WATER QUALITY ASSESSMENT OF HARVESTED RAINWATER IN BENIN CITY, EDO STATE, NIGERIA.

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A PROJECT SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING, FACULTY OF ENGINEERING, UNIVERSITY OF BENIN, BENIN CITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINNERING (B.Eng.) DEGREE. IN UNIVERSITY OF BENIN, BENIN CITY, NIGERIA

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PLAGIARISM

This work **WATER QUALITY ASSESSMENT OF HARVESTED RAINWATER IN BENIN CITY, EDO STATE, NIGERIA** by AGWAZIE Abraham, with Mat. Number ENG2002084, of The Department of Civil Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria, has PASSED the PLAGIARISM TEST.

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HEAD OF DEPARTMENT

DEDICATION

I dedicate this endeavor primarily to God, who has been my unwavering support throughout my academic journey. A heartfelt tribute to my beloved parents, Mr. and Mrs. Agwazie, whose guidance, love, care and financial support have been instrumental in shaping my path. Gratitude extends to my siblings who stood by me in challenging moments. My prayer is that the benevolent forces above continue to safeguard, guide and bestow blessings upon them, Amen.

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I express deep appreciation to my parents and siblings, whose immense contributions have been pivotal to my academic journey. May God Almighty bless and enrich you all.

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ACRONYMS

TSS - Total Suspended Solids

WQI - Water Quality Index

TDS -Total Dissolved Solids

DO - Dissolved Oxygen

WHO -World Health Organization

NTU - Nephelometric Turbidity Units

TCU - True Color Units

Na - Sodium

K -- Potassium

FAO - Food and Agriculture Organization

NSDWQ - Nigerian Standard for Drinking Water Quality

ABSTRACT

This study assessed the water quality of harvested rainfall in different parts of Benin City, Edo State, Nigeria, due to increasing dependence on rainwater as an alternative domestic water source amid erratic municipal supply. The research aimed to evaluate the physicochemical and bacteriological quality of harvested rainwater from three communities—Ekosodin, BDPA, and Oluku—comparing direct rainfall and rooftop catchment sources. It further aimed to determine their Water Quality Index (WQI) using the Arithmetic weightage index model.

Rainwater samples were systematically collected from pre-selected rooftops with different materials (corrugated iron, aluminum, and asbestos) and direct rainfall collectors. Standard laboratory methods were used for analyzing physicochemical parameters—pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), hardness, salinity, bicarbonate, chloride, sulfate, nitrate, heavy metals (Fe, Cd, Pb, Cu, Zn, Cr, Ni, V), and microbiological indicators. The results indicated that directly collected rainwater in all locations had excellent quality with pH (6.6–6.8), low EC (70–80 μS/cm), low TDS (41–45 mg/L), and negligible microbial contamination (0 CFU/mL). These samples had WQI values between 20 and 23, classifying them as "excellent" and safe for drinking and domestic use after minimal treatment such as filtration or boiling. However, rooftop-harvested rainwater showed slightly elevated concentrations of Fe (0.557 mg/L), Pb (0.026 mg/L), and Cd (0.01 mg/L).

In conclusion, harvested rainwater in Benin City is an important alternative water source but varies in quality based on collection method and surface. While direct rainfall met WHO and NSDWQ standards and can be safely used for domestic purposes, rooftop-harvested rainwater requires adequate treatment—through filtration, disinfection, and proper maintenance of roofing and storage systems—to ensure safety. The study recommends that individuals, communities, and government agencies adopt regular testing before use.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Water is the world's most valuable resource. Water sustains all plant, animal, and human life. No society can exist without a healthy clean source of water. The majority of the world and Nigeria are also equally plagued with very severe water-related issues supplying safe water. In Benin City, one may often not be able to serve everyone, even with public water, as there are issues with infrastructure, frequent poor upkeep or no water during some months of the year. It is for this reason that many people opt for alternative water sources to provide their homes and one that is popular and affordable is rainwater harvesting. Rainwater harvesting is a process of gathering rainwater from your roof or any other location and saving it to use later.

Because it is easy to do, inexpensive and that it is eco-friendly, the system is common among the inhabitants of rural and city communities. The majority of structures and houses in Benin City harvest rainwater during rainy times since there is not enough water from the city's supply. This water from plastic or cement tanks is used to facilitate a human being to clean, cook, bathe and, in some homes, even drink. This initial rainwater is clean but could collect some types of impurities as it flows over roofs, gutters and finally to the containers. These impurities can include dust, soot, bird droppings, leaves, insects or chemicals applied to treat the roofs. Also, just like the situation of air pollution, the houses or industries around or waste from the city may contribute significantly to the purity of the water we get from rain. Thus, using rainwater for your needs may be more dangerous than you can imagine more often, especially if it is not well treated or checked. This research attempts to address some of the key issues regarding the application of harvested rainwater in Benin City.

To begin with, it will determine if rainwater obtained at different locations of the city meets the anticipated safety levels.

This encompasses examining how weather makes rainwater quality harvested from roofs change. Second, the Water Quality Index will be computed for rainwater samples through the study to definitively reveal whether the water is "safe" or "unsafe" for various purposes. Third, through research, helpful guidance concerning what the harvested rainwater can safely be utilized for—drinking, cooking, washing, or gardening—will be provided depending on the quality rating. For such a purpose, the study will be systemic. Rainwater samples will be collected from various locations around Benin City, representing different types of places: residential, commercial estates, and industrial estates. Laboratory analysis of each sample will determine its physical, chemical, and biological properties.

This information that is gathered will be computed and utilized in calculating the Water Quality Index via the Arithmetic Weightage Index Model. Next, the samples of water will be ranked according to their WQI values and recommendations provided accordingly, depending on their appropriateness for various uses. Lastly, the research is relevant and timely because it will give critical information to the public as well as the scientific community. Through determining the quality of rainwater collected from different areas of Benin City, this study will direct better water management and public health. This study will further raise awareness on why rainwater needs to be tested and treated prior to consumption.

1.2 Statement of the Problem

Clean and portable water is still a problem in Nigeria, even in Benin City. Because the city is growing at a rapid pace, its public water supply cannot keep up with increased demand. Most of its residents now depend on alternative sources such as boreholes, wells, and particularly harvested rainwater, due to affordability as well as being environmentally friendly.

Very little is done for the quality of rainwater collected although it is in high demand. Although everybody thinks that it is safe straight from heaven above, rainwater is contaminated on its journey through dirty air, dirty rooftops, gutters, or dirty tanks. There are contaminants like dust, bird droppings, and factory wastes that can significantly affect its safety, especially in urban areas where pollution is diverse.

This research investigates whether rainwater harvested from different environments—residential, commercial, and industrial—is safe for use. The problem is that little public and scientific information is available regarding the safety of the water. Most consumers do not analyze the water prior to consumption, hence exposing them to waterborne diseases.

To prevent this, the study will utilize the Arithmetic Weightage Index Model of the Water Quality Index (WQI) that provides a simple water safety grade based on the number of parameters. This simplifies it to easily reduce complicated laboratory test results into a single figure to ease judgment on water usability.

1.3 Aim and Objectives

The main aim of this research is to assess the water quality of harvested rain water in different parts of Benin City, Edo State, Nigeria.

The specific objectives are:

1. To assess the physical, chemical, and biological quality of harvested rainwater in Benin City, Edo State, Nigeria.

2. To determine the Water Quality Index (WQI) of rainwater samples from different locations using the Arithmetic Weightage Index Model.

3. To evaluate the suitability of harvested rainwater for domestic uses.

4. To provide recommendations for safe usage and treatment of rainwater.

1.4 Scope of Study

This study focuses on the quality of harvested rainwater in different parts of Benin City (Ekosodin community, 19th Street and Environment, Oluku Community). The research aims to provide a comprehensive assessment of rainwater by examining its physical, chemical, and biological characteristics. The central idea is to determine how clean or contaminated rainwater is in various locations studied and, based on that, suggest the most suitable ways to use it—whether for drinking, cooking, cleaning, or irrigation.

1.5 Justification of the Study

The research is prompted by the widespread and on-going practice of rainwater harvesting in Benin City due to inadequate public water supply and unreliability. Highly populated areas like Ekosodin, 19th and Environs., and Oluku suffer perpetual water shortages and rely on rainwater harvesting systems for domestic consumption—ranging from drinking and cooking to bathing and laundry (Igbinosa and Aighewi, 2017). Although widely utilized, the majority of the such rainwater is accumulated and harvested without treatment or quality evaluation of any type, posing an enormous risk to public health through potential contamination with air-borne contaminants, roof debris, and soiled storage reservoirs.

The older sub-areas like GRA, Ugbowo Government Quarters, and Ikpoba Hill employ municipal or borehole water and have only infrequently practiced rainwater harvesting, meaning spatial disparities in access to water in the city.

As rainwater collected may be polluted by microbials and chemicals—such as Escherichia coli, heavy metals, and high turbidity due to previous research findings (Adeniyi and Olabanji, 2005; Amoo et al., 2019)—its quality is seriously in need of scientific evaluation. The present investigation uses the Water Quality Index (WQI) for converting laboratory jargon into an easy score to meet public health convenience and awareness for water safety (Agaja et al.).

The research thus not only presents information to guide safe rainwater use in high-dependence areas but also supports better water management and public health policy within Benin City.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The existing source of information on water quality and rainwater harvesting is thoroughly reviewed in this chapter. Recurring terms and notions, relevant theories, important parameters, existing norms, and the many factors, which affect the quality of rainwater, are generalized. The specific attention is paid to the Water Quality Index (WQI) modelling framework, the guidelines of the World Health Organization (WHO) and previous studies are revisited. The review, therefore, provides a very insightful theoretical foundation on the assessment of rainwater quality in Benin City.

2.1 Water Quality Concepts

2.1.1 Definition

The quality of water can be defined as the physical, chemical and biological characteristics of drinkable water which determines how appropriate it can be used in drinking, cooking, irrigating and industrial processes. Quality water is essential to the socio-economic development and environment sustainability as well as human health. On the other hand, the low water quality will trigger water-borne diseases, including cholera, typhoid and diarrhea, which pose major public-health threats, especially in third-world societies like in Nigeria (World Health Organization [WHO], 2017). In example of Benin City, water-quality evaluation is essential due to the use of alternative source of water in the region due to unreliable public water supply, and it is crucial that the quality of rainwater collected be properly assessed before allowing it to be used in the domestic setup (Igbinosa et al.). A fine knowledge of water quality would help to optimize management processes in treating water and finally make clear the safe uses of the water to the end users and in turn, reduce health hazards and promotion of sustainable water management.

2.1.2. Physical, Chemical, and Biological Parameters

Physical, chemical, and biological are the three broad classes of parameters used in water quality measurement. Each class provides information on different aspects of water usability and safety.

Physical Parameters

Physical parameters include sensory qualities such as turbidity, color, taste, odor, and temperature. Turbidity is a measure of the cloudiness of water caused by suspended material that can contain pathogens and reduce the effectiveness of disinfection treatments (WHO, 2017). Elevated turbidity, for instance, may signal dust or organic contamination, which is characteristic of harvested rainwater (Adeniy & Olabanji, 2005). Colour, taste, and smell are sensory parameters that determine user acceptability; metallic or fishy smells in water may be a sign of chemical or organic contamination (Ojo, 2016). Temperature affects microbial growth, with higher temperature facilitating the growth of pathogens, thus temperature is an important parameter in stored rainwater (Igbinosa et al.).

Chemical Parameters

Chemical parameters encompass compounds like pH, total dissolved solids (TDS), nitrates, nitrites, and heavy metals (like lead, copper). The pH measure, the acidity or basicity of water, should be 6.5-8.5 for drinking so that notably different figures discourage taste and health (WHO, 2017). TDS is an estimate of dissolved salts and minerals, and high levels are expected to impact taste or indicate contamination (Amoo et al., 2019). Nitrates, typically introduced by farm runoff, are toxic to infants, and heavy metals from dirty air or shingles have the potential to concentrate in rainwater and cause long-term health issues (Nriagu & Pacyna, 1988).

Biological Parameters

Biological parameters consist of microorganisms such as bacteria (e.g., Escherichia coli), viruses, and algae. Ecoli or coliforms typically indicates fecal contamination from sources such as bird droppings from roofs, rendering water unsafe to drink without treatment (Igbinosa et al.). Algae and mold can develop on badly maintained storage tanks, infecting water quality and possibly making individuals sick (WHO, 2017). These biological contaminants are less of a problem in rural regions but more of a problem in urban regions like Benin City, where environmental pollution assists in elevating the contamination risks.

2.2 Theoretical Framework

The theoretical framework provides theoretical backing for the establishment of factors influencing the quality of harvested rainwater in Benin City. Four theories underpin this study, and these are water pollution, environmental determinism, Water Quality Index (WQI), and public health theory. All these theories collectively address the sources of contamination, the environment's role, methods of evaluation, and the effect on health as a result of the consumption of harvested rainwater.

2.2.1 Theories of Water Pollution

Water pollution assumptions explain how pollutants enter and contaminate water resources, including rainwater. The pollution load theory postulates that natural as well as human-induced impurities build up in water bodies and lower the quality (Galloway et al., 1984). In rainwater harvesting, pollutants from the environment such as sulfur dioxide and nitrogen oxides from industrial activities and automobile emissions can be dissolved in rainwater during rainfall, forming acid rain or chemical pollution (Likens et al., 1996). In urban centers like Benin City, the pollution is ubiquitous from vehicle and industrial emissions with the potential of polluting the quality of harvested rainwater. This theory highlights the need to quantify chemical content in rainwater in detecting and correcting contamination points.

2.2.2 Environmental Determinism

Environmental determinism argues that environmental nature determines natural resource quality and availability, e.g., water. The theory outlines how site-related parameters, e.g., air, roof coverings, and source of pollution distance, influence rainwater quality (Weathers et al., 2006). Rainwater collected in Benin City's industrial area would be more polluted with heavy metals due to industrial emissions atmospheric deposition, while houses with roofs comprising a combination of materials (e.g., zinc, asbestos) would yield mixed pollutants (Amoo et al., 2019). Environmental determinism involves the reality that local environmental conditions need to be considered when analyzing water saved from rain because they make it ready to be used at home.

2.2.3 Water Quality Index Theory

Water Quality Index theory provides a technique for summarizing complex water quality data in a single, readable number that shows overall water safety. Arithmetic Weightage Index Model employed in this study assigns weights to water quality parameters (such as pH, turbidity, E. coli) based on their health impact and scores to categorize water as Excellent, Good, Poor, Very Poor, or Unsuitable (Agaja et al.,). This model works best in conveying water quality to the common person, thereby making residents of Benin City aware if rainwater harvested is drinkable or can be utilized for non-drinking applications like irrigation. The WQI theory rationalizes the study aim of providing clear, actionable findings after laboratory testing.

2.2.4 Arithmetic Weightage Index Model

The Arithmetic Weightage Index Model is a statistical method used to calculate a weighted average of various parameters or indicators. The Arithmetic Weightage Index Model uses weighted average calculations to compute the WQI. It assigns weight to each parameter and computes the quality rating to evaluate the overall water quality (Ramakrishnaiah et al., 2009). It is commonly used in decision making and evaluation processes such as assessing water quality, environmental impacts. (Chatterjee & Raziuddin, 2002).

2.2.5 Public Health Theory

Public health theory emphasizes the relationship between water quality and disease prevention, particularly in regions of limited access to safe water. Diarrhea, colera, and typhoid are some of Nigeria's main public health concerns and are most commonly transmitted through contaminated water (World Health Organization [WHO], 2017). Chemical or biological contaminants like Escherichia coli from bird droppings or chemical contaminants from roofing materials are health risks when not treated to rainwater harvesting (Igbinosa et al.). The case is for rigorous testing and treatment of the harvested rainwater to WHO safety standards for public protection where dependency is increasing in Benin City because of periodic municipal supplies.

2.3 Water Quality Parameters

This refers to the water quality parameters that are very crucial indicators used to ascertain the usability and safety of rainwater collected, particularly in urban cities like Benin City, where contamination rates are controlled by environmental elements. The parameters are physical, chemical, or biological in nature, with specific details concerning water quality. Evaluation of these parameters makes rainwater collected safe for consumption or non-potable uses, such as irrigation, and prescribes treatment measures that need to be undertaken (World Health Organization [WHO], 2017).

2.3.1 Physical Parameters

Physical parameters are sensory characteristics affecting the esthetics and safety of water. Significant physical parameters are:

a) **Turbidity:** Turbidity is an index of the clarity of water with higher values indicating suspended matter like silt, clay, or pathogenic organic material. According to WHO (2017), turbidity must be less than 5 Nephelometric Turbidity Units (NTU) in drinking water since high turbidity reduces disinfection and even indicates roof debris contamination (Adeniy & Olabanji, 2005).

b) **Color:** The water should be colorless and the WHO (2017) has a maximum limit of 15 True Color Units (TCU). Colored water may be caused by organic matter or chemical impurities and affect acceptability by the user and signify contamination potential (Ojo, 2016).

c) **Taste and Odour:** Safe water should be free from objectionable odours or tastes, as a result of organic pollutants, algae, or chemical contaminants like heavy metals. For instance, metallic tastes in collected rainwater may be indicative of roof material leaching (Amoo et al., 2019).

d) **Temperature:** Microbial development is influenced by temperature, and higher temperatures will promote pathogen growth. Rainwater collected in tanks exposed to heat in Benin City might require cooling or treatment before it can be considered safe for use (Igbinosa et al.).

2.3.2 Chemical Parameters

Chemical parameters are odorless and colorless substances that affect water's safety, taste, and acceptability with regard to infrastructure. The key chemical parameters for rainwater assessment are:

a) **pH**: pH is the water alkalinity or acidity measurement and, as stipulated by WHO, must be between 6.5–8.5 to safely drink water to prevent health issues or storage facility deterioration (WHO, 2017). Urbanization in cities like Benin City can cause acid rainwater pH below 6.5 due to atmospheric pollutants like sulfur dioxide (Likens et al., 1996).

b) **Total Dissolved Solids (TDS):** TDS has also been employed in the determination of dissolved organic content, salt, and minerals, where less than 300 mg/L is acceptable for safety and taste reasons (WHO, 2017). High TDS in harvested rainwater may indicate contamination by dust or roofing material (Amoo et al., 2019).

c) **Nitrates and Nitrites**: These are substances, typically introduced into water via agricultural runoff or atmospheric deposition, which are toxic, particularly to infants, and lead to illnesses like methemoglobinemia. WHO (2017) advises a maximum of 50 mg/L for nitrates in potable water.

d) **Heavy Metals:** Heavy metals such as lead, copper, and cadmium may find their way into rainwater by atmospheric deposition or leaching from roofing materials. They are long-term health risks and encompass neurologic and renal injury (Nriagu & Pacyna, 1988).

2.3.3 Biological Parameters

Biological parameters entail microorganisms which signal contamination as well as health risks. Some of the key biological parameters include:

a) **Coliforms and Escherichia coli:** Fecal contamination, perhaps by bird or animal droppings on roofs, is proved by the presence of total coliforms or E. coli. WHO (2017) requires zero CFU of E. coli per 100 mL for potable water. Studies in Benin City indicated amounts of up to 45.5 CFU/mL of E. coli in harvested rainwater, which would need treatment (Igbinosa et al).

b) **Algae and Mold:** They can develop in dirty storage tanks, especially under warm weather, to discharge toxins into the water, causing water quality effects and health effects such as gastrointestinal irritation (WHO, 2017). The tanks need to be cleaned periodically to prevent such algae from growing in Benin City's rainwater harvesting systems.

2.4 WHO Drinking Water Standards

The World Health Organization (WHO) provides comprehensive guidelines on the quality of drinking water to ensure safety and public health protection. These standards are very critical points of reference for establishing the quality of rainwater harvested in Benin City, due to the uncertainty of municipal supplies. WHO standards give the physical, chemical, and biological requirements for making the water safe for drinking and suitable for other household uses (World Health Organization [WHO], 2017). This section is identifying key WHO standards relative to rainwater harvesting based on health, appearance, and usability parameters.

2.4.1 Significant WHO Standards

WHO (2017) guidelines have some water quality parameters as limits to restrict health risks and establish acceptability. The next standards are of particular significance to quantify harvested rainwater:

a) **Colour**: The water must be colorless with the highest acceptable value of 15 True Colour Units (TCU). Colored water indicates organic or chemical contamination and will affect the acceptability of users as well as could imply health risks (WHO, 2017). Benin City rainwater color could be due to organic or chemical contaminants on the roof (Igbinosa et al.).

b) **Turbidity**: Turbidity should not be greater than 5 Nephelometric Turbidity Units (NTU) in drinking water. Low turbidity discourages effective disinfection and reduces the risk of harboring pathogens, which is significant in rainwater collected from rooftops that is exposed to litter or dust on roofs (WHO, 2017; Adeniy & Olabanji, 2005).

c) **pH**: The pH of drinking water should range between 6.5 and 8.5 in order to be neither alkaline nor excessively acidic. Too low or too high pH changes taste, destroys storerooms, or is harmful to health. Rainwater, which is not uncommon in urban settlements like Benin City due to atmospheric contaminants, typically requires pH-balancing (WHO, 2017; Likens et al., 1996).

d) **Total Dissolved Solids (TDS):** A TDS of less than 300 mg/L is preferred in drinking water so that it tastes good and does not pose any health risks through dissolved minerals or salts. High TDS in harvested rainwater may be a sign of contamination by roofing materials or atmospheric deposition (WHO, 2017; Amoo et al., 2019).

e) **Nitrates**: According to the WHO (2017), the maximum allowable concentration of 50 mg/L nitrates in drinking water to avert health ailments such as methemoglobinemia, especially among infants. Nitrates in rainwater could be due to agricultural runoff or nitrogen oxides from the atmosphere (Galloway et al., 1984).

f) **Heavy Metals**: Lead, copper, and cadmium have to be within specified limits as set by WHO (e.g., 0.01 mg/L for lead) since they are poisonous. Rainwater harvesting in the urban context of Benin City can be concomitant with heavy metals by virtue of industrial pollution or by roof materials, hence the need for cautious monitoring (WHO, 2017; Nriagu & Pacyna, 1988).

g) **Escherichia coli and Coliforms**: Drinking water should have zero CFU of E. coli or fecal coliforms in 100 mL to prevent waterborne disease. Rainwater harvested for collection is particularly susceptible to microbially soiled bird faeces or organic matter on roofs and therefore must be treated in order to meet this standard (WHO, 2017; Igbinosa et al.).

2.4.2 Rainwater Harvesting

Rainwater harvesting is increasingly practiced in urban cities like Benin City, Nigeria, whose municipal water supply is unreliable and has to be supplemented by other sources of water. Definition and significance of rainwater harvesting, quality concerns on the topic of harvested rainwater, and primary factors influencing the quality of rainwater are explained in this section in an attempt to create background for ascertaining its safety and acceptability.

2.5 Use for Rainwater Harvesting

The WHO guidelines form the key point of reference in maintaining the safety of Benin City harvested rainwater. Compliance with the guidelines ensures that harvested rainwater is safe for drinking or suitable for non-potable applications in areas like irrigation or sanitation. Research work currently conducted in Nigeria has provided evidence that harvested rainwater can be inconsistent with the standards of WHO for criteria like E. coli and turbidity due to environmental pollution and improper storage practices (Igbinosa et al., n.d.; Ojo, 2016). For instance, rainwater harvested from roofs in Benin City can be filtered and disinfected to remove microbial and physical contaminants, chemical processes being utilized to adjust pH or for heavy metal removal. Adherence to WHO standards not only guarantees public health but also enhances the acceptability of rainwater harvesting as a secondary source of water in cities.

2.5.1 Definition and Importance

Rainwater harvesting refers to the collection and storage of rainwater from roofs, roads, or ground catchment for domestic, agricultural, or industrial use (World Health Organization [WHO], 2017). In Benin City, where public supply is in doubt and water scarcity is the norm, rainwater harvesting is a cost-effective and viable way of meeting domestic water demand (Igbinosa et al.). Through reduced reliance on overburdened urban systems, it keeps pressure away from groundwater resources and promotes environmental conservation. Harvested rainwater is drinkable, or to use for cooking, watering, or cleaning purposes, as long as its quality is good enough. The purpose of rainwater harvesting is to enhance water security, particularly in densely populated urban areas with low infrastructure (Amoo et al., 2019).

2.5.2 Water Quality Problems in Harvested Rainwater

Harvested rainwater, as good as it is, is vulnerable to contamination, which can taint its safety for household use. Some of the water quality problems are:

a) **Microbial Contamination**: The rainwater that was collected usually contains pathogens such as Escherichia coli or coliforms from avian droppings, animal dung, or organic compounds on the collection surfaces such as roofs. Studies conducted within Benin City recorded up to 45.5 CFU/mL concentrations of E. coli in harvested rainwater, rendering it not fit for consumption without treatment (Igbinosa et al., n.d.; WHO, 2017)

b) **Chemical Contamination**: Automotive exhausts or industrial processes discharge air toxics such as sulfur dioxide and nitrogen oxides that in rainwater dissolve to create acidic pH or elevated nitrates and heavy metal levels (Likens et al., 1996; Nriagu & Pacyna, 1988). Asphalt or zinc roofing also releases chemicals further polluting water (Amoo et al., 2019).

c) **Physical Contamination**: Suspended sediment on collection surfaces, organic matter, or dust can cause turbidity and color, which affect the safety and quality of water and the aesthetic quality. Levels of turbidity that are too high (e.g., 6.4–24.7 NTU) in rainwater collected from rooftops imply that filtration is necessary (Adeniy & Olabanji, 2005).

2.5.3 Environmental Parameters Affecting Rainwater Quality

Some anthropogenic and environmental parameters affect the quality of rainwater harvesting, especially in urban settings such as Benin City:

a) **Environmental Conditions**: The extent of air pollution contributes greatly to rainwater quality. Rainwater is polluted by sulfur dioxide and nitrogen oxides from industrial sources in industrial regions, particularly resulting in acid rain, pH reduction, and chemical pollutant content increase (Likens et al., 1996). Benin City urban air quality, which is gauged by automobile and industrial emissions, increases this threat (Galloway et al., 1984).

b) **Anthropogenic Emissions:** Pollutants are emitted due to human activities, for example, industrial processes and transportation, that subject rainwater during precipitation to contact with them. Factory discharge, for example, emits heavy metals like lead and cadmium into rainwater, which is harmful to human health (Nriagu & Pacyna, 1988).

c) **Catchment Surface**: Surface type and condition of roofing materials, such as rooftops, play a big role in water quality. Metal roofs may leach copper or zinc, and asphalt shingles may leave behind organic matter. Bird-dropping- and debris-covered low-maintenance roofs remain responsible for high levels of pollution (Amoo et al., 2019).

d) **Location**: Urban rainwater is of varying quality compared to rural areas. Urban proximal-distance from industrial sites or traffic locations elevates pollutant deposition above cleaner rural locations (Weathers et al., 2006).

e) **Storage and Handling**: Pesticide pollution is caused by poorly maintained pipes or storage containers. Static tank water encourages mold and algae development, with corroded pipes leaving heavy metals deposits (Igbinosa et al.).

2.6 Rainwater Harvesting Techniques

Rainwater harvesting techniques differ according to collecting surface, and each presents a different implication in terms of water quality and usability. In urban areas such as Benin City in Nigeria, where water scarcity and undependable municipal supplies are the order of the day, these need to be understood for the design of effective systems to provide safe water for domestic or agricultural purposes. There are three main methods of rainwater harvesting that are roof-based, pavement-based, and ground-based, and each one is discussed here in the context of their nature, the upkeep required, and their water quality implications.

2.6.1 Roof-Based Harvesting

Roof-based harvesting involves the gathering of rainwater from roofs and channeled through gutters into reservoirs or tanks for storage. Roof-based harvesting is the most common technique in urban centers like Benin City since rooftops are easily accessible and simple to install in comparison with other techniques (Amoo et al., 2019). The key water quality factors to be considered are:

a) **Roof Maintenance:** There should be regular cleaning of the rooftop to remove debris, bird droppings, and dust, which can contribute physical and microbial contaminants. It was illustrated in a Nigerian study that unclean roofs lead to high Escherichia coli and turbidity of harvested rainwater (Igbinosa et al.).

b) **Roofing Material:** The material of the roof has a significant impact on water quality. Metal roofs constructed from zinc or aluminum and clay tiles are safer and less reactive, while asphalt shingles leach organic compounds and asbestos roofs shed harmful fibers (Amoo et al., 2019). Since metal and asbestos roofs are common in Benin City, the material choice and upkeep should be maintained to prevent chemical contamination.

c) **First-Flush Systems**: First-flush devices, which divert the initial runoff carrying the accumulated pollutants, can improve water quality by decreasing turbidity and microbial content (World Health Organization [WHO], 2017).

2.6.2 Pavement-Based Harvesting

Pavement-run harvesting collects rainwater from paved roofs such as roads, walkways, or courtyards, typically leading runoff to storage tanks or recharge pits. Pavement-run harvesting is not quite common in Benin City but can be seen in some institutions and urban areas. Some factors influencing water quality are:

a) **Pavement Material**: Both asphalt and concrete pavement can leach chemical contaminants, e.g., hydrocarbons from asphalt or heavy metals from vehicle residues, into captured water (Ojo, 2016). Concrete is less reactive but also has the potential to collect contaminants where traffic is high.

b) **Traffic and Pollution:** Urban high-traffic pavements are exposed to pollutants like oil, grease, and tire wear particles that increase physical and chemical contamination

(Weathers et al., 2006). Pavement-collected water in Benin City can render water unsafe for drinking without advanced treatment.

c) **Surface Cleanliness:** Paved surfaces must be regularly swept to reduce debris and microbial contamination, even though it is hard to achieve in open spaces (Adeniy & Olabanji, 2005).

2.6.3 Ground-Based Harvesting

Groundwater collection involves the harvesting of rainwater from natural or treated ground surfaces, such as open areas, or directing it into shallow wells or recharge pits. The practice is not very popular in urban Benin City but is undertaken in peri-urban or rural settlements. Most significant regarding water quality are:

a) **Soil Type**: The composition of the ground surface affects filtration and contamination. Soil composition made of clay can retain contaminants, while soil composition made of sand provides greater filtration but can also permit groundwater contaminants to pass (WHO, 2017). Because there are different soil types in Benin City, utmost care should be taken during site selection.

b) **Groundwater Pollution:** Proximity to agricultural land, septic systems, or industry can potentially lead to the introduction of nitrates, pesticides, or heavy metals into harvested water (Galloway et al., 1984). Urban fringe ground-harvested rainwater could be particularly vulnerable to these kinds of pollutants.

c) **Surface Treatment:** Grounds must be free from organic matter and pollutants in order to minimize pollution. Urban ground-based systems will probably require additional filtration to remove suspended solids (Adeniy & Olabanji, 2005).

2.6.4 Implications for Water Quality Management

There are opportunities and challenges for ensuring water quality for each of the applications. Roof-based systems are optimal in Benin City because of ease of access and lower initial contamination compared to pavement- or ground-based systems. All these approaches, however, require regular upkeep, i.e., cleaning collection surfaces and storage tanks, and using filtration or disinfection equipment to meet WHO standards (WHO, 2017). This kind of knowledge informs rainwater harvesting system design with local relevance in Benin City towards fostering safe and sustainable water usage.

2.7 Emperical Framework

2.7.1 Case Review on Prior Studies

Some of the scholarly literature on water quality assessment of harvested rainwater, especially from Nigeria and other places, acknowledges roofing material, climate, and maintenance culture influences on water quality and environmental health. These studies are as follows:

A 2018 study by B.L. Gav, R.N. Vesuve, and A.O. Ijeomah discusses the heavy metal concