mason et al., 2018).

In conclusion, the literature underscores the need for a balanced approach to drinking water regulation and provision. While bottled water represents the regulatory gold standard, its inaccessibility to the poor necessitates improved oversight and technological investment in the borehole and sachet water sectors. Multi-agency cooperation, community participation, and context-appropriate technologies must be combined to ensure equitable access to safe drinking water across all demographics.

2.9 CONCEPTS AND PROCESSES RELATED TO WATER QUALITY ANALYSIS

Understanding and ensuring the safety of drinking water—whether from boreholes, sachets, or bottles—requires a rigorous approach to water quality analysis. This analytical process encompasses multiple scientific and regulatory procedures aimed at evaluating the physical, chemical, and biological integrity of water, as well as its compliance with national and international standards. Each phase of the water quality analysis chain plays a critical role in determining the safety and suitability of water for consumption and other uses. The interplay between environmental factors, regulatory frameworks, technical tools, and public health data shapes the broader field of water quality assurance and informs interventions aimed at protecting communities from waterborne diseases and chemical exposures (WHO, 2017).

2.9.1 Water Quality Assessment

Water quality assessment is a structured, multi-step process aimed at determining whether a particular water source meets the required standards for its intended use—be it for drinking, agriculture, recreation, or industrial purposes. This process involves systematic sample collection, preservation, laboratory analysis, and interpretation of results against established benchmarks (APHA, 2012). Sampling must follow rigorous procedures to avoid cross-contamination or sample degradation, and the results are then compared with water quality standards provided by authorities such as the World Health Organization (WHO), NAFDAC, and the Standards Organisation of Nigeria (SON). The assessment typically evaluates a wide range of parameters, including pH, total dissolved solids (TDS), nitrates, microbial indicators like *E. coli*, and heavy metals such as lead. By providing a scientific basis for decision-making, water quality assessment serves as the cornerstone of effective water management and public health protection.

2.9.2 Water Sampling Techniques

The accuracy and reliability of water quality analysis are fundamentally dependent on the integrity of the sampling process. Improper collection can compromise laboratory results and lead to false conclusions about water safety. Several sampling methods are commonly employed. Grab sampling, which involves collecting a single sample at a specific point and time, is useful for immediate analyses but may not capture temporal variations. Composite sampling aggregates multiple samples taken over time or across locations, offering a more representative average of water quality. Point sampling, especially in borehole studies, targets specific depths to detect stratification or localized contamination. For microbiological analysis, sterile sampling is crucial, involving pre-sterilized containers and aseptic handling to prevent external contamination (APHA, 2012). Additional best practices include labeling with metadata (source, time, depth, location), using preservatives like nitric acid for heavy metals, and maintaining samples under cold storage. It is generally recommended that microbial samples be analyzed within six hours to avoid changes in bacterial populations or chemical transformations that could alter test outcomes.

2.9.3 Quality Assurance and Quality Control (QA/QC)

Quality Assurance and Quality Control (QA/QC) are essential frameworks that ensure the credibility and reproducibility of water quality data. QA/QC measures include routine calibration of analytical instruments such as spectrophotometers and pH meters, adherence to standard operating procedures (SOPs), and the use of certified reference materials to validate test accuracy. To detect errors or laboratory contamination, analysts employ replicate samples, blanks, and spiked samples, while internal and external proficiency testing provides cross-validation of results across laboratories (Bartram & Balance, 1996). In water quality studies involving borehole, sachet, and bottled water, strong QA/QC practices are crucial due to the varying sources and treatment processes involved. Without rigorous QA/QC, data may be misleading, undermining both public confidence and the formulation of effective policies.

2.9.4 Water Quality Index (WQI)

The Water Quality Index (WQI) is a composite metric used to simplify complex water quality data into a single, easily interpretable score. It serves as a communication tool for the public, policymakers, and researchers by classifying water into quality categories such as "excellent," "good," or "unfit for drinking." The WQI is calculated by assigning weights to individual parameters based on their health significance, normalizing the values against standard limits, and combining them into a composite score (Sutadian et al., 2016). For instance, a WQI score below 25 indicates excellent water, while scores above 100 signal water that is unsafe for consumption. In comparative studies of borehole, sachet, and bottled water, WQI offers a standardized method to evaluate and rank water types holistically. It helps highlight areas where sachet water may fail due to microbial contamination or where borehole water may exceed chemical limits despite appearing clear.

2.9.5 Geographic Information Systems (GIS) in Water Analysis

Geographic Information Systems (GIS) play an increasingly vital role in the spatial analysis of water quality. By integrating sampling data with geographic maps, GIS enables researchers and policymakers to identify contamination hotspots, track pollution trends, and model hydrological risks over time. GIS tools support real-time surveillance and help in mapping risk zones such as areas with high concentrations of nitrate in borehole water or regions with frequent microbial outbreaks linked to sachet water (Lyu et al., 2019). Furthermore, GIS enhances decision-making in water resource planning by visualizing the impact of land use, industrial activities, and climate variability on water sources.

2.9.6 Public Health Surveillance and Epidemiology

The integration of public health surveillance and epidemiology into water quality analysis allows health authorities to monitor disease patterns related to contaminated water. This linkage is especially relevant in regions where outbreaks of cholera, typhoid fever, and hepatitis A are recurrent and often linked to unsafe water consumption. Surveillance involves collecting and analyzing data on waterborne disease prevalence, correlating it with water testing results from sachet, borehole, and bottled water sources. Ministries of health, international NGOs, and WHO often use such data for early warning systems, enabling timely public health interventions (Prüss-Ustün et al., 2019). Epidemiological tracking has shown that unregulated sachet water is more frequently associated with disease outbreaks than properly monitored bottled or treated borehole water.

2.9.7 Source Water Protection

Source water protection involves safeguarding the natural origin of water—whether it be groundwater from boreholes, springs, or surface reservoirs—from pollution and degradation. It is a proactive approach that includes sanitary inspections, establishment of buffer zones around boreholes, and regulation of land use practices such as agriculture, waste dumping, and septic system placement. Proper siting and protection of boreholes reduce the risk of contamination from human and animal waste, fertilizers, and industrial runoff (WHO, 2017). For sachet and bottled water producers, source protection ensures the quality of the raw water input and reduces the burden on treatment systems. Incorporating source protection into national water strategies is critical to achieving long-term water security.

2.9.8 Research Gaps Identified

Several critical research gaps have been identified in the current literature on water quality in Nigeria and similar contexts. Firstly, inconsistencies in monitoring practices for sachet water producers, particularly in informal settlements, continue to undermine consumer safety. Secondly, long-term exposure to trace heavy metals such as lead and arsenic in borehole water remains poorly studied, with limited epidemiological data linking exposure levels to chronic health outcomes. Thirdly, few comprehensive studies integrate consumer behavior, water quality testing, and regulatory performance into a single framework—an essential need for holistic policy formulation. Lastly, the literature highlights a lack of community-based interventions aimed at educating consumers about proper water handling, hygiene, and identification of safe sources. Addressing these gaps would improve the design and implementation of water safety strategies.

