QUALITY ASSESSMENT OF DRINKING WATER IN HOUSEHOLDS OF UTAGBAN COMMUNITY, BENIN CITY, NIGERIA

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AN UNDERGRADUATE DISSERTATION SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN CITY, EDO STATE, NIGERIA; IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR AWARD OF BACHELOR OF SCIENCE (B. Sc) DEGREE IN ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY

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CERTIFICATION

This is to certify that this research titled **"QUALITY ASSESSMENT OF DRINKING WATER IN HOUSEHOLDS OF UTAGBAN COMMUNITY, BENIN CITY, NIGERIA"** was carried out by **"OSAYI FESTUS OMONBHUDE"** and presented to the Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City, in partial fulfilment of the requirements for the award of a Bachelor of Science (B. Sc.) in Environmental Management and Toxicology. It was conducted under suitable conditions, was carefully supervised and subsequently approved as having met the requirements for the award of a Bachelor of Science degree in Environmental Management and Toxicology.

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(HEAD OF DEPARTMENT)

DECLARATION

I **"OSAYI FESTUS OMONBHUDE"** declare that **QUALITY ASSESSMENT OF DRINKING WATER IN HOUSEHOLDS OF UTAGBAN COMMUNITY, BENIN CITY, NIGERIA"** is my work and that all sources that I have used or quoted have been acknowledged using complete references and that this work has not been submitted before for any other degree at any other university.

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OSAYI FESTUS OMONBHUDE **DATE**

DEDICATION

This project is dedicated to God Almighty for His grace, wisdom, and strength throughout my academic journey. I also dedicate it to my loving parents Mr. and Mrs. OMONBHUDE, whose support and prayers have carried me through every stage of this work.

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I give sincere thanks to Almighty God for His unending grace, wisdom, and strength from the beginning of this research to its completion. Every step of this journey was made possible through His guidance, especially during challenging moments when I needed clarity and perseverance.

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ABSTRACT

This study assessed the quality of drinking water in households within Utagban Community, Benin City, Nigeria, an area largely inhabited by artisans and small business owners who depend on sachet, borehole, and well water for domestic use. The aim of the study was to evaluate the drinking water quality and household water management and hygiene practices, in Utagban community. The study examined physicochemical characteristics, and determined the levels of total heterotrophic bacteria, coliforms, and *Escherichia coli* across various water sources. A structured questionnaire was used to assess the various household hygiene practices. Water samples (25) were aseptically collected from household for laboratory analysis. Physicochemical parameters such as pH, temperature, total dissolved solids (TDS), electrical conductivity (EC), and salinity were measured using a digital water quality meter, while microbiological analysis was conducted using the spread plate technique on Nutrient Agar and Chromogenic Coliform Agar to quantify bacterial loads. Data were analyzed using SPSS version 22.0 and Microsoft Excel. Results showed that sachet water was the most consumed (67%), followed by borehole water (30%) and well water (2%). Physicochemical parameters were generally within WHO limits, with pH ranging from 6.2 to 7.7. Mean heterotrophic bacterial counts varied from 0 to 82×10^2 CFU/mL, highest in well water. Coliforms were detected in borehole and sachet water but absent in bottled water, and E. coli was not found in any sample. The findings highlight moderate microbiological contamination in some water sources, underscoring the need for regular monitoring and improved household hygiene practices to ensure safe drinking water.

CHAPTER ONE

1.0 INRODUCTION

1.1 Background of study

Access to safe and clean drinking water is essential for human health, economic progress, and environmental sustainability. The World Health Organization (WHO) considers water quality a key determinant of public health, especially in low- and middle-income countries, where access remains a major concern. Globally, about 740 million people still lack access to improved water sources, while over 173 million people rely on untreated surface water for their domestic needs (WHO, 2017). Despite its fundamental importance, the availability of potable water and basic sanitation is unevenly distributed, especially in sub-Saharan Africa. To address this, access to safe water was formally recognized as a basic human right through the United Nations General Assembly's 2010 Declaration (UN, 2010), which Nigeria endorsed.

In spite of this commitment, water insecurity persists in Nigeria. According to the WHO, although 70% of Nigerians may have access to some form of water supply, only about 19% access drinking water that meets international safety standards (WHO, 2017). Recent statistics from the Nigerian Institution of Water Engineers (NIWE) suggest that nearly 179 million Nigerians, approximately two-thirds of the population, do not have access to safely managed drinking water. Compounding the issue is the fact that roughly 79% of the country's waterworks are either non-functional, partially functional, or completely moribund, leaving large segments of the population dependent on unreliable or unsafe water sources.

The consequences of poor water access are profound. Waterborne diseases such as cholera, typhoid, and dysentery remain prevalent, particularly in rural and peri-urban areas where infrastructure is weak and sanitation services are minimal. According to the WHO and UNICEF

Joint Monitoring Programme (2019), more than 2.1 billion people globally lack access to safe, readily available water at home, with rural populations disproportionately affected. In Nigeria, this is especially the case in semi-urban and rural communities, where seasonal variations, environmental degradation, and inadequate water governance further complicate access to clean water.

A notable example of such a community is Utagban, located along Upper Ekenwan Road, Ugbiyoko Quarters in Benin City, Edo State. Utagban is a growing semi-urban settlement characterized by mixed residential and commercial activities, limited public water infrastructure, and high reliance on alternative water sources such as boreholes, hand-dug wells, sachet water, and surface runoff. Many of these sources are often unregulated and susceptible to contamination from poorly managed waste disposal systems, leaky septic tanks, and seasonal floods. These vulnerabilities make the water in Utagban a potential vector for disease transmission and environmental health challenges.

The importance of water quality assessment in such settings cannot be overstated. Regular testing and monitoring help detect chemical, biological, and physical contaminants that may not be apparent to the naked eye. Parameters such as pH, turbidity, conductivity, and concentrations of heavy metals, including iron, zinc, and lead, as well as microbial indicators like Escherichia coli are critical in determining water safety (WHO, 2017; Amadi *et al*., 2020). In Nigeria, unsafe water contributes to an estimated 60,000 deaths annually from waterborne diseases (Nwankwoala, 2011), making localized data on water quality crucial for public health planning and community interventions.

Several studies in Benin City and across Edo State have reported varying levels of contamination in water sources, depending on environmental conditions, infrastructure quality, and population density (Ize-Iyamu *et al*., 2011; Okoye *et al*., 2021). However, there remains a significant knowledge gap in the specific case of Utagban. The lack of empirical data hinders the ability of local authorities, non-governmental organizations, and health practitioners to implement targeted solutions for improving water safety in the area.

1.2 Statement of the Problem

Access to safe and potable drinking water remains a critical public health concern in many Nigerian communities, including Utagban in Benin City. Despite the growing population and urban expansion, water infrastructure development has lagged, resulting in households relying on alternative sources such as boreholes, wells, and sachet water, many of which are vulnerable to contamination (Nwinyi *et al*., 2020; Ijioma *et al*., 2025).

In Utagban, the absence of centralized water treatment systems and poor sanitation practices, such as open defecation and improper waste disposal, pose significant risks to water quality. These anthropogenic activities contribute to the infiltration of pathogens and chemical pollutants into groundwater and surface water sources (Lapworth *et al*., 2017). Studies have shown that microbial contamination, particularly by E. coli and coliform bacteria, is prevalent in sachet water and boreholes in similar urban settings, raising concerns about waterborne diseases like cholera and diarrhea (CDC, 2015; NCDC, 2021).

Furthermore, the lack of continuous monitoring and enforcement of water safety regulations exacerbates the situation. Although Nigeria has adopted international frameworks such as the WHO Guidelines for Drinking Water Quality and Sustainable Development Goal 6 (SDG 6), implementation remains weak due to institutional inefficiencies and limited local governance (Ogunkan, 2022; WHO, 2011).

Given these challenges, there is an urgent need to assess the physicochemical and microbiological quality of drinking water in Utagban households. Such an assessment will provide evidence-based insights into the health risks associated with current water sources and inform policy interventions aimed at improving water safety and public health outcomes.

1.3 Aim and Objectives

This study aimed to evaluate the quality of drinking water in households within Utagban Community, Benin City, with particular attention on factors influencing water safety and suitability for domestic consumption.

The specific objectives of this study were to:

i. examine household water quality management and hygiene behaviors using a structured questionnaire to identify practices affecting drinking water quality;
ii. assess the physicochemical characteristics of household drinking water to determine its quality;
iii. estimate the total heterotrophic bacterial load in household drinking water;
iv. investigate the distribution of heterotrophic bacteria across different water sources;
v. measure the total coliform and *Escherichia coli* counts in household drinking water to assess fecal contamination and potential health risks; and
vi. evaluate the distribution of total coliforms and *Escherichia coli* across various water sources to determine differences in microbiological water quality.

1.4 Justification of the study

This study is necessary to safeguard public health and support sustainable development in Utagban Community, Benin City. Although residents rely on various water sources, such as boreholes, wells, and sachet water, many of these are increasingly contaminated by microbial and chemical pollutants.

Firstly, there is a high prevalence of waterborne diseases like typhoid, diarrhea, and dysentery, especially among users of untreated water sources. In similar Nigerian communities, typhoid fever has reached up to 20%. Secondly, Utagban lacks a centralized water treatment system, making households dependent on self-managed sources that may not meet safety standards.

Furthermore, the enforcement of water safety regulations is weak, despite Nigeria's adoption of WHO guidelines and SDG 6 targets. Accurate water quality data from this study will enable the design of targeted interventions such as point-of-use treatment, source protection, and public awareness campaigns. Lastly, the study supports Nigeria's progress toward SDG 6, ensuring access to clean water and sanitation, by providing localized evidence for policy formulation and community action.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Water Quality Standards and Guidelines

The World Health Organization's Guidelines for Drinking-water Quality constitute the most widely recognized international framework for water quality assessment and management. First published in 1958 and subsequently revised multiple times, the current fourth edition with its addendum represents the culmination of decades of scientific research and practical experience in water quality management (WHO, 2017). These guidelines establish health-based targets for chemical, microbiological, and radiological contaminants, providing the foundation for national standards development worldwide.

The WHO guidelines adopt a risk-based approach that considers both acute and chronic health effects, establishing guideline values based on tolerable daily intake calculations and exposure assumptions (Bartram and Ballance, 2019). For microbiological quality, the guidelines emphasize the concept of "absence of fecal contamination" as the primary objective, recognizing that waterborne pathogens pose the most immediate and widespread health risks globally (WHO, 2017). The framework incorporates specific guidance for different water sources, treatment technologies, and distribution systems, acknowledging the complexity of ensuring water safety from source to consumer.

The microbiological guidelines establish specific targets for indicator organisms, including Escherichia coli and thermotolerant coliform bacteria, which serve as proxy measures for faecal contamination and potential presence of waterborne pathogens (Ashbolt *et al*., 2001). The WHO framework also addresses emerging pathogens such as Cryptosporidium and Giardia, reflecting evolving understanding of waterborne disease transmission mechanisms and the limitations of traditional bacterial indicators in assessing viral and parasitic contamination risks.

Chemical water quality standards encompass a broad spectrum of naturally occurring and anthropogenic substances that may pose health risks through acute or chronic exposure. The WHO guidelines establish specific values for heavy metals including lead, arsenic, mercury, and cadmium, based on extensive toxicological research and epidemiological evidence of adverse health effects (WHO, 2017). These standards consider vulnerable populations, particularly children and pregnant women, who may experience disproportionate health impacts from chemical contaminants.

Inorganic chemical parameters include essential elements such as fluoride, where the guidelines recognize both beneficial effects in preventing dental caries and potential adverse effects including dental and skeletal fluorosis at elevated concentrations (Edmunds and Smedley, 2013). The establishment of fluoride guidelines demonstrates the complexity of balancing health benefits and risks, particularly in regions where natural fluoride levels vary significantly due to geological factors.

Organic chemical contaminants addressed in WHO guidelines include pesticides, industrial chemicals, and disinfection by-products, reflecting increasing concern about anthropogenic contamination of water sources (Richardson and Postigo, 2021). The guidelines establish specific values for commonly detected pesticides based on agricultural use patterns and environmental fate characteristics, while acknowledging that local contamination patterns may require additional parameter monitoring beyond those specified in international guidelines.

Nigeria's national water quality standards, developed by the Standards Organisation of Nigeria (SON) and the Federal Ministry of Water Resources, provide the regulatory framework for water quality management within the country. The Nigerian Standard for Drinking Water Quality (NIS 554:2015) largely aligns with WHO guidelines while incorporating specific considerations for local conditions and contaminant sources prevalent in Nigerian water supplies (Standards Organisation of Nigeria, 2015).

The Nigerian standards address specific regional challenges including high levels of naturally occurring fluoride in northern regions, iron and manganese contamination in groundwater sources, and microbiological contamination associated with inadequate sanitation infrastructure (Adimalla and Qian, 2019). The standards establish maximum permissible limits for physical parameters including turbidity, color, and total dissolved solids, recognizing their importance for consumer acceptance and as indicators of treatment effectiveness.

Microbiological standards in Nigerian regulations emphasize the absence of pathogenic organisms and establish specific limits for indicator bacteria, reflecting the significant burden of waterborne diseases in the country. The standards also address emerging concerns including antibiotic-resistant bacteria and chemical contaminants associated with industrial activities and agricultural practices (Oyeleke et al., 2020).

The translation of water quality standards into effective regulatory frameworks presents significant challenges, particularly in developing countries where monitoring capacity and enforcement mechanisms may be limited. Studies have documented substantial gaps between established standards and actual water quality conditions, highlighting the need for strengthened regulatory systems and improved monitoring capabilities (Bain *et al*., 2014).

In Nigeria, regulatory enforcement faces challenges including limited laboratory capacity, inadequate funding for monitoring programs, and fragmented institutional responsibilities across multiple agencies (Emenike *et al*., 2017). The decentralized nature of water supply services, with responsibilities distributed among federal, state, and local government levels, complicates coordinated standard implementation and enforcement efforts.

Research has demonstrated that effective standard implementation requires not only appropriate technical guidelines but also robust institutional frameworks, adequate financial resources, and technical capacity at local levels (Hunter *et al*., 2010). The experience of countries that have successfully improved water quality through strengthened standards and enforcement provides valuable lessons for improving regulatory effectiveness in Nigerian contexts.

Comparative analysis of international water quality standards reveals both convergence around core health-based principles and divergence reflecting local priorities and conditions. European Union drinking water standards, established through the Drinking Water Directive, incorporate more stringent requirements for certain parameters and emphasize risk assessment approaches at the distribution system level (European Commission, 2020).

United States Environmental Protection Agency standards employ a dual approach combining health-based maximum contaminant level goals with technically and economically feasible maximum contaminant levels, recognizing practical constraints in achieving theoretical health-based targets (USEPA, 2018). This approach acknowledges the trade-offs between health protection and technical feasibility that characterize water quality management in many contexts.

The development of standards in developing countries increasingly reflects lessons learned from international experience while adapting to local conditions and priorities. Studies comparing standards across sub-Saharan African countries reveal common challenges in addressing microbiological contamination while managing resource constraints and limited technical capacity (Gelting *et al*., 2013).

Research has documented significant disparities between urban and rural areas in meeting established water quality standards, highlighting the need for targeted approaches and appropriate technology solutions (Bain *et al*., 2014).

Studies in Nigerian rural communities have revealed widespread non-compliance with national water quality standards, particularly for microbiological parameters, emphasizing the gap between regulatory requirements and actual conditions (Akoachere *et al*., 2013).

2.2 Water Quality Assessment Methods and Techniques

Water quality assessment employs a combination of field and laboratory techniques to evaluate the physical, chemical, microbiological, and biological characteristics of water, ensuring it meets safety standards for human consumption. Sampling methods such as grab sampling are commonly used to collect representative water samples for analysis (Atlas, 2025).

Physical parameters provide immediate indicators of water quality that affect consumer acceptance and treatment effectiveness. Turbidity measurement using nephelometric methods remains the standard approach, with acceptable limits typically below 5 NTU for drinking water (APHA, 2017). Portable turbidimeters enable field testing, though laboratory nephelometers provide greater accuracy for regulatory compliance monitoring.

Color assessment utilizes visual comparison methods or spectrophotometric analysis, with true color measured after filtration to remove suspended particles. Taste and odor evaluation, while subjective, provides valuable information about potential contamination sources and consumer acceptance (WHO, 2017). Temperature and conductivity measurements offer rapid field assessment of water source characteristics and potential contamination indicators.

Chemical parameter analysis encompasses both field-based screening methods and laboratory techniques. pH measurement using electronic meters provides immediate results, while laboratory methods ensure greater precision for regulatory reporting. Heavy metal analysis typically requires atomic absorption spectroscopy (AAS) or inductively coupled plasma mass spectrometry (ICP-MS), with detection limits suitable for health-based guidelines (USEPA, 2018).

Nutrient analysis includes colorimetric methods for nitrates, phosphates, and ammonia, with portable kits enabling field screening and laboratory methods providing quantitative results. Ion chromatography offers comprehensive analysis of major anions and cations in single analytical runs (Weiss, 2016). Organic compound analysis requires sophisticated techniques including gas chromatography-mass spectrometry (GC-MS) for pesticides and volatile organic compounds.

Laboratory instrumental techniques provide precise quantification of contaminants. Ion chromatography is widely used for detecting anions and cations, while atomic absorption spectroscopy and inductively coupled plasma spectroscopy measure trace metals. Gas chromatography and high-performance liquid chromatography analyze organic compounds, and advanced methods like nuclear magnetic resonance and Fourier-transform infrared spectroscopy identify complex chemical structures (Atlas, 2025).

Microbiological assessment techniques include culture methods, epifluorescence microscopy, and flow cytometry (FCM). FCM, in particular, offers rapid and sensitive quantification of total, viable, and active bacteria in drinking water, proving useful for monitoring treatment efficacy (Helmi *et al*., 2015).

Risk-based approaches such as the Water Quality Index (WQI) integrate multiple parameters into a single score, facilitating comprehensive water quality evaluation. Recent advances incorporate machine learning and fuzzy logic to improve accuracy and interpretability across diverse water sources (Wu *et al*., 2025).

Regulatory agencies like the US EPA develop and approve standardized analytical methods to ensure consistency and reliability in water quality testing. These methods cover sample collection, preservation, contaminant identification, and quality control, supporting compliance monitoring and public health protection (Epa, 2024).

2.3 Rural Water Sources and Supply Systems

Groundwater represents the primary water source for rural communities globally, accessed through various extraction methods ranging from traditional hand-dug wells to mechanized boreholes. Hand-dug wells, typically 10-30 meters deep, provide accessible groundwater extraction using simple construction techniques and local labor (MacDonald *et al*., 2016). These wells are particularly common in areas with shallow water tables and adequate manual drilling capabilities.

Boreholes offer access to deeper aquifers through mechanical drilling, typically reaching depths of 50-200 meters depending on local geology and water table conditions (Bonsor *et al*., 2018). Hand pumps, motorized pumps, and solar-powered systems provide various extraction mechanisms suited to different community needs and maintenance capabilities. However, borehole sustainability depends on appropriate siting, construction quality, and ongoing maintenance support.

Tube wells and driven wells represent intermediate technologies between hand-dug wells and drilled boreholes, offering cost-effective groundwater access in suitable geological conditions. Surface water sources include rivers, streams, ponds, and lakes that provide readily accessible water supplies for rural communities, particularly during rainy seasons. River and stream abstraction through gravity-fed systems offers low-cost water supply solutions but faces quality challenges from upstream contamination and seasonal flow variations (Hunter *et al*., 2010).

Constructed ponds and reservoirs enable surface water storage during wet periods for use during dry seasons, though water quality deterioration during storage presents significant challenges (Shaheed *et al*., 2014). Traditional water harvesting structures including check dams and farm ponds demonstrate community-based approaches to surface water management that integrate with local agricultural practices.

Springs provide naturally emerging groundwater that often requires minimal treatment, making them valuable rural water sources where geological conditions permit. Rainwater harvesting offers decentralized water supply solutions particularly suited to areas with adequate precipitation but limited groundwater or surface water access. Roof catchment systems utilizing household and community buildings provide high-quality water sources with minimal treatment requirements (Gould and Nissen-Petersen, 2019).

Ground catchment systems capture rainfall from prepared surfaces including rock outcrops and constructed catchments, enabling larger-scale water collection but requiring filtration and treatment before consumption.

2.4 Contaminants in Household Drinking Water

Access to clean and safe drinking water is essential for human health and well-being. However, household drinking water is often contaminated by various pollutants, including microbiological, chemical, and physical contaminants. These contaminants can originate from natural sources, human activities, or inadequate water treatment and distribution systems.

Microbiological contaminants, including bacteria, viruses, and protozoa, pose significant health risks. Pathogens such as Escherichia coli, Salmonella, and Vibrio cholerae are commonly found in contaminated water and can cause gastrointestinal infections and other diseases (Kristanti *et al*., 2022). Studies indicate that poor sanitation and improper waste disposal contribute to the presence of these microorganisms in household drinking water (Alabbasy *et al*., 2019). Waterborne diseases remain a major public health concern, particularly in developing regions where access to safe drinking water is limited.

Chemical contaminants in drinking water include heavy metals, pesticides, nitrates, and industrial pollutants. Arsenic, lead, and fluoride are among the most hazardous chemical contaminants, with long-term exposure leading to severe health effects such as cancer, neurological disorders, and developmental issues (Jurczynski *et al*., 2024). Agricultural runoff and industrial waste disposal are major contributors to chemical contamination in household water supplies (Alabbasy *et al*., 2019). Studies highlight the need for stringent regulations and improved monitoring to mitigate the risks associated with chemical pollutants.

Physical contaminants, such as sediments, suspended solids, and turbidity, affect the aesthetic and physical properties of drinking water. High turbidity levels can reduce water clarity and interfere with disinfection processes, making water unsafe for consumption (Kristanti *et al*., 2022). Poor infrastructure and inadequate filtration systems are common causes of physical contamination in household drinking water (Alabbasy *et al*., 2019). Addressing these issues requires investment in water treatment technologies and improved distribution networks.

2.5 Previous Studies on Water Quality in Nigeria

2.5.1 National Trends and Challenges

Studies on water quality in Nigeria between 2000 and 2020 have consistently revealed systemic issues affecting the safety, accessibility, and management of drinking water. Rainwater generally shows lower levels of contamination compared to surface and groundwater sources, which frequently exceed the World Health Organization (WHO) standards for microbial and chemical parameters (Ewuzie *et al*., 2021). This pattern suggests that while rainwater may offer temporary relief in some areas, long-term reliance on untreated groundwater and surface water poses significant health risks.

There are notable regional disparities in research output and water quality outcomes across Nigeria's six geopolitical zones. These differences are often influenced by institutional capacity, literacy rates, infrastructure availability, and proximity to pollution sources (Ewuzie *et al*., 2021; Imam *et al*., 2023). For instance, studies indicate that in northern Nigeria, as much as 55.7% of water sources are contaminated and unfit for human consumption (Imam *et al*., 2023). Nationally, although 70% of the population has access to basic water sources, only 19% of these sources meet acceptable safety standards. Compounding the issue, approximately 79% of public water supply facilities are reported to be non-functional, highlighting a significant infrastructural gap (Ewuzie *et al*., 2021; Vosa *et al*., 2025).

2.5.2 Regional Case Studies

Northern Nigeria:

In states like Gombe, boreholes and wells serve as the primary sources of household water. However, water quality is highly affected by seasonal variations, with the rainy season typically exacerbating microbial contamination. Water Quality Index (WQI) assessments in this region often report turbidity, nitrate, and coliform levels that exceed WHO recommended limits (Imam *et al*., 2023; Sulaiman *et al*., 2020). Alarmingly, only 13.1% of the population in northern Nigeria has access to safely managed drinking water, posing a major challenge to achieving Sustainable Development Goal 6 (clean water and sanitation for all) by 2030 (Imam *et al*., 2023).

Imam *et al*. (2023) conducted a detailed study on drinking water quality in northern Nigeria, focusing on both physical-chemical and microbiological parameters. Their findings revealed that while many physical and chemical parameters such as temperature, pH, conductivity, total dissolved solids (TDS), and turbidity were within acceptable limits according to WHO and Nigerian standards, microbial contamination remained a significant challenge. Approximately 31.14% of water sources were classified as fair, suitable for consumption but requiring additional treatment to prevent disease outbreaks. The study highlighted those biological contaminants and heavy metals were the major obstacles to ensuring safe potable water in the region, emphasizing the urgent need for improved water treatment and monitoring systems (Imam *et al*., 2023).

Niger Delta Region:

The Niger Delta faces severe contamination from industrial activities, particularly oil exploration and refining. Heavy metals such as lead and cadmium, alongside petroleum hydrocarbons, have been detected in domestic water supplies. A study conducted in a tertiary institution in the western Niger Delta revealed that 72.7% of household water samples failed to meet microbiological safety standards, with Escherichia coli contamination strongly linked to poor sanitation and inadequate waste disposal (James and Obukowh, 2023). Although boreholes are commonly used in this region, many require additional treatment due to pollution from industrial and domestic sources (Nwachukwu and Onyenechere, 2023).

Effiong *et al*. (2022) conducted across 40 secondary schools in Rivers State assessed the quality of water at points of consumption within school premises. The findings revealed significant concerns regarding both microbial and chemical safety.

Microbiological contamination was observed in 30% of water samples, with total heterotrophic bacterial counts exceeding the WHO safe limit of 10 colony-forming units per millilitre (cfu/mL). In some schools, concentrations reached as high as 120 cfu/mL, indicating substantial microbial presence and potential health risks.

Chemical analysis further revealed elevated levels of key parameters. Nitrate concentrations were as high as 3.00 mg/L, approaching the WHO permissible limit of 3.87 mg/L. Phosphate levels were particularly alarming, with values reaching up to 3.38 mg/L, more than twelve times the acceptable standard, suggesting contamination from fertilizers, sewage, or detergent residues.

pH values ranged from 5.2 to 6.4, indicating that the water was slightly acidic and potentially corrosive. Such acidity not only affects taste but also poses risks to plumbing infrastructure and may increase the leaching of metals, thereby making the water unsafe for consumption without proper treatment. These findings underscore broader systemic challenges in ensuring water safety in both institutional and household settings.

Southwestern Nigeria:

In peri-urban areas such as Sapele in Delta State, a significant urban-rural divide exists in terms of water access and quality. While 68% of households rely on boreholes, 42% report irregular water availability, and only 28% utilize improved water sources. These highlights ongoing disparities in water infrastructure and the need for targeted interventions to ensure equitable access (Edeki *et al*., 2023).

Adepeju *et al*. (2025) reported that in Lagos, groundwater Total Dissolved Solids (TDS) levels ranged from 205 to 304 mg/L, indicating water of good to excellent quality based on standard classifications. Surface water sources exhibited even lower TDS values, reflecting excellent water quality in terms of dissolved solids. However, despite the generally acceptable TDS levels, some studies highlighted elevated concentrations of water hardness and lead in both groundwater and surface water. These exceedances pose potential health risks to consumers, particularly with prolonged exposure, and underscore the need for comprehensive water quality monitoring beyond basic physical parameters.

2.5.3 Common Sources of Contamination

Across Nigeria, drinking water is frequently contaminated by both microbial and chemical agents. Fecal coliforms, particularly E. coli, are widespread due to inadequate sanitation and the infiltration of human and animal waste into water supplies. Chemical pollutants such as nitrates (primarily from agricultural runoff), heavy metals like arsenic and lead, and hydrocarbons from oil spills are also prevalent (Vosa *et al*., 2025; James and Obukowh, 2023; Nwachukwu and Onyenechere, 2023). Additionally, the decay of water infrastructure such as corroded pipes and poorly maintained boreholes contributes to the presence of iron, manganese, and other undesirable elements in household water supplies (Sulaiman *et al*., 2020; James and Obukowh, 2023).

2.5.4 Methodological Advances in Water Quality Assessment

The use of the Water Quality Index (WQI) has become more common in recent studies as a means of integrating multiple water quality parameters into a single, interpretable score. This approach has revealed that about 31.1% of water sources in northern Nigeria require treatment to be considered safe for consumption (Imam *et al*., 2023). Furthermore, scholars have advocated for the adoption of standardized data collection and reporting protocols, as well as the incorporation of advanced statistical models, including machine learning techniques, to enhance the accuracy of water quality risk assessments (Ewuzie *et al*., 2021; Nwachukwu and Onyenechere, 2023).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The research was carried out in Benin City, the capital of Edo State, located in the southern region of Nigeria.

3.2 Sample location

This study was conducted in Utagban Community, located along Upper Ekenwan Road in Ugbiyoko Quarters, Benin City, Edo State, Nigeria. The community lies within the tropical rainforest belt of southern Nigeria and experiences a humid climate with two distinct seasons: a rainy season that spans from April to October and a dry season from November to March. The average annual rainfall is between 2,000 and 2,200 mm, while temperatures range from 24 °C to 30 °C. Geographically, Benin City is situated at latitude 6.3382° N and longitude 5.6258° E, with an elevation of about 88 meters above sea level. Utagban, being a part of this urban landscape, shares the same geographic and climatic profile.

Utagban is a semi-urban settlement with a steadily growing population made up of civil servants, traders, artisans, and small-scale entrepreneurs. Residential buildings are interspersed with shops and small commercial centers, reflecting a mixed socio-economic character. The settlement continues to expand due to its proximity to the Benin City metropolitan area, which attracts migrants seeking affordable housing and livelihood opportunities.

The community lacks a centralized water supply system, and households rely on multiple alternative sources such as boreholes, hand-dug wells, sachet and bottled water, and water vendors. Water is often stored in plastic containers, overhead tanks, and buckets, while sanitation facilities are limited, with some households depending on pit latrines or shared facilities. Waste management practices are inadequate, and indiscriminate disposal of refuse is common, raising concerns about contamination of both surface and groundwater.

The selection of Utagban as the study area is based on its semi-urban nature, the diversity of household water sources, and the potential public health risks associated with poor sanitation and lack of effective water quality monitoring. These factors make the community suitable for a comprehensive assessment of drinking water quality and its implications for residents' health.

3.3 Questionnaire Survey

A structured questionnaire was utilized to evaluate household practices influencing the quality of drinking water. The instrument was designed to collect data on sources of water, storage conditions, treatment methods, and sanitation behaviors that could affect water safety. Respondents were selected using a random sampling technique to ensure a representative distribution of households within the study area. Face-to-face interviews were conducted to enhance accuracy and reduce potential bias. The collected data were systematically coded and analyzed using descriptive and inferential statistical techniques to identify factors contributing to variations in household drinking water quality. A total of 100 households participated in the assessment.

3.4 Sample Collection

A total of twenty-five (25) drinking water samples were collected using sterile plastic containers. Each sample was accurately labeled with unique identifiers and promptly transported to the laboratory under aseptic conditions for further analysis.

3.5 Preparation of Culture Media

Nutrient Agar (NA) (Lab M, Lancashire, United Kingdom) was prepared by dissolving 28 g of agar powder in 1000 mL of distilled water, followed by sterilization in an autoclave at 121°C for 15 minutes. This medium was used for the general assessment of microbial quality in household drinking water. Chromogenic Coliform Agar (CCA) (Lab M, Lancashire, United Kingdom) was prepared by dissolving 26.5 g of agar powder in 1000 mL of distilled water and heating with continuous agitation using a magnetic stirrer until the medium was completely dissolved. The CCA medium was not autoclaved or overheated to maintain its chromogenic properties, allowing for the accurate differentiation and enumeration of coliforms and *Escherichia coli*.

3.6 Determination of Physicochemical Parameters

Physicochemical parameters, including pH, temperature, electrical conductivity, salinity, and total dissolved solids (TDS), were measured using a digital water quality tester (MWC-TDS2355, China) in accordance with the manufacturer's instructions. The instrument was calibrated using standard buffer solutions prior to measurement. After calibration, the electrode was rinsed with distilled water, immersed in each water sample, and allowed to stabilize for 2–5 minutes before readings were recorded.

3.7 Enumeration of Total Heterotrophic Bacteria

Total heterotrophic bacterial counts were determined using the spread plate technique. Undiluted water samples (200 µL each) were inoculated onto sterile Nutrient Agar plates (Lab M, Lancashire, United Kingdom) and evenly spread using a sterile glass spreader. The plates were incubated at 37°C for 18–24 hours. After incubation, discrete colonies were enumerated, and the results were expressed as mean colony-forming units per millilitre (CFU/mL).

Table 3.1. Coordinates of Samples taken from the Households

S/N	Sample Codes	Sample Sources	Latitude	Longitude
1	UTG1	Sachet Water	6°18′27″ N	5°34′28″ E
2	UTG2	Sachet Water	6°18′26″ N	5°34′24″ E
3	UTG6	Borehole Water	6°18′32″ N	5°34′25″ E
4	UTG7	Borehole Water	6°18′32″ N	5°34′33″ E
5	UTG10	Borehole Water	6°18′34″ N	5°34′35″ E
6	UTG13	Sachet Water	6°18′41″N	5°34′232″ E
7	UTG14	Sachet Water	6°18′45″ N	5°34′39″ E
8	UTG15	Sachet Water	6°18′59″ N	5°34′33″ E
9	UTG19	Borehole Water	6°19′9″ N	5°34′32″ E
10	UTG20	Sachet Water	6°19′10″ N	5°38′36″ E
11	UTG21	Well Water	6°19′8″ N	5°34′35″ E
12	UTG23	Sachet Water	6°19’8″ N	5°33′31″ E
13	UTG24	Sachet Water	6°19′8″ N	5°32′30″ E
14	UTG26	Bottled Water	6°19′5″ N	5°34′31″ E
15	UTG27	Sachet Water	6°19′5″ N	5°33′30″ E
16	UTG31	Sachet Water	6°19′11″ N	5°34′31″ E
17	UTG32	Sachet Water	6°19′10″ N	5°34′30″ E
18	UTG33	Sachet Water	6°18′58″ N	5°34′20″ E
19	UTG34	Borehole Water	6°19′9″ N	5°34′29″ E
20	UTG35	Sachet Water	6°19′8″ N	5°34′31″ E
21	UTG36	Borehole Water	6°19′6″ N	5°34′29″ E
22	UTG37	Sachet Water	6°19′4″ N	5°34′26″ E
23	UTG38	Sachet Water	6°19′3″ N	5°34’26″ E
24	UTG40	Sachet Water	6°18′34″ N	5°33′32″ E
25	UTG41	Sachet Water	6°18′59″ N	5°33′32″ E

3.8 Cultural Characterization and Enumeration of Total Coliforms and *Escherichia coli*

Total coliform and Escherichia coli counts were analyzed to assess the microbiological quality of household drinking water using the spread plate technique. A 200 µL aliquot of each water sample was evenly distributed on sterile Chromogenic Coliform Agar (CCA) plates (Lab M, Lancashire, United Kingdom) with the aid of a sterile glass spreader. The plates were incubated at 44°C for 18–24 hours to facilitate bacterial growth. Following incubation, colonies were counted, and results were expressed as colony-forming units per millilitre (CFU/mL). Blue or violet colonies were identified as presumptive *E. coli* (fecal coliforms), indicating potential fecal contamination and associated health risks, while pink or red colonies represented other coliforms (non-fecal coliforms). Presumptive isolates were subsequently purified through subculturing on Nutrient agar plates and stored on Nutrient agar slants for further analysis.

3.9 Biochemical Characterization of Coliform Bacteria

Presumptive coliform isolates were subjected to biochemical screening, including Gram reaction using the potassium hydroxide (3% KOH) test, catalase test, and oxidase test. For KOH test**,** a sterile wire loop was used to mix bacterial cells with 2–3 drops of 3% KOH on a clean glass slide. A viscous or slimy reaction indicated a positive result. The catalase test was determined by having a few drops of freshly prepared 3% hydrogen peroxide placed on a bacterial smear. The production of gas bubbles indicated catalase activity (positive reaction). The oxidase test was determined using a piece of filter paper that was moistened with 2–3 drops of freshly prepared oxidase reagent. Presumptive colonies were smeared onto the paper. The appearance of a purple-blue coloration within 10 seconds indicated a positive oxidase reaction, while the absence of color change indicated a negative result.

Presumptive coliform isolates were characterized as KOH-positive, catalase-positive, and oxidase-negative.

3.10 Data Analysis

Data obtained from the study were processed and analyzed using Microsoft Excel and the Statistical Package for the Social Sciences (SPSS) version 22.0 (SPSS Inc., Chicago, IL, USA). Data that followed a normal distribution were presented as mean ± standard deviation (SD).

CHAPTER FOUR

RESULTS

In Table 4.1, the demographic and environmental characteristics of the surveyed households reveal the population structure and living conditions of the study area. The majority of respondents were female (65%). In terms of age distribution, respondents were fairly spread across all age groups, with the 28–37 years group (25%) being the most represented, followed closely by those aged 38–47 years (23%) and 48–57 years (22%). With respect to marital status, a substantial proportion were married (64%), while 27% were single and 7% widowed. The religious composition was mostly Christian (95%), with minor representation from Islam (4%) and traditional religion (1%). Educational attainment was relatively high, as 57% of respondents possessed tertiary education, and another 31% had secondary education. Only 6% had no formal education, which is relatively low. Occupationally, a large share of the population were artisans or skilled workers (30%), followed by traders/business owners (26%) and private sector employees (22%).

The income data revealed that a high proportion (69%) of households earned ₦150,000 and above monthly. Only a small fraction earned below ₦50,000 (4%), while 2% declined to disclose their income. Household size was mostly moderate, with 59% living in households of 4–6 members, and fewer having 1–3 members (19%) or 7–9 members (19%). Only 3% had households larger than 10 people. In terms of environmental conditions, 63% of respondents reported no nearby waste dump site, while 37% had one within proximity. Among those exposed, the majority (68%) indicated that the dump site was 50–100 meters away, a distance still close enough to pose potential environmental and health risks. Similarly, 24% of households reported the presence of open sewage or stagnant water. The general cleanliness of the surroundings was rated as moderately clean by 64% of respondents, clean by 30%, and dirty by only 6%.

Table 4.1. Demographics and Environmental Observations of Households

Parameters		Frequency (n=100)	Percentage (%)
Sex	Male	35	35.0
	Female	65	65.0
Age in years	18-27	17	17.0
	28-37	25	25.0
	38-47	23	23.0
	48-57	22	22.0
	58 and above	13	13.0
Marital status	Single	27	27.0
	Married	64	64.0
	Widowed	7	7.0
	Divorced	2	2.0
Religion	Christianity	95	95.0
	Islam	4	4.0
	Traditional	1	1.0
Educational Level Attained	No Formal Education	6	6.0
	Vocational	2	2.0
	Primary School	4	4.0
	Secondary School	31	31.0
	Tertiary Education	57	57.0
Occupation	Student	2	2.0
	Private sector Employee	22	22.0
	Trader/Business Owner	26	26.0
	Civil Servant	15	15.0
	Artisan/Skilled Worker	30	30.0
	Housewife	4	4.0
	Farmer	1	1.0
Household Size	1-3	19	19.0
	4-6	59	59.0
	7-9	19	19.0
	10 and above	3	3.0
Monthly Household Income (N)	<20,000	2	2.0
	20,000-49,999	2	2.0
	50,000-99,999	12	12.0
	100,000-149,999	13	13.0
	≥150,000	69	69.0
	Can't say	2	2.0
Is there a waste dump site near the household?	Yes	37	37.0
	No	63	63.0
If yes, what is the estimated distance of their residence to the nearest waste dump site	<50m	10	10.0
	50-100m	68	68.0
	>100m	22	22.0
Is there any open sewage or stagnant water nearby?	Yes	24	24.0
	No	76	76.0
General condition of the surroundings	Clean	30	30.0
	Moderately clean	64	64.0
	Dirty	6	6.0

The findings from Table 4.2 show that the majority of respondents (67%) rely primarily on sachet water, followed by borehole water (30%), with a little depending on well water (2%) and bottled water (1%). However, 68% of respondents reported borehole water as their secondary source. Proximity to water sources was largely favorable, with 94% of respondents accessing water within 100 meters of their homes. Only 4% reported distances between 100–500 meters, while none exceeded 500 meters. Despite this accessibility, only 26% of households treated their water before drinking, while 74% consumed untreated water. Among those who practiced treatment, boiling (50%) was the most common method, followed by filtration (26.9%), use of alum (19.2%), and chlorination (3.9%).

Almost all respondents (96%) reported storing water for drinking. Most stored water in covered containers (62.5%), ensuring some level of hygiene protection, while others used overhead tanks (21.9%) or uncovered containers (13.5%). Water was mostly collected using cups with handles (89.6%), while bowls is 9.4% or cups without handles is 1%. Cleaning frequency of storage containers varied in which 40.6% cleaned monthly, 32.3% weekly, and only 14.6% daily. Availability of water sources throughout the year was reported by 96% of respondents. Nevertheless, nearly half (47%) had faced water-related problems recently. The main challenges were poor taste (48.9%), high cost (19.2%), bad odour (12.8%), contamination (10.6%), and intermittent supply (8.5%). Alarmingly, 75% of respondents believed that people could get sick from the water they drink, and 46% reported actual water-related illnesses in their households within the past six months. Among those affected, typhoid fever was the most prevalent (78.2%), followed by diarrhea (13%), cholera (4.4%), and combined diarrhea and typhoid (4.4%). In terms of sensory perception, 77% of respondents reported no unpleasant physical characteristics, but 18% noticed an unusual taste and 5% reported discoloration.

Table 4.2. Water Source and Quality Assessment of Households

Parameters		**Frequency (n=100)**	**Percentage 2(%)**
Main source of drinking water?	Borehole	30	30.0
	Sachet Water	67	67.0
	Well Water	2	2.0
	Bottled Water	1	1.0
Secondary source of drinking water?	Borehole	68	68.0
	Bottled Water	3	3.0
	Sachet Water	10	10.0
	Rain Water	1	1.0
	Well Water	18	18.0
Distance of main source of drinking water from home?	<100m	94	94.0
	100-500m	4	4.0
	>500m	0	0.0
Do you treat your water before drinking?	**Yes**	26	26.0
	No	74	74.0
If yes, what treatment method do you use?	Boiling	13	50.0
	Filtration	7	26.9
	Use of Alum	5	19.2
	Chlorination	1	3.9
Do you store water for drinking purpose?	Yes	96	96.0
	No	4	4.0
If yes, how do you store your drinking water?	Covered container	60	62.5
	Jerry can	2	2.1
	Uncovered container	13	13.5
	Overhead tank	21	21.9
How do you collect water from the storage container?	Cup with handles	86	89.6
	Cup without handles	1	1.0
	Bowl	9	9.4
How frequently do you clean your water storage containers?	Daily	14	14.6
	Weekly	31	32.3
	Monthly	39	40.6
	Rarely	12	12.5
Is your source available year-round?	Yes	96	96.0
	No	4	4.0
Have you faced any problem with your water supply recently?	Yes	47	47.0
	No	53	53.0
If yes, what kind of problems?	Contamination	5	10.6
	High cost	9	19.2
	Intermittent supply	4	8.5
	Poor taste	23	48.9
	Bad odour	6	12.8
Can people get sick with the water they drink?	Yes	75	75.0
	No	25	25.0
Have your household experienced water-related illness in the past 6 months?	Yes	46	46.0
	No	54	54.0
If yes, which illness(es)?	Diarrhea	6	13.0
	Typhoid	36	78.2

	Diarrhea and Typhoid	2	4.4
	Cholera	2	4.4
Any unpleasant physical characteristics associated with your water? If yes, name them	No	77	77.0
	Colour	5	5.0
	Taste	18	18.0

The results from Table 4.3 showed that large majority of households (93%) reported using flush toilets, while 7% used pit latrines and none practiced open defecation. Furthermore, 89% of respondents had tiled toilet floors, suggesting hygienic and easily cleanable surfaces, while 10% had concrete floors and 1% had wooden floors. Toilet sharing was uncommon, with 84% of households having private toilets and only 16% sharing facilities with other households. Notably, 95% had access to handwashing facilities near their toilets while only 5% lacked such access. Regarding toilet cleanliness, 68% reported weekly cleaning, while 16% cleaned daily and another 16% monthly. Hand hygiene practices appeared strong, as 97% of respondents always washed their hands after toilet use, and only 3% did so sometimes. Similarly, 97% also always washed their hands before preparing food. The frequency of handwashing per day showed that 53% washed 4–6 times daily, 27% whenever hands were dirty, and 16% only 1–3 times daily, with 4% unsure. Soap use during handwashing was reported as consistent among most respondents, with 61% always using soap, 30% using it sometimes, and 9% only when available. Bathing habits were showed that 99% bath daily.

In terms of waste disposal, 56% relied on waste management services. However, 23% still dumped or burned waste in open spaces, 18% dumped waste directly without burning, and 3% buried waste. Environmental cleanliness showed that 88% cleaned their surroundings daily and 12% weekly. When asked about awareness of safe water, sanitation, and hygiene (WASH), only 29% described themselves as very aware, 22% somewhat aware, and 49% not aware. Concerning community water quality monitoring, 63% acknowledged that testing programs had recently occurred, while 37% had not observed such activities. Encouragingly, 83% of respondents expressed willingness to consent to testing their water sources.

Table 4.3. Sanitation and Hygiene Practices of Households

Parameters		Frequency (n=100)	Percentage (%)
What type of toilet facility is available to your household?	Flush toilet	93	93.0
	Pit latrine	7	7.0
	Open defecation	0	0.0
Type of floor in the toilet?	Concrete	10	10.0
	Wooden	1	1.0
	Tiles	89	89.0
Is the toilet shared with other households?	**Yes**	16	16.0
	No	84	84.0
Do you have access to regular handwashing facility near the toilet?	**Yes**	95	95.0
	No	5	5.0
How often is the toilet facility cleaned?	Daily	16	16.0
	Weekly	68	68.0
	Monthly	16	16.0
How often do you wash your hands after using the toilet?	Always	97	97.0
	Sometimes	3	3.0
How often do you wash your hands per day?	1-3 times	16	16.0
	4-6 times	53	53.0
	Whenever hands are dirty	27	27.0
	Not sure	4	4.0
How often do you wash your hands before preparing food?	Always	97	97.0
	Sometimes	3	3.0
How often do you use soap when you wash your hands?	Always	61	61.0
	Sometimes	30	30.0
	When available	9	9.0
Do you bath daily?	**Yes**	99	99.0
	No	1	1.0
How do you dispose your household waste?	Waste management services	56	56.0
	Dump in Open Space, Burning	23	23.0
	Buried	3	3.0
	Dump in Open Space	18	18.0
How often do you clean your surroundings?	Daily	88	88.0
	Weekly	12	12.0
	Occasionally	0	0.0
Are you aware of the importance of safe water, sanitation, and hygiene (WASH)?	Very aware	29	29.0
	Somewhat aware	22	22.0
	Not aware	49	49.0
Have there been any water quality testing programs in your area recently?	Yes	63	63.0
	No	37	37.0
	Not sure	0	0.0
Would you consent to having your water source tested for quality parameters?	Yes	83	83.0
	No	17	17.0

The physicochemical analysis of drinking water samples presented in Table 4.4. Temperature values ranged from 26.5°C to 28.6°C, with a mean around 27.5°C. The pH values varied between 6.2 and 7.7, indicating that most samples were near neutral. Total Dissolved Solids (TDS) values ranged from 12 mg/L to 114 mg/L. Electrical Conductivity (EC) readings varied between 18 µS/cm and 134 µS/cm. The salinity values, all recorded as 0.00%. Oxidation–Reduction Potential (ORP) ranged from 185 mV to 315 mV. Hydrogen concentration (ppb) was generally low across most samples (0.0–0.7 ppb). The specific gravity of all samples remained stable at 1.0 while resistivity values ranged from 69 to 150 Ω·m.

Table 4.5 presents the mean total heterotrophic bacterial counts of various drinking water samples. The mean heterotrophic bacterial counts ranged from 0±0.0 CFU/mL $\times 10^0$ in bottled water to as high as 82±2.9 CFU/mL $\times 10^0$ in well water. Generally, sachet and borehole water samples showed moderate bacterial loads, while well water recorded the highest contamination level. Sachet water samples demonstrated counts ranging between 10±2.5 and 67±3.1 CFU/mL $\times 10^0$, with an average value of approximately 35 CFU/mL $\times 10^0$. Borehole water samples recorded higher variability, with values ranging from 43±2.2 to 86±2.6 CFU/mL $\times 10^0$ and an average of about 63 CFU/mL $\times 10^0$. The bottled water sample (UTG26) showed no detectable bacterial growth (0±0.0 CFU/mL $\times 10^0$).

The mean heterotrophic bacterial counts across the different drinking water sources revealed notable variations in Figure 4.1. Borehole water samples exhibited a mean count of 63.2 CFU/mL $\times 10^0$. Sachet water samples recorded a mean count of 35.8 CFU/mL $\times 10^0$ while well water sample showed the highest bacterial count at 82.0 CFU/mL $\times 10^0$. In contrast, bottled water recorded 0.0 CFU/mL $\times 10^0$ indicating an absence of heterotrophic bacterial growth.

Table 4.4. Physicochemical Profile of Drinking Water Samples from Households

Sample Codes	Parameters								
	Temperature (℃)	pH	TDS (mg/L)	EC (µs/cm)	Salinity (%)	ORP (mv)	Hydrogen (ppb)	Specific Gravity	Resistivity (Ω .m)
UTG1	26.5±1.2	7.2±0.3	35±2.4	70±2.3	0.00±0.0	215±2.1	0.0±0.0	1.0±0.0	84±1.5
UTG2	27.3±0.3	7.1±0.6	42±2.5	72±3.1	0.00±.0.0	315±.2.6	0.0±0.0	1.0±0.0	121±.3.1
UTG6	27.4±1.7	7.7±0.4	57±2.6	36±1.9	0.00±0.0	297±2.3	0.5±0.0	1.0±0.0	136±2.9
UTG7	28.0±0.3	6.2±0.2	84±2.1	66±2.3	0.00±0.0	244±3.1	0.0±0.0	1.0±0.0	149±2.7
UTG10	28.4±0.9	7.3±0.2	57±2.5	62±2.6	0.00±0.0	287±2.4	0.0±0.0	1.0±0.0	143±2.0
UTG13	27.5±0.5	7.1±0.3	38±2.3	50±2.6	0.00±0.0	264±2.5	0.3±0.0	1.0±0.0	114±3.5
UTG14	26.9±0.3	6.9±0.6	47±2.5	82±2.5	0.00±0.0	233±2.4	0.0±0.0	1.0±0.0	91±2.8
UTG15	27.7±0.5	7.1±0.5	51±2.1	91±3.3	0.00±0.0	252±2.6	0.0±0.0	1.0±0.0	141±2.6
UTG19	26.8±0.6	7.5±0.1	91±1.8	104±3.6	0.00±0.0	298±3.1	0.0±0.0	1.0±0.0	86±2.4
UTG20	27.3±0.3	7.2±0.5	52±1.7	57±3.1	0.00±0.0	217±3.1	0.0±0.0	1.0±0.0	97±2.3
UTG21	27.6±0.3	7.4±0.3	114±2.6	134±3.5	0.00±0.0	185±3.3	0.7±0.0	1.0±0.0	91±2.5
UTG23	28.4±0.8	6.9±0.6	41±2.6	95±3.4	0.00±0.0	243±4.2	0.0±0.0	1.0±0.0	92±2.9
UTG24	28.2±0.3	6.8±0.5	45±3.0	82±2.8	0.00±0.0	231±3.7	0.4±0.0	1.0±0.0	86±2.0
UTG26	28.0±0.4	7.1±0.2	12±2.5	18±2.4	0.00±0.0	243±3.3	0.0±0.0	1.0±0.0	77±3.1
UTG27	27.2±0.8	6.8±0.4	30±2.4	54±2.7	0.00±0.0	274±3.0	0.1±0.0	1.0±0.0	150±4.2
UTG31	27.1±0.5	7.4±0.7	39±3.1	71±2.9	0.00±0.0	261±2.5	0.0±0.0	1.0±0.0	84±2.9
UTG32	28.3±0.3	6.8±0.8	27±3.3	67±3.1	0.00±0.0	283±2.4	0.0±0.0	1.0±0.0	95±2.3
UTG33	28.6±0.5	7.1±0.6	48±2.3	64±3.7	0.00±0.0	265±3.1	0.3±0.0	1.0±0.0	111±3.3
UTG34	28.1±0.9	7.2±0.5	36±2.7	101±2.5	0.00±0.0	277±2.7	0.0±0.0	1.0±0.0	101±3.9
UTG35	27.5±0.5	6.9±0.4	99±2.2	73±2.2	0.00±0.0	284±2.4	0.0±0.0	1.0±0.0	93±2.9
UTG36	27.6±0.6	6.7±0.5	20±2.7	69±2.4	0.00±0.0	266±2.6	0.0±0.0	1.0±0.0	83±3.5
UTG37	27.1±0.4	6.9±0.9	37±2.9	36±2.0	0.00±0.0	209±2.1	0.1±0.0	1.0±0.0	74±2.6
UTG38	26.6±0.9	7.1±0.8	44±2.5	45±3.4	0.00±0.0	211±3.3	0.0±0.0	1.0±0.0	69±2.9
UTG40	27.3±1.4	7.0±0.3	23±2.1	40±2.3	0.00±0.0	201±2.9	0.0±0.0	1.0±0.0	79±2.8
UTG41	28.1±1.9	6.8±0.8	19±2.3	37±3.3	0.00±0.0	203±1.9	0.2±0.0	1.0±0.0	81±3.3

KEY: TDS = Total dissolved solids; EC= Electrical conductivity; ORP= Oxidation-Reduction Potential

Table 4.5. Mean Total Heterotrophic Counts of Drinking Water Samples from Households

Sample Code	Sample Source	Mean Counts of Heterotrophic Bacteria CFU/mL $\times 10^0$
UTG1	Sachet Water	10±2.5
UTG2	Sachet Water	27±1.9
UTG6	Borehole Water	43±2.2
UTG7	Borehole Water	86±2.6
UTG10	Borehole Water	53±2.4
UTG13	Sachet Water	49±2.3
UTG14	Sachet Water	50±2.7
UTG15	Sachet Water	36±2.2
UTG19	Borehole Water	61±2.3
UTG20	Sachet Water	27±2.4
UTG21	Well Water	82±2.9
UTG23	Sachet Water	67±3.1
UTG24	Sachet Water	41±2.5
UTG26	Bottled Water	0±0.0
UTG27	Sachet Water	19±1.4
UTG31	Sachet Water	30±2.9
UTG32	Sachet Water	23±2.7
UTG33	Sachet Water	41±4.2
UTG34	Borehole Water	75±3.6
UTG35	Sachet Water	25±1.3
UTG36	Borehole Water	61±2.7
UTG37	Sachet Water	35±3.1
UTG38	Sachet Water	40±2.1
UTG40	Sachet Water	15±2.4
UTG41	Sachet Water	48±1.9

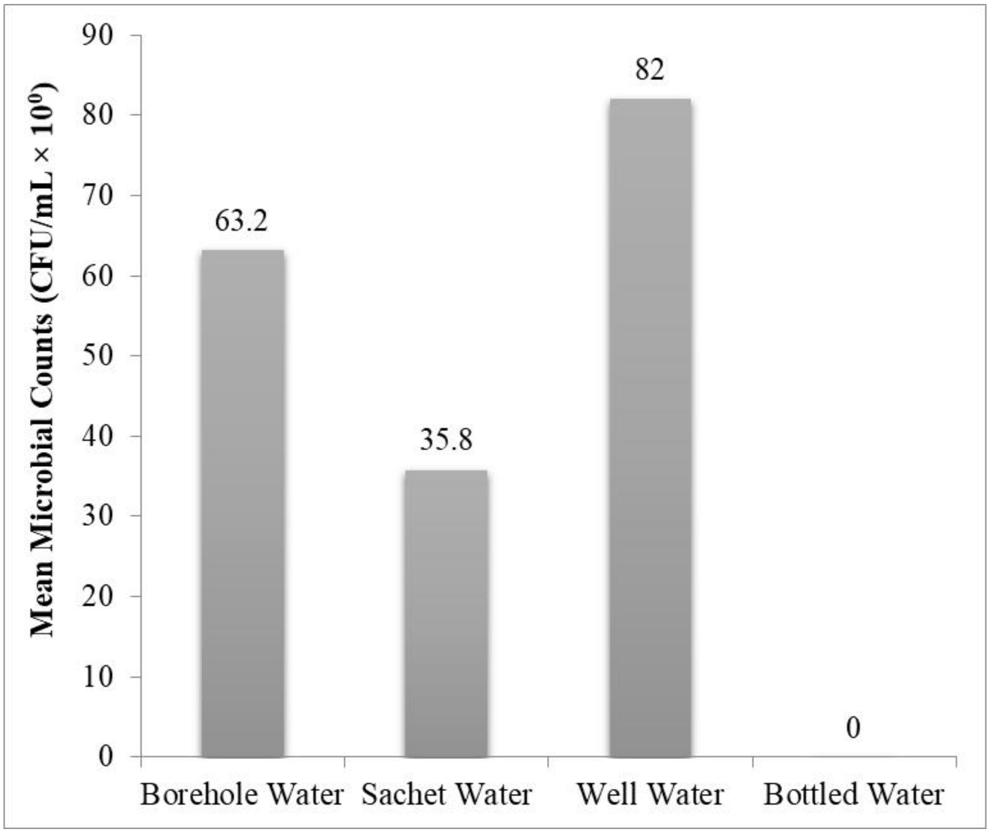

Figure 4.1. Mean Distribution of Heterotrophic Bacterial Based on Sample Sources

In Table 4.6, the mean total coliform and *Escherichia coli* counts across the different household drinking water sources demonstrated varying levels of microbial quality. Borehole water samples showed a mean total coliform count of 6.8 CFU/mL $\times 10^0$, while *E. coli* was entirely absent (0 CFU/mL $\times 10^0$). Sachet water samples exhibited a slightly lower mean total coliform count of 3.7 CFU/mL $\times 10^0$, with *E. coli* also absent. The well water sample recorded the highest total coliform count of 35.0 CFU/mL $\times 10^0$, with *E. coli* remaining undetected. In contrast, bottled water showed no detectable coliforms or *E. coli* (0 CFU/mL $\times 10^0$).

In Figure 4.2, *Escherichia coli* was absent in all water samples, indicating that none of the water sources showed direct evidence of fecal contamination. In Figure 4.3, the mean total coliform counts were highest in well water (35.0 CFU/mL $\times 10^0$), followed by borehole water (6.8 CFU/mL $\times 10^0$) and sachet water (3.7 CFU/mL $\times 10^0$), while bottled water recorded no detectable coliforms.

CHAPTER FIVE

DISCUSSION

The demographic profile of Utagban Community revealed a predominantly female respondent population (65%), which aligns with the global pattern of women bearing primary responsibility for household water management. According to the WHO/UNICEF Joint Monitoring Programme, women and girls are disproportionately responsible for water collection in developing countries, making them key stakeholders in water quality and hygiene practices (WHO/UNICEF, 2023). The relatively high educational attainment in this study population, with 57% possessing tertiary education, contrasts with typical rural Nigerian communities and may influence water handling practices and health-seeking behaviors.

The proximity of waste dump sites to 37% of households, with 68% of these within 50-100 meters, represents a significant environmental health concern. This finding is consistent with studies across Nigerian urban settlements where uncontrolled waste disposal near residential areas contributes to groundwater contamination (Alabi *et al*., 2024). Similarly, 24% of households reported nearby open sewage or stagnant water, which poses potential risks for water source contamination and disease transmission. Environmental sanitation conditions directly influence household water quality, as demonstrated in several Nigerian studies documenting correlations between poor waste management and elevated microbial contamination of drinking water sources (Kumpel *et al*., 2020).

The heavy reliance on sachet water as the primary drinking water source (67%) reflects a broader trend across urban Nigeria, where packaged water has become the preferred choice due to perceived safety and convenience. Agbasi *et al*. (2024) reported that approximately 18% of urban Nigerian households depend on packaged sachet water as their primary drinking water source. However, this perception of safety may not always align with actual water quality, as numerous studies have documented varying levels of microbial contamination in commercially available sachet water (Olaoye and Onilude, 2009; Agbasi *et al*., 2024).

Alarmingly, only 26% of households treated their water before drinking, despite 75% acknowledging that contaminated water could cause illness. This disconnects between knowledge and practice represents a critical gap in household water safety management. Among those who treated water, boiling (50%) was the most common method, followed by filtration (26.9%). These findings are comparable to water treatment practices reported in other Nigerian communities, where low treatment rates persist despite awareness of waterborne disease risks (Adamu *et al*., 2022).

The storage practices observed in this study revealed both positive and concerning trends. While 96% of households stored water, and 62.5% used covered containers, the monthly cleaning frequency reported by 40.6% of respondents may be insufficient to prevent biofilm formation and bacterial regrowth. The WHO guidelines emphasize that water storage containers should be cleaned regularly and kept covered to prevent contamination, particularly when water collection methods involve hand contact with stored water (WHO, 2022). The predominant use of cups with handles (89.6%) for water collection represents a relatively hygienic practice that minimizes hand-water contact, potentially reducing post-collection contamination.

The physicochemical analysis revealed generally favorable water quality parameters. Temperature values ranging from 26.5°C to 28.6°C (mean 27.5°C) fall within typical ambient tropical ranges and are consistent with groundwater temperatures reported in similar Nigerian climatic zones (Oyem *et al*., 2014). The pH values (6.2-7.7) were predominantly within the

WHO acceptable range of 6.5-8.5 for drinking water, though some samples exhibited slightly acidic tendencies. Similar pH patterns have been documented in groundwater across southern Nigeria, where geological formations and organic matter decomposition influence water acidity (Egbueri *et al*., 2022).

Total Dissolved Solids (TDS) concentrations ranged from 12 mg/L to 114 mg/L, well below the WHO guideline value of 1000 mg/L and the Nigerian Standard for Drinking Water Quality (NSDWQ) limit of 500 mg/L. These low TDS values are characteristic of shallow aquifers in recharge areas and indicate minimal mineralization and ionic content (Oyem *et al*., 2014). Correspondingly, electrical conductivity (EC) values (18-134 µS/cm) remained considerably below the WHO guideline of 1000 µS/cm, suggesting low salt concentrations and limited ionic pollution. The strong correlation between TDS and EC observed in this study is consistent with established hydrogeological principles, as both parameters reflect the degree of mineralization in water (Egbueri *et al*., 2020).

The salinity values of 0.00% across all samples confirm the freshwater nature of these sources and the absence of saline intrusion, which can occur in coastal or over-exploited aquifers. The Oxidation-Reduction Potential (ORP) values (185-315 mV) indicate oxidizing conditions favorable for the breakdown of organic matter but insufficient for complete inactivation of microorganisms, necessitating additional treatment or protection measures.

The heterotrophic bacterial counts revealed significant variations across water sources, with mean values of 0 CFU/mL ×100 in bottled water, 35.8 CFU/mL ×100 in sachet water, 63.2 CFU/mL ×100 in borehole water, and 82.0 CFU/mL ×100 in well water. These findings are particularly concerning when compared to international drinking water quality standards. The South African National Standards specify that good-quality drinking water should have heterotrophic plate counts (HPC) below 1,000 CFU/mL, while the US Environmental Protection Agency recommends no

\more than 500 CFU/mL (CDC, 2024; Molale-Tom *et al*., 2024).

The elevated bacterial counts in well water align with findings from similar studies in Nigerian communities. Alabi *et al*. (2024) reported heterotrophic bacterial counts ranging from 0 to 3.0×10^5 CFU/mL in household water from Ibadan, with well water consistently showing higher contamination than borehole sources. The vulnerability of hand-dug wells to surface contamination through improper construction, lack of protective covers, and proximity to pollution sources has been extensively documented (Idowu *et al*., 2011; Kumpel *et al*., 2020).

The intermediate contamination levels observed in sachet water samples (ranging from 10±2.5 to 67±3.1 CFU/mL ×100) reflect the variable quality control practices among sachet water producers. Olaoye and Onilude (2009) reported similar heterotrophic bacterial contamination in sachet water samples from Western Nigeria, attributing contamination to poor personal hygiene of handlers, inadequate source water treatment, and suboptimal packaging processes. The finding that bottled water showed no detectable bacterial growth (0±0.0 CFU/mL ×100) suggests superior processing standards, though the limited sample size (n=1) prevents definitive conclusions.

Borehole water contamination (mean 63.2 CFU/mL ×100) indicates potential issues with source protection or post-extraction handling. Factors contributing to borehole water contamination include inadequate sealing of well heads, proximity to sanitary facilities or waste disposal sites, and contamination during water collection and storage (Aboh *et al*., 2015). The presence of heterotrophic bacteria, while not necessarily pathogenic, indicates conditions conducive to microbial growth and suggests potential vulnerabilities in water quality maintenance (Bartram *et al*., 2003).

The absence of Escherichia coli across all water samples represents a positive finding, indicating the absence of recent fecal contamination in the tested samples. However, the detection of total coliforms, particularly in well water (35.0 CFU/mL ×100), borehole water (6.8 CFU/mL ×100), and sachet water (3.7 CFU/mL ×100), remains concerning. The WHO Guidelines for Drinking Water Quality specify that E. coli or thermotolerant coliforms must not be detectable in any 100-mL sample of water intended for drinking (WHO, 2022).

Total coliforms, while not exclusively fecal in origin, serve as indicators of potential pathway contamination and treatment adequacy. Their presence suggests opportunities for pathogenic organisms to enter and survive in the water supply system (Bartram *et al*., 2003). The highest coliform counts in well water correspond with findings from across Nigeria, where hand-dug wells frequently show elevated coliform contamination due to inadequate source protection and vulnerability to surface water infiltration (Alabi *et al*., 2024; Idowu *et al*., 2011).

Interestingly, the absence of E. coli despite the presence of total coliforms may reflect several possibilities: (1) contamination sources other than recent fecal material, (2) die-off of more sensitive E. coli in stored or treated water while more resilient coliforms persist, or (3) sampling and detection limitations. Adugna *et al*. (2024), in a systematic review of pathogenic indicator bacteria in Ethiopian household drinking water, reported that total coliforms often persist in water systems even after fecal indicator bacteria become undetectable, particularly in tropical climates where environmental coliforms can proliferate in water storage systems.

The reported waterborne disease experience in this community is alarming, with 46% of households experiencing water-related illness in the past six months. This finding significantly exceeds the national averages reported in previous studies and suggests substantial ongoing transmission of waterborne pathogens. The predominance of self-reported typhoid fever (78.2% of reported illnesses) is particularly striking and warrants careful interpretation.

The high prevalence of typhoid fever reports aligns with broader epidemiological patterns across Nigeria. Studies in various Nigerian cities have consistently identified typhoid fever as a major waterborne disease burden, with hospital-based surveillance showing typhoid accounting for 39.3% of waterborne disease cases in some urban areas (Adegbola *et al*., 2010; Enabulele and Awunor, 2016). The Severe Typhoid in Africa programme documented high disease incidence exceeding 100 per 100,000 person-years in several African countries including Nigeria, highlighting typhoid as a major public health challenge in the region (Marks *et al*., 2024).

However, the exceptionally high proportion of typhoid reports in this study raises questions about diagnostic accuracy. In many Nigerian healthcare settings, presumptive typhoid diagnosis based on clinical presentation and Widal test results may lead to overdiagnosis, as these methods have limited specificity (Enabulele and Awunor, 2016). Nevertheless, the substantial burden of febrile illness attributed to waterborne transmission underscores the urgent need for improved water quality and sanitation interventions.

The reported incidence of diarrhea (13%), cholera (4.4%), and combined diarrhea-typhoid (4.4%) further emphasizes the ongoing transmission of enteric pathogens through water and sanitation pathways. These findings are consistent with studies linking inadequate water quality to increased odds of household diarrheal disease in Nigeria (Adamu *et al*., 2022). Contaminated water and poor sanitation are linked to diseases including cholera, diarrhea, dysentery, hepatitis

A, typhoid, and polio, and microbiologically contaminated drinking water is estimated to cause approximately 505,000 diarrhoeal deaths annually worldwide (WHO, 2023).

The sanitation profile of Utagban Community revealed generally positive practices, with 93% of households using flush toilets and 95% having access to handwashing facilities near toilets. These figures considerably exceed national averages for Nigeria, where many communities still rely on pit latrines or practice open defecation. The WHO/UNICEF Joint Monitoring Programme reported that in 2022, 419 million people globally practiced open defecation, and 3.5 billion lacked safely managed sanitation services (WHO/UNICEF, 2023).

Hand hygiene practices appeared strong, with 97% of respondents always washing hands after toilet use and before food preparation. However, the actual practice of using soap during handwashing revealed gaps, with only 61% always using soap, 30% sometimes using soap, and 9% only when available. This inconsistency in soap usage represents a critical vulnerability, as handwashing with soap is one of the most cost-effective interventions for preventing diarrheal diseases and other infections (WHO, 2023).

The waste disposal practices showed concerning patterns, with 41% of households either dumping waste in open spaces (18%), burning waste openly (23%), or burying it (3%). These practices can contribute to environmental contamination and groundwater pollution through leachate generation, potentially affecting borehole and well water quality. Studies in similar Nigerian urban settings have documented significant associations between proximity to waste dumps and elevated microbial contamination of groundwater sources (Alabi et al., 2024).

Paradoxically, despite relatively good sanitation infrastructure and hygiene practices, only 29% of respondents described themselves as "very aware" of WASH importance, while 49% reported being "not aware." This gap between practice and conscious awareness suggests that good behaviors may be culturally embedded rather than based on informed understanding of disease transmission pathways. Health education interventions targeting this knowledge gap could potentially enhance adherence to optimal practices and improve household water safety management.

The integration of questionnaire data, physicochemical analysis, and microbiological testing reveals a complex picture of water quality in Utagban Community. While physicochemical parameters generally met international standards, indicating minimal chemical contamination, the microbiological quality showed significant deficiencies, particularly in groundwater sources (wells and boreholes). This pattern is typical of many Nigerian urban communities where chemical pollution may be limited, but microbial contamination remains the primary water quality challenge (Egbueri *et al*., 2022).

The disconnect between the relatively acceptable microbiological test results (particularly the absence of E. coli) and the high reported burden of waterborne diseases suggests several possibilities: (1) temporal variation in water quality not captured by single-point sampling, (2) post-collection contamination during storage and handling, (3) seasonal influences on water quality, or (4) disease transmission through pathways not evaluated in this study, such as food contamination or person-to-person transmission.

Alabi *et al*. (2024) demonstrated significant seasonal variations in water quality across Nigerian communities, with aerobic and coliform bacterial counts varying substantially between dry and wet seasons. The timing of sampling in relation to seasonal patterns may have influenced the results obtained in this study. Additionally, the potential for biofilm formation and bacterial regrowth in household storage containers, particularly given the monthly cleaning frequency reported by many households, could contribute to water quality degradation between source and point of consumption (Kumpel *et al*., 2020).

Conclusion

This comprehensive assessment of drinking water quality in Utagban Community, Benin City, revealed concerning microbiological contamination despite generally acceptable physicochemical parameters. The heavy reliance on sachet water and the high reported burden of waterborne diseases, particularly typhoid fever, underscore the urgent need for multi-faceted interventions addressing water source protection, household water treatment and storage practices, and environmental sanitation. While the absence of E. coli in tested samples provides some reassurance, the presence of total coliforms and elevated heterotrophic bacterial counts, particularly in groundwater sources, indicates ongoing vulnerabilities in water safety.

The findings contribute to the growing body of evidence documenting persistent water quality challenges in Nigerian urban communities and highlight the continued relevance of improved WASH interventions for public health protection. Achieving Sustainable Development Goal 6, which aims to ensure availability and sustainable management of water and sanitation for all, will require intensified efforts addressing the specific challenges identified in this and similar communities across Nigeria. The integration of improved source water protection, household-level interventions, robust monitoring systems, and comprehensive health education represents the most promising pathway toward ensuring safe drinking water access for all residents of Utagban Community.

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Appendix 1

Appendix 2

Appendix 2