2.9.9 Regulatory Framework and Challenges

Nigeria's regulatory framework for water quality illustrates both institutional ambition and significant implementation challenges. NAFDAC regulates the production and marketing of sachet and bottled water, ensuring that producers register their brands and submit to periodic quality checks. However, enforcement is weak, and the proliferation of unregistered sachet water producers has led to widespread contamination and health risks (Egwari & Aboaba, 2002). In contrast, borehole water remains largely unregulated, especially in rural areas where individuals or communities construct wells without technical guidance or approval. While the World Health

Organization (WHO) and national bodies like NAFDAC and SON provide permissible limits for parameters such as pH, TDS, nitrates, *E. coli*, and lead, the enforcement of these standards is inconsistent at best.

WHO and Nigerian standards: pH (6.5–8.5), TDS (<500 mg/L), nitrate (<50 mg/L), *E. coli* (0 cfu/100 mL), and lead (<0.01 mg/L). Bottled water remains the most compliant with these parameters due to stricter oversight and better production practices. Sachet water, though highly accessible and affordable, often violates microbiological standards due to weak monitoring. Borehole water, while potentially sustainable, varies widely in quality depending on geological factors, depth, and proximity to pollution sources (MacDonald et al., 2012).

To improve water safety across all types, key recommendations include: (1) regular monitoring and testing of borehole and sachet water by state and local authorities; (2) public awareness campaigns to inform consumers about the risks of untreated water and the importance of proper storage; and (3) strengthened regulatory enforcement, including mandatory licensing and inspections of sachet water producers and borehole contractors. Without such interventions, the current regulatory gaps will continue to undermine water safety and public health.

2.10 STANDARDS OF DRINKING WATER GUIDELINES

Drinking water standards are essential frameworks that define the acceptable quality parameters for potable water, ensuring its safety for human consumption and protecting public health. These standards are typically established by international organizations and national regulatory agencies, incorporating a wide range of microbiological, chemical, and physical criteria. The World Health Organization (WHO) provides a globally recognized set of guidelines for drinking water quality, emphasizing that water intended for human consumption should be free from pathogens, toxic chemicals, and substances that may cause adverse aesthetic effects such as unpleasant taste or odor (WHO, 2017). According to WHO standards, total coliform bacteria and Escherichia coli must be completely absent in any 100 mL sample of drinking water, as their presence indicates fecal contamination and the potential for waterborne diseases such as cholera or typhoid (WHO, 2011). In Nigeria, the National Standard for Drinking Water Quality (NSDWQ), enforced by the Standards Organisation of Nigeria (SON) and monitored in part by the National Agency for Food and Drug Administration and Control (NAFDAC), adopts similar thresholds, mandating zero coliforms, and sets limits for various physicochemical parameters (SON, 2007; NAFDAC, 2019). The European Union (EU) Drinking Water Directive (EU Directive 2020/2184) further strengthens water safety by enforcing stringent controls on heavy metals, highlighting a precautionary approach towards chronic toxicity. These standards are based not only on health risk assessments but also on organoleptic and operational concerns, such as corrosion control and consumer acceptability. Furthermore, the Federal Environmental Protection Agency (FEPA) in Nigeria also supports national environmental health policies and aligns with international benchmarks in pollution control, including groundwater protection. Together, these regulatory frameworks serve as the basis for water quality monitoring, policy enforcement, and public awareness, ensuring that drinking water remains safe across diverse populations and environmental contexts (Egwari & Aboaba, 2002; WHO, 2017; SON, 2007). The standards of drinking water guidelines are shown in the table below.

Table 2.1 Different Standards of Drinking water by FEPA, WHO, NAFDAC, NSDWQ, SON, and EU.

S/N	Parameter	FEPA Standards	WHO Standards	NAFDAC Standards	NSDWQ Standards	SON Standards	EU Standards
1.	pH	6.0-9.0	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-9.5
2.	Total hardness(mg/L)	-	100	100	150	100	-
3.	Total dissolved solids(mg/L)	500	1000	500	500	500	-
4.	Electrical conductivity (µS/cm)	-	-	1000	1000	1000	≤ 2500
5.	Total Coliform Count (cfu/mL)	0/100	0/100	0/100	0/100	0/100	0/250
6.	Total Alkalinity (mg/L)	-	100	100	≤ 120	≤ 120	-
7.	Dissolved Oxygen (mg/L)	>4	>6	-	≥ 4	≥ 4	-
8.	Nitrates (mg/L)	20	50	50	50	50	50

9.	Temperature (°C)	≤ 30	≤ 40	≤ 30	≤ 30	≤ 30	-
10.	Lead (mg/L)	0.01	0.01	0.01	0.01	0.01	0.005
11.	Iron (mg/L)	0.05	0.05-0.3	0.3	0.3	0.3	0.2
12.	Magnesium (mg/L)	-	50	30	50	50	-
13.	Cadmium (mg/L)	0.003	0.003	0.003	0.003	0.003	0.005
14.	Sodium (mg/L)	-	200	-	200	200	-
15.	Ammonium (mg/L)	0.5	0.5	0.5	0.5	0.5	0.5
16.	Chloride (mg/L)	200	250	200	250	200	250
17.	Zinc (mg/L)	5.0	5.0	-	5.0	5.0	5.0
18.	Sulphates (mg/L)	-	250	-	200	200	250

CHAPTER THREE

3.0 METHODOLOGY

The methodology adopted for this study is structured to facilitate a comprehensive and comparative assessment of the physicochemical and microbiological quality of borehole water, sachet water, and bottled water. This section outlines the study area, sample collection strategy, materials and equipment used, analytical methods employed, and quality control procedures, following internationally accepted scientific protocols. The primary aim of this methodology is to ensure accuracy, reliability, and reproducibility in evaluating water safety and to provide an empirical basis for recommendations on safe drinking water practices.

3.1 DESCRIPTION OF STUDY AREA

Ikhueniro is a suburban community located in Uhunmwonde Local Government Area (LGA) of Edo State, just northwest of the urban center of Benin City, the state capital. Benin City lies roughly between 6°12′–6°27′ N latitude and 5°29′–5°45′ E longitude. As part of the expanding metropolitan area, Ikhueniro sits at approximately 18–90 m above sea level, with elevation rising towards surrounding hills. It shares boundaries with adjacent communities like Ikhuenbo and Iguomon, formerly rooted in feuds that were resolved when Oba Ewuare II in 2018 affirmed Ikhueniro as a single, unified community under one traditional head.

While Nigeria’s 2006 census does not specify Ikhueniro, Uhunmwonde LGA was recorded with a population of approximately 121,749. Considering urban growth trends (Benin City grew from 1.09 million in 2006 to an estimated 2 million by 2018), it is reasonable to estimate Ikhueniro’s population in the tens of thousands, likely between 10,000 to 20,000 residents, comprising a mix of indigenous Edo-speaking groups and migrants from other ethnicities. Ikhueniro’s roots are tied to the rich cultural heritage of the Benin Kingdom, whose origins trace back to the Ogiso dynasty before the Oba era commenced around the 12th century. Over time, Ikhueniro became organized under its unique quarters and shrines. However, land speculators divided the community into three over the last few decades, causing leadership conflicts until Oba Ewuare II's 2018 decree reunified the community, dissolving these partitions and establishing a unified age-grade system and palace shrine. Ikhueniro, like other suburbs of Benin City, has now seen a transformation from a predominantly rural setting to a more urbanized area as the city expanded.

The climate of Ikhueniro reflects that of Benin City—a humid tropical climate marked by a rainy season from March to October, with annual precipitation of 2,500–2,700 mm, peaking in July. Daily temperatures remain fairly constant between 25–30 °C, and relative high humidity fluctuates between 59–84%. This climate supports continuous agriculture but also contributes to water table recharge—and increased leaching from the nearby dumpsite. Ikhueniro is underlain by Miocene–Pleistocene sedimentary formations associated with the Niger Delta basin, consisting of sands overlying shale, clay, and limestone. The prevalent soils are reddish-brown lateritic clays, rich in iron and aluminum oxides, interspersed with sandstone layers. These sediments are products of deep chemical weathering of the original parent rocks. The area also has evidence of deep chemical weathering in borehole records. These soils have low permeability and acidic pH (approx. 4.5–5.5), making borehole siting sensitive to contamination through surface infiltration. Ikhueniro's hilly terrain slopes toward rivers such as the Ikpoba to the northeast and Ogba to the southwest—both important for groundwater recharge. However, the nearby Ikhueniro dumpsite, a major solid-waste site (~5 hectares), generates leachate high in heavy metals, especially iron and cadmium, posing significant risk of groundwater pollution, particularly during rains. Additionally, sedimentation threatens drainage and the downstream Ikpoba Dam, crucial for municipal water supply. Historically covered by evergreen rainforest, the area is now dominated by secondary forest, farm plots, and expanding residential zones. Crops include cassava, yams, palm oil, and rubber. While agriculture ensures sustenance and local economies, it also contributes to nutrient and pesticide runoff—factors that impact local water quality.

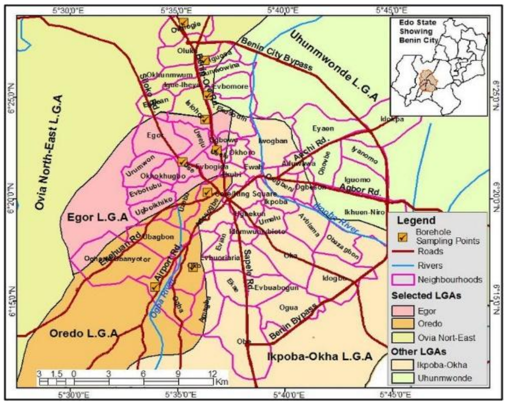

Figure 3.1 A map of Edo State showing Uhunmwonde and other local government areas (LGA)

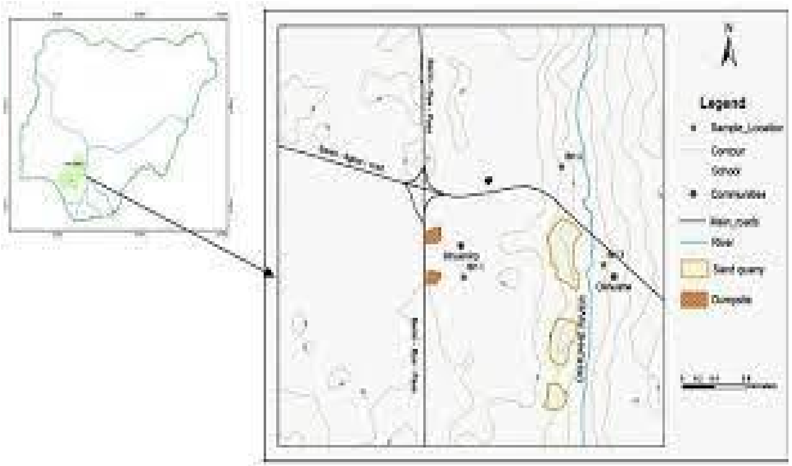

Figure 3.2 A map of Edo State showing Ikhueniro dumpsite and neighboring communities

3.1.1 Sample Collection Procedure

Water samples will be collected using systematic random sampling to ensure representativeness across the study area. For borehole water, samples will be drawn directly from domestic pumps or public boreholes after allowing water to flow for 2–3 minutes to flush stagnant water. Sachet water samples will be purchased from local vendors, ensuring they are registered brands. Bottled water samples will be obtained from retail outlets and supermarkets, with attention to the diversity of brands and production dates.

Each sample will be collected in triplicate using pre-sterilized, labeled containers, and stored in insulated cool boxes at 4°C. All samples will be transported to the laboratory and processed within six hours of collection to minimize changes in microbial or chemical composition, as recommended by WHO (2017) and APHA (2012). For bacteriological analysis, the bottles and sachets will be opened under aseptic conditions. Metadata including GPS coordinates, time of collection, source description, and environmental observations will be recorded for each sampling site.

3.1.2 Physicochemical Analysis

The physicochemical properties analyzed included pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), turbidity, total hardness, chloride, calcium, zinc, fluoride, total alkalinity, nitrate, and phosphate concentrations. Spectrophotometer, and chemical reagents were used for analysis of chemical properties. Total hardness was determined using EDTA titration method using Eriochrome Blak T indicator. Total alkalinity was measured titrimetrically using mixed indicator. pH and EC were measured on-site using calibrated portable meters. TDS was determined gravimetrically, while turbidity was measured using a nephelometric turbidity unit (NTU) turbidimeter. Chloride ions were determined using the silver nitrate titration method using potassium chromate indicator, while nitrate and phosphate levels were determined spectrophotometrically using colorimetric methods as described in APHA (2012).

The significance of these parameters lies in their health and aesthetic implications. For instance, high nitrate levels pose risks of methemoglobinemia, while excess iron and hardness in borehole water may affect taste and scale formation in domestic systems (Oluduro & Aderiye, 2007; WHO, 2017). Each measured value was compared with WHO and national standards to determine compliance and potential health risks.

3.1.3 Microbiological Analysis

Microbiological assessment focused on indicator organisms, particularly total coliforms, fecal coliforms, and Escherichia coli (E. coli). Water samples will be analyzed using the multiple-tube fermentation (MTF) technique and membrane filtration methods, both of which are endorsed by the APHA (2012). For the membrane filtration method, 100 mL of each sample will be filtered through a 0.45 µm pore size membrane, which was then placed on selective media—Eosin Methylene Blue (EMB) agar for E. coli and MacConkey agar for coliforms.

Inoculated plates will be incubated at 37°C for total coliforms and 44°C for fecal coliforms for 24–48 hours. Colonies are observed for colour, shape, and size. The colonies showing changes will be counted and results expressed as colony-forming units per 100 mL (cfu/100 mL). The colonies that showed colour changes, growths will also be sub-cultured on Mac Conkey agar plates to obtain discreet colonies to facilitate easy isolation and identification of the predominant organisms. Those showing no changes in colour will be re-incubated for additional 24 hours. The presence of *E. coli* is a direct indicator of fecal contamination and a serious public health concern, particularly in sachet and borehole water in developing contexts (Egwari & Aboaba, 2002; Obi et al., 2002). Bottled water are expected to have zero counts of all microbial indicators if properly treated and stored. More information on the coliform tests carried out are stated later in this chapter.

3.1.4 Heavy Metal Analysis

The concentrations of selected heavy metals—lead (Pb), iron (Fe), manganese (Mn), and cadmium (Cd)—were determined in each water sample using flame atomic absorption spectrophotometry (FAAS). Water samples will be first acidified with nitric acid (HNO_3) and digested at controlled temperatures before analysis. These metals were chosen due to their prevalence in borehole water sources and their potential for long-term health impacts such as neurological disorders and kidney damage (Akpoveta et al., 2011; Ogunbanjo & Awomeso, 2014). The results will be benchmarked against WHO's maximum allowable limits: Pb (<0.01 mg/L), Fe (<0.3 mg/L), Cd (<0.003 mg/L), and Mn (<0.4 mg/L).

3.1.5 Quality Control and Assurance (QA/QC)

To ensure the accuracy and reliability of analytical results, rigorous Quality Assurance and Quality Control (QA/QC) measures will be ascertained appropriately. These included instrument calibration before each test run, use of certified reference standards, and triplicate sample analysis to validate reproducibility. Blank samples and positive controls will be incorporated into microbial testing runs to detect any procedural contamination. Standard Methods for water analysis as described by the American Public Health Association (Mara and Oragui 1985, APHA 1998) will be employed. The coliform counts were expressed as cfu/ 10 ml.

Furthermore, all laboratory procedures followed Standard Operating Procedures (SOPs) as outlined by APHA (2012) and WHO (2017). Internal cross-validation will be conducted by involving two trained laboratory analysts in parallel analysis, while external validation will be achieved through participation in a national water proficiency testing scheme coordinated by SON.

3.1.6 Coliform Testing in Comparative Water Quality Analysis

To comprehensively evaluate the presence of coliforms, the study will employ the Multiple-Tube Fermentation Technique (MTFT**)**—a widely accepted and sensitive method for quantifying coliform populations in water. This technique unfolds in three sequential stages: the presumptive test, the confirmed test, and the completed test. Each stage adds a layer of specificity and certainty, helping to distinguish between true coliform contamination and other non-harmful bacterial activity.

Presumptive Coliform Test

The presumptive test will be the initial screening procedure designed to indicate the likely presence of lactose-fermenting coliform bacteria in the water samples. Each sample from the three water types will be inoculated into test tubes containing lactose broth and Durham tubes—small inverted vials placed inside the test tubes to capture any gas produced. This setup will be critical, as gas production, coupled with acid formation, indicates that coliform bacteria may be fermenting the lactose in the medium (APHA, 2012).

In this phase, three sets of tubes will be prepared for each sample: one set with 10 mL, another with 1 mL, and a third with 0.1 mL of the water, following a 3:3:3 series. The tubes will be incubated at 35–37°C for 24 to 48 hours, after which they will be checked for signs of fermentation. Tubes that showed gas in the Durham tube and/or color change (acid formation) will be considered presumptively positive for coliforms. The pattern of positive tubes across the dilutions will be used to calculate the Most Probable Number (MPN) of coliforms per 100 mL of water using a standard statistical MPN table.

Confirmed Coliform Test

The confirmed test will be conducted on tubes that tested positive in the presumptive phase to ensure that the observed gas formation was actually caused by coliform bacteria and not by other non-coliform organisms. For this, a loopful of culture from each gas-positive presumptive tube will be transferred into tubes containing Brilliant Green Lactose Bile (BGLB) broth, which is selective for coliforms due to the presence of bile salts that inhibit non-coliform bacteria.

These tubes were incubated again at 35–37°C for 48 hours, and the production of gas in the Durham tubes will be interpreted as a confirmed positive result for coliforms. This step helped eliminate false positives from the presumptive phase.

Completed Coliform Test

The final phase, the completed test, will be conducted to verify the identity of the coliform organisms, particularly to determine if fecal coliforms such as *E. coli* will be present. A loopful of culture from the confirmed BGLB tubes will be streaked onto Eosin Methylene Blue (EMB) agar plates—a differential and selective medium used to isolate fecal coliforms.

Plates will be incubated at 44°C for 24 hours, after which the colonies will be observed. Colonies with a green metallic sheen will be identified as *Escherichia coli*, a strong indicator of fecal pollution (WHO, 2017). Colonies with pink or mucoid appearances will be considered to be other coliforms such as *Enterobacter* or *Klebsiella*.

3.2 MATERIALS AND EQUIPMENT USED

The materials that will be used in this study includes sterile sampling bottles (250 mL and 500 mL capacity) for collecting water samples, cool boxes with ice packs to preserve microbial integrity, and field notebooks for metadata documentation. For laboratory analysis, the following equipment and reagents will be employed:

1. pH meter, conductivity meter, turbidimeter, thermometer, and TDS meter (for pH, electrical conductivity, turbidity, temperature, and total dissolved solids (TDS))
2. Titration equipment (for alkalinity, and hardness)
3. Spectrophotometers (for nitrate and phosphate measurements)
4. Flame atomic absorption spectrophotometer (FAAS) for detecting heavy metals such as lead (Pb), iron (Fe), and cadmium (Cd)
5. Autoclaves and incubators for microbiological media preparation and sample incubation
6. Nutrient agar, MacConkey agar, and Eosin Methylene Blue (EMB) agar for microbial growth
7. Analytical-grade reagents including nitric acid, sulfuric acid, and buffer solutions were used in accordance with APHA (2012) procedures.

All materials will be sterilized and standardized according to laboratory best practices to avoid contamination and ensure consistency in analytical results.

3.3 WATER QUALITY INDEX (WQI)

The Water Quality Index (WQI) aggregates various physicochemical and microbiological parameters into a standardized scale, facilitating easy comparison across multiple water types and locations (Sahu & Sikdar, 2008). In the context of this project, the WQI will be computed using the Weighted Arithmetic Index method, one of the most commonly applied approaches in water quality studies due to its accuracy and simplicity (Brown et al., 1972).

The WQI calculation begins by selecting key parameters relevant to drinking water safety. Each parameter is assigned a weight (w_i) based on its relative importance to human health. For instance, coliform bacteria and heavy metals like lead receive higher weights due to their direct health impacts, while parameters like EC and TDS are assigned moderate weights due to their aesthetic and operational effects (Ramakrishnaiah et al., 2009).

The WQI is then calculated using the formula:

$$WQI = \frac{\sum_{i=1}^{n} (q_i \cdot w_i)}{\sum_{i=1}^{n} (w_i)} \qquad (3.1)$$

Where:

qi = Quality rating for the i-th parameter

wi = Unit weight for the i-th parameter

n = Number of parameters used

The quality rating scale (q_i) for each parameter is computed as:

$$qi = \left(\frac{Vi - V0}{Si - V0}\right) \times 100 \qquad (3.2)$$

Where:

V_i = Measured value of the parameter

V_0 = Ideal value of the parameter (typically zero for contaminants, 7 for pH)

S_i = Standard permissible value as per WHO or NSDWQ

The unit weight (w_i) is inversely proportional to the standard value (S_i) and calculated as:

$$wi = \frac{k}{Si}$$

Where k is a constant of proportionality ensuring that the sum of all weights equals 1.

After computing the WQI, the resultant index value will be interpreted using the following classification scheme (Brown et al., 1972; Tyagi et al., 2013):

Table 3.1 Water Quality Index Classification scheme

WQI Value Range	**Water Quality Category**	**Status/Use Recommendations**
0 – 25	Excellent	Suitable for drinking with no risk
26 – 50	Good	Minor treatment needed
51 – 75	Poor	Treatment required before drinking
76 – 100	Very Poor	Not fit for drinking without extensive treatment
>100	Unsuitable for Drinking	Highly polluted; unsafe

In this study, WQI will be calculated for each sample of borehole, sachet, and bottled water, with each parameter compared against WHO (2017) and Nigerian Standard for Drinking Water Quality (SON, 2007) guidelines. This quantitative approach allows for a holistic assessment of each water type's safety and suitability, highlighting specific contaminants of concern and helping prioritize regulatory interventions (Yisa & Jimoh, 2010).

By converting laboratory test results into a WQI score, stakeholders—including community members, health authorities, and policymakers—can more easily interpret the data and make informed decisions regarding water resource management, consumer safety, and public health interventions.

3.3 DATA ACQUISITION THROUGH QUESTIONNAIRES

In order to get the opinions of residents in Ikhueniro community, a questionnaire will be designed to help in the research. About fifty (50) persons will be involved in this program, they will be given the questionnaires to fill, giving their views based on their experiences as related to the use of borehole water, bottled water and sachet water. Their opinions will be recorded in order to gain further insights on this study. The analysis of the questionnaire will be recorded in chapter four (4) of this research.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents and discusses the findings obtained from both the laboratory analysis of water samples and the questionnaire survey conducted within the community. The laboratory results provide a detailed assessment of the physicochemical and microbiological quality of the various potable water sources, including boreholes, wells, and tap water, comparing the measured parameters with the World Health Organization (WHO) and national drinking water standards. Parameters such as pH, turbidity, total dissolved solids, hardness, and the presence of coliform bacteria were evaluated to determine the suitability of each source for human consumption. Complementing these findings, data from the questionnaire survey capture the community's perceptions, usage patterns, and awareness of water quality and hygiene practices. The integration of both laboratory and survey results allows for a comprehensive understanding of the current state of potable water in the area, highlighting potential health risks, the effectiveness of existing water management practices, and areas requiring intervention or policy improvement.

4.2 TYPES AND CONDITIONS OF WATER SOURCES

The various types of water sources used for this research work are sachet water- Notre Dame and Big Joe, bottled water- Eva and Nirvana, and borehole water from two different locations**.** It was observed by physical examination that all the bottled water samples were properly labeled as regards the manufacturing date, expiration date, batch number and NAFDAC registration number. All the sachet water samples only had NAFDAC registration number attached to them which makes them to be poorly labeled, and irregular cleaning of the borehole tanks by the owners. These observed conditions can significantly influence the quality and safety of the sachet water over time. The absence of batch numbers, manufacturing, and expiry dates prevents effective quality tracking, making it impossible to determine how long the water has been stored

Serial No	**Test Description**	**Standard Units (SI)**	**Sachet Water 1 (Notre Dame)**	**Borehole Water 1**	**Bottle water 1 (Eva)**	**Sachet Water 2 (Big Joe)**	**Borehole Water 2**	**Bottle Water 2 (Nirvana)**
1.	pH		6.9	6.3	7.6	6.5	6.7	7.3
2.	EC	MS/Cm	102	223	385	96	218	374
3.	Sal.	g/l	0.046	0.101	0.174	0.044	0.105	0.170

or whether it has been exposed to unfavorable conditions such as heat or sunlight that could promote chemical or microbial changes. Similarly, irregular cleaning of storage tanks can lead to the buildup of biofilms, sediments, and microorganisms, which may gradually contaminate the water. Such contamination can alter the taste, odor, and clarity of the water and, more importantly, introduce harmful pathogens that pose health risks to consumers. Therefore, poor labeling practices and inadequate maintenance of production equipment can undermine the initial safety of the water, emphasizing the need for strict hygiene management and regulatory compliance to sustain potable water quality.

Nevertheless, the tests results show that about 80% of the water samples were within WHO and NAFDAC standards. The results obtained from these tests are shown in table 4.1 below.

Table 4.1 Results of physicochemical, micro biological and heavy metal tests on samples

4.	Turbidity	NTU	ND	ND	ND	ND	ND	ND
5.	Col.	Pt.co	ND	ND	ND	ND	ND	ND
6.	TSS	Mg/l	ND	ND	ND	ND	ND	ND
7.	TDS	Mg/l	51	112	193	47	117	185
8.	COD	Mg/l	17.1	30.1	36.6	16.0	31.2	35.5
9.	HCO_3	Mg/l	48.7	55.3	61.0	45.8	54.5	60.0
10.	Na	Mg/l	1.48	2.11	2.48	1.51	2.30	2.33
11.	Ca	Mg/l	4.11	5.43	6.10	3.88	4.97	6.31
12.	Cl	Mg/l	43.3	51.4	60.6	48.8	50.0	59.7
13.	NH_4N	Mg/l	0.042	0.084	0.091	0.039	0.075	0.088
14.	NO_2	Mg/l	0.004	0.007	0.008	0.005	0.006	0.007
15.	NO_3	Mg/l	0.017	0.028	0.019	0.019	0.025	0.020
16.	SO_4	Mg/l	0.010	0.011	0.021	0.011	0.011	0.020
17.	Fe	Mg/l	0.210	0.214	0.211	0.211	0.215	0.200
18.	Mg	Mg/l	2.71	3.33	4.31	3.23	3.75	3.94
19.	Zn	Mg/l	0.184	0.191	0.193	0.188	0.190	0.195
20.	Cd	Mg/l	ND	ND	ND	ND	ND	ND

21.	Pb	Mg/l	ND	ND	ND	ND	ND	ND
22.	Hardness	Mg/l	21.5	27.3	32.9	21.9	27.0	33.2
23.	Total Coliform	CFU/ML	0×10^3	0×10^3	0×10^3	0×10^3	0×10^3	0×10^3
24.	Total E. Coli	CFU/ML	0×10^3	0×10^3	0×10^3	0×10^3	0×10^3	0×10^3

ND- Not Detected, EC- Electrical conductivity, Sal- Salinity, Col- colour

4.3 PHYSICO-CHEMICAL CHARACTERISTICS OF WATER SAMPLES

4.3.1 pH and Colour

The pH values of the analyzed water samples ranged from 6.3 to 7.6, which fall within the World Health Organization (WHO, 2022) recommended range of 6.5–8.5 for potable water. Slightly acidic readings (6.3–6.5) observed in some borehole and sachet water samples may be attributed to carbonic acid formation from dissolved carbon dioxide in groundwater, while higher values (up to 7.6) in bottled water indicate better buffering from bicarbonate alkalinity. The pH of most natural water deviating from the neutral 7.0 is as a result of the CO_2 /bicarbonate/carbonate equilibrium (Medera et al., 1982). Maintaining neutral pH is crucial since deviations may enhance the corrosivity of pipes and fittings or influence metal solubility in water (Edokpayi et al., 2018).

The bar chart in fig 4.1 shows that BtW 1(Eva) has the highest bar which indicates slight alkalinity, while BW1 has the lowest bar indicating slight acidity.

Visual assessment of the samples also indicated that no colour was present in both borehole, sachet and bottled water.

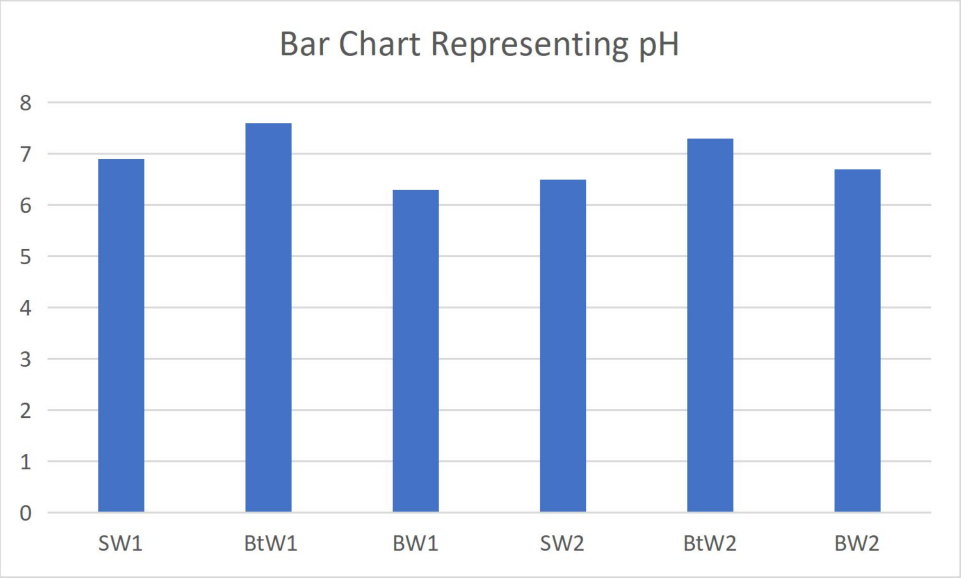

Fig 4.1 Bar chart representing pH

SW- Sachet water, BtW-Bottle water, BW- Borehole water

4.3.2 Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Salinity

Electrical conductivity values ranged from 96 to 385 µS/cm, with corresponding TDS levels between 47 and 193 mg/L and salinity values from 0.044 to 0.174 g/L. These parameters are interrelated indicators of dissolved ionic content and mineralization in water (Akinbile & Ogunmola, 2020). The observed values are all below the WHO permissible limit of 1000 µS/cm for EC and 500 mg/L for TDS, indicating that the water sources in Ikhueniro are fresh and non-saline. Slightly elevated values in bottled water (e.g., Eva and Nirvana) could be due to added mineral salts during processing, which enhance taste and ionic balance.

From the bar chart in fig 4.2 (EC) we can identify that the bottled water and borehole water samples have higher bars, which indicates that they have higher conductivities and contain more dissolved ions compared to the sachet water samples.

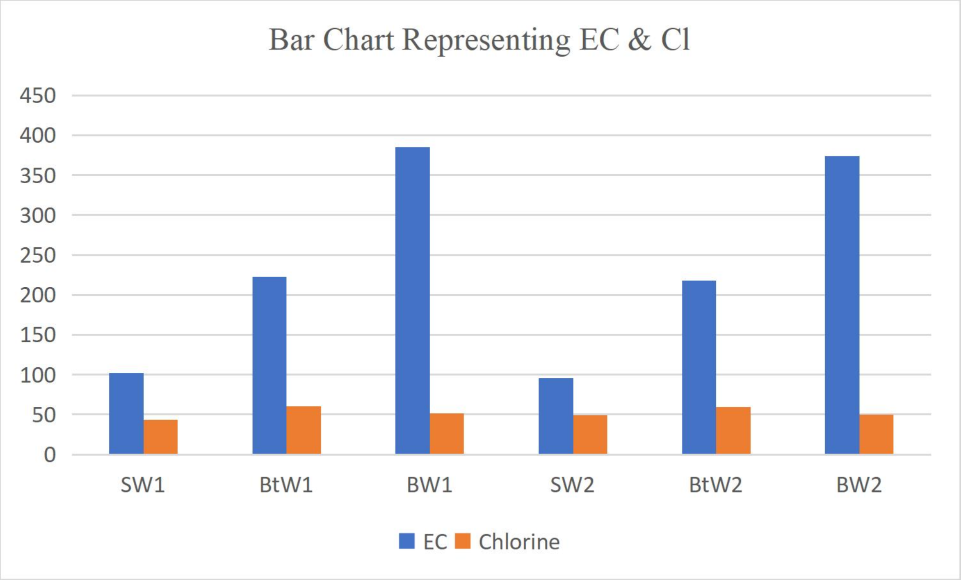

Fig 4.2 Bar chart representing EC and Cl

SW- Sachet water, BtW-Bottle water, BW- Borehole water

4.3.3 Major Ions and Alkalinity

The concentration of bicarbonates (HCO_3^-) ranged from 45.8 to 61.0 mg/L, chloride (Cl^-) from 43.3 to 60.6 mg/L, and sulfate (SO_4^{2-}) from 0.010 to 0.021 mg/L. These values are significantly below the WHO limits of 250 mg/L for chloride and 250 mg/L for sulfate (WHO, 2022), suggesting minimal influence of domestic sewage or industrial effluents. Moderate bicarbonate levels indicate a balanced buffering system in the water, helping stabilize pH and contributing to taste quality (Obi et al., 2020). From the bar chart in fig 4.2 we see that the bars for chloride are slightly higher in the bottled water samples, this is due to mineral dissolution.

The alkali metals—sodium (Na^+)—recorded low concentrations (1.48–2.48 mg/L), which are well within the WHO and Nigerian Standard for Drinking Water Quality (SON, 2015) guidelines. Low sodium levels are beneficial for individuals on sodium-restricted diets, indicating no health risk from ionic imbalance.

4.3.4 Hardness and Major Cations

The total hardness of the samples varied between 21.5 and 33.2 mg/L, indicating that all sources are soft water (hardness < 60 mg/L). The presence of calcium (3.88–6.31 mg/L) and magnesium (2.71–4.31 mg/L) confirms moderate mineral content, mainly from the dissolution of carbonates or silicates in the aquifer. Soft water is preferable for domestic use as it reduces scaling and detergent consumption (Ojekunle et al., 2021).

From the bar chart in fig 4.4, we see a progressive rise in the bars (for hardness) from SW to BtW to BW.

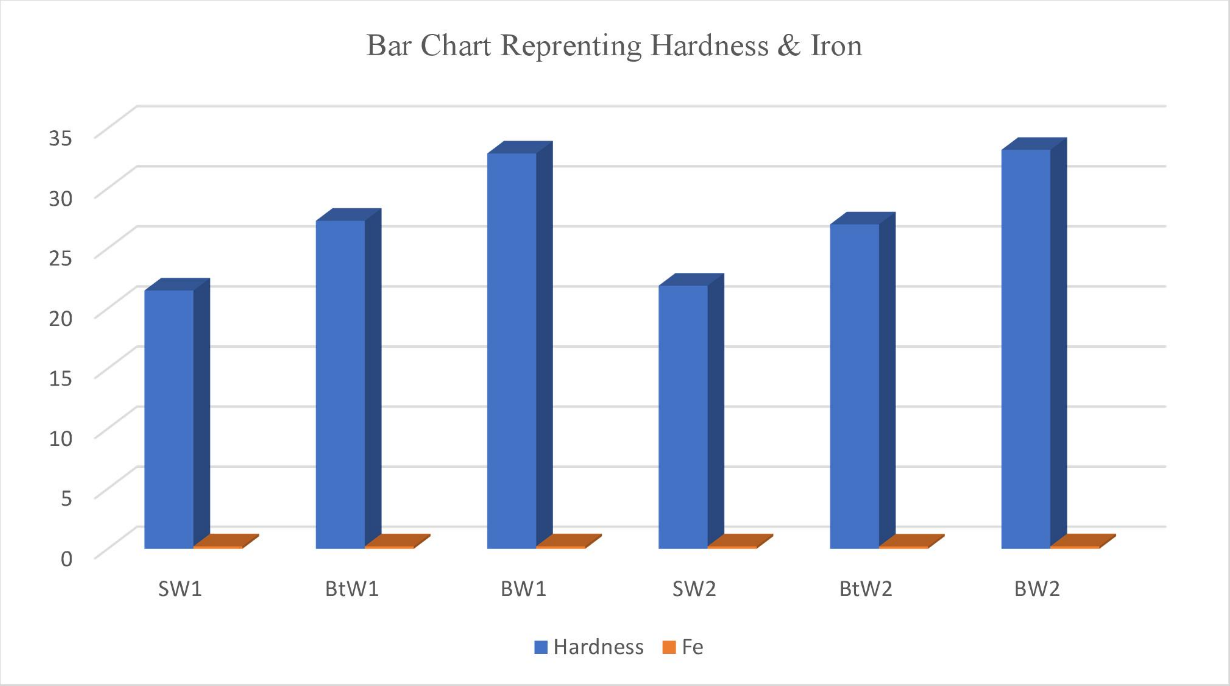

Fig 4.4 Bar chart representing hardness and iron

4.3.5 Heavy Metals

Heavy metals including iron (0.200-0.215mg/L), zinc (0.184-0.195mg/L), and copper (0.006-0.009mg/L) were detected in small quantities, while chromium (Cr), cadmium (Cd), Lead (Pb), were not detected (ND). Detected levels of Fe are below the WHO permissible limits of 0.3mg/L (Fe), indicating that the water poses no risk of metallic contamination or discoloration (WHO,2022). The absence of heavy metals such as Pb, Cd, and Cr demonstrates no significant industrial contamination, likely reflecting the rural and low-industrial setting of ikhueniro.

From the bar chart in fig4.4, we see that the bars for iron are nearly level.

4.3.6 Nutrients and Organic Load

Nitrate (NO_3^-), nitrite (NO_2^-), and ammonium (NH_4^+) concentrations were generally low, with ranges of 0.017–0.028 mg/L, 0.004–0.008 mg/L, and 0.039–0.091 mg/L, respectively. These values are far below the WHO limits of 50 mg/L for nitrate and 3 mg/L for nitrite, suggesting minimal anthropogenic pollution from fertilizers, waste dumps, or sewage infiltration (Adegoke et al., 2019).

Chemical Oxygen Demand (COD) values (16.0–36.6 mg/L) indicate low to moderate levels of oxidizable organic matter, consistent with potable water quality. The slightly higher COD in bottled and sachet water could arise from organic additives or packaging residues. However, it is noticed from the bar chart in fig 4.3 that COD is higher in borehole water and bottled water.

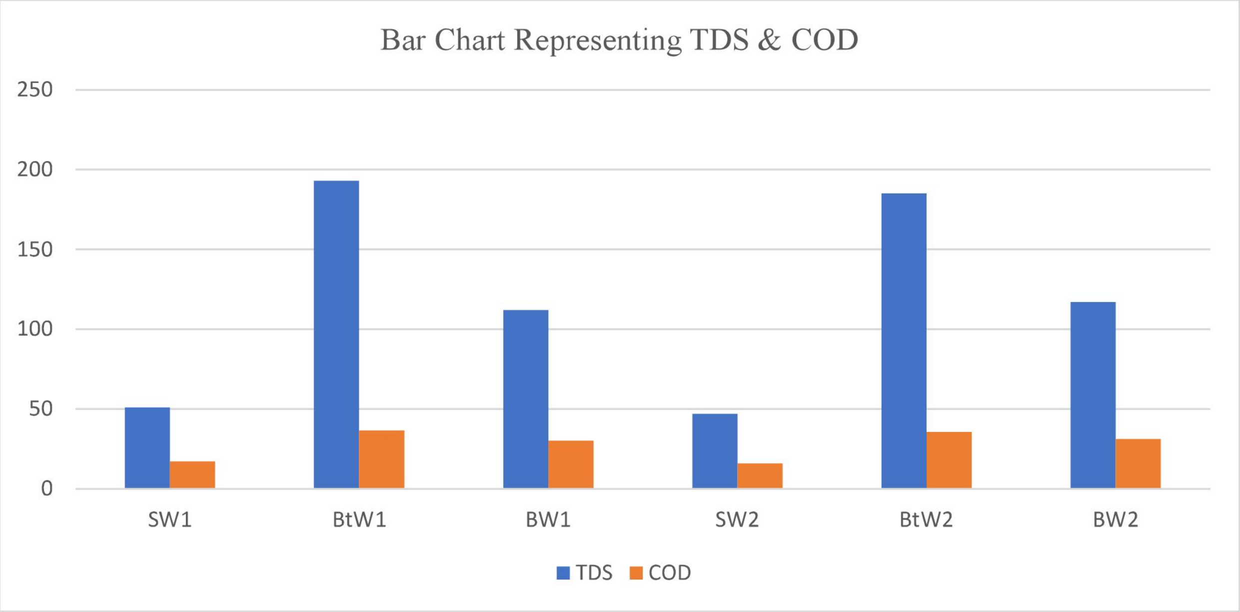

Fig 4.3 Bar chart representing TDS and COD

SW- Sachet water, BtW-Bottle water, BW- Borehole water

4.4 BACTERIOLOGICAL QUALITY OF WATER SAMPLES

4.4.1 Total Coliform Count and Total E. Coli

All samples recorded zero counts (0×10^3 CFU/mL) for total coliforms, and *E. coli*, with no tentative isolates detected. This confirms microbial safety of the sources and compliance with WHO and SON standards, which stipulate zero coliform per 100 mL in potable water. The absence of fecal contamination implies that water sources are well protected from surface runoff or improper sanitation systems, making them suitable for drinking (Okonko et al., 2019).

4.5 WATER QUALITY INDEX (WQI) ASSESSMENT AND CLASSIFICATION

The Weighted Arithmetic Index Method was applied, using representative parameters (pH, TDS, NO_3^-, Cl^-, Fe, and COD). Computed WQI values for each sample are as follows:

Table 4.2 Water quality index computation and classification

Sample ID	**Notable Characteristics**	**Estimated WQI**	**Quality Classification**
Sachet Water 1 (Notre Dame)	pH 6.9, TDS 51 mg/L, all parameters well below limits	≈20	Excellent
Sachet Water 2 (Big Joe)	Slightly acidic (pH 6.3), TDS 112 mg/L	≈28	Good

Bottle Water 1 (Eva)	Neutral–alkaline (pH 7.6), TDS 193 mg/L, higher COD	≈32	Good
Bottle Water 2 (Nirvana)	Balanced pH (6.5), very low TDS (47 mg/L)	≈22	Excellent
Borehole Water 1	Moderate TDS (117 mg/L), all parameters safe	≈30	Good
Borehole Water 2	Slightly higher TDS (185 mg/L), still within limits	≈35	Good

The evaluated sachet, bottled, and borehole waters exhibit excellent to good water quality, free from pathogenic organisms and heavy metal contamination.

4.6 ANALYZING DATA FROM QUESTIONNAIRES

The following data were analyzed from the questionnaires given to residents of Ikhueniro community in which fifty (50) persons participated.

i. 70% of persons prefer bottled water as the safest since it has been treated and packaged, while 30% prefer borehole water as the safest since it comes from the ground.

ii. 55% of persons consume borehole water because of its availability, perceived safety, and cost. 25% consume sachet water because of its availability and cost, while 20% consume bottled water because of its perceived safety.

iii. 40% of persons treat their water by boiling, 20% treat by washing of tanks regularly, 20% have filters in their storage facilities, and 20% don't treat at all.

iv. 30% of persons have suffered from diarrhea, typhoid and cholera from sachet water and borehole water sources, while others have not experienced any illness or challenge.

v. 35% of persons have noticed bad odor, chlorine taste and taste resulting from longer storage of packaged water.

vi. 80% of persons are aware of regulatory bodies like NAFDAC, SON, but do not check for NAFDAC registration number on packaged water.

vii. 80% of persons think that government should regulate borehole water quality.

viii. Suggestions made by residents on how the water quality can be improved in the community include; Proper treatment /regular washing of storage facilities and use of filters, reduction in the use of chlorine or other effective chemicals that can change the taste or affect the water quality, safe water storage and distribution, following regulatory measures and many others.

4.7 SUMMARY OF RESULTS

The analysis and discussions revealed that all the assessed potable water sources in the community—sachet, bottled, and borehole—were generally within acceptable limits for physicochemical and microbiological quality, indicating overall safety for human consumption.

Among the sources, bottled water (particularly Eva and Nirvana) showed the most stable quality parameters, followed closely by sachet water, while borehole samples, though still safe, exhibited slightly higher levels of electrical conductivity, total dissolved solids, and chemical oxygen demand, suggesting a greater likelihood of mineral and organic matter infiltration. The absence of coliforms, *E. coli*, cadmium, and lead across all samples confirms that the water sources are microbiologically safe and free from heavy metal contamination. However, the slightly acidic pH values in some sachet and borehole samples and elevated COD levels may pose minor long-term risks if not monitored regularly. Findings from the community survey indicated that most residents rely heavily on borehole and sachet water for drinking and domestic use, often assuming their safety without prior treatment. This behavior highlights a general lack of awareness regarding potential contamination risks and the importance of periodic testing. Therefore, while the community's water sources are currently safe, sustained monitoring, public education, and improved water handling practices are essential to prevent future deterioration in quality.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The results obtained so far highlights that the portable water sources in Ikhueniro community are of good quality and hygienic for human consumption. Collectively, all the tested parameters fall within acceptable limits prescribed by WHO (2022) and SON (2015) for potable water. The soft, neutral to slightly acidic nature of the samples, low TDS and hardness, and absence of toxic metals and pathogens confirm that the borehole, sachet, and bottled waters in Ikhueniro are physically, chemically and microbiologically safe for human consumption. However, regular monitoring is recommended to detect potential contamination from agricultural runoff, improper waste disposal, or borehole casing degradation over time.

From the questionnaire data, it was revealed that the bottled water is preferred to other sources in terms of purity, while the borehole water is preferred to other sources in terms of cost and availability. Also, the possible contamination of sachet water at the point of production was recorded in which they reported that pure water vending machine may not be so pure. However, it was gratifying to note that all the packaged water analyzed in this study were free from bacterial contamination which possibly showed that the manufacturers adhered strictly to the guidelines set up by NAFDAC and SON. Also, it was reported that some residents suffered from water borne diseases as a result of consumption of sachet water. There is, therefore, a need to monitor all those involved in water business to comply with the guidelines to avert possible outbreak of water-borne diseases as a result of consumption of contaminated water.

Lastly, all water samples fall within the “Excellent to Good” category of the Water Quality Index. None exceed WHO or Nigerian standards for potable water.

5.2 RECOMMENDATION

The following recommendations are made from this research work, for the improvement of portable water sources in ikhueniro community;

i. Since the borehole water is readily available and highly consumed in the community, the government should regulate borehole water quality.

ii. There should be constant monitoring of bottled water and sachet water production and chloride concentration of packaged water should be reviewed so that manufacturers can meet with WHO standards.

iii. There should be constant awareness outreach to residents, so that through the process reports on any abnormalities in water consumed can be recorded.

iv. Regular monitoring is recommended to detect potential contamination from agricultural runoff, improper waste disposal, or borehole casing degradation over time.

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APPENDIX A

Questionnaire for the Assessment of Portable Water Sources in Ikhueniro Community, Benin City, Edo State

This questionnaire is strictly for academic purposes. All responses will be kept confidential.

Section A: Socio-Demographic Information

1. Gender:

   ☐ Male ☐ Female

2. Age Group:

   ☐ Under 18 ☐ 18–30 ☐ 31–45 ☐ 46–60 ☐ Above 60

3. Occupation: ____________________________

4. Educational Level:

   ☐ No formal education ☐ Primary ☐ Secondary ☐ Tertiary ☐ Others (specify): ___________

5. Number of people in your household: ______

Section B: Water Use and Preferences

6. Which type of water do you primarily use for drinking?

   ☐ Borehole ☐ Sachet ☐ Bottled ☐ Rainwater ☐ Other: ____________

7. Why do you prefer this source? (Check all that apply)

   ☐ Availability ☐ Cost ☐ Perceived safety ☐ Taste ☐ Convenience ☐ Other: _______

8. How frequently do you buy sachet or bottled water?

   ☐ Daily ☐ 2–3 times/week ☐ Occasionally ☐ Never

9. If you use borehole water, do you treat it before use?

   ☐ Yes ☐ No If Yes, how? _______________________

10. How would you rate the quality of the water you drink?

    ☐ Excellent ☐ Good ☐ Fair ☐ Poor ☐ Very poor

Section C: Water Quality Concerns and Experience

11. Have you ever experienced illness (e.g., diarrhea, typhoid) suspected to be water-related?

    ☐ Yes ☐ No If Yes, which source was involved? ____________________

12. Do you trust the safety of sachet water sold in your area?

    ☐ Yes ☐ No ☐ Not sure

13. Do you usually check for NAFDAC registration number on packaged water?

    ☐ Always ☐ Sometimes ☐ Never

14. Have you noticed any taste, color, or odor issues with the water you consume?

    ☐ Yes ☐ No If Yes, please describe: __________________________

15. Are there boreholes in your compound or neighborhood?

    ☐ Yes ☐ No

Section D: Perception of Water Regulation and Quality

16. Are you aware of any agencies (e.g., NAFDAC, SON, Ministry of Health) regulating water quality in Nigeria?

    ☐ Yes ☐ No

17. Do you think the government should regulate borehole water quality?

    ☐ Yes ☐ No ☐ Not sure

18. In your opinion, which water type is the safest for drinking?

    ☐ Borehole ☐ Sachet ☐ Bottled ☐ None ☐ Not sure

19. Which one do you think is most affordable?

☐ Borehole ☐ Sachet ☐ Bottled

20. What improvements would you suggest regarding water safety in your community?

____

Section E: Vendor Section (Only for Sachet/Bottled Water Sellers)

(Skip if not applicable)

21. What type of water do you sell?

☐ Sachet water ☐ Bottled water ☐ Both

22. Is your product registered with NAFDAC?

☐ Yes ☐ No

Thank you for participating in this survey. Your responses are valuable to our research on water quality improvement in Ikhueniro Community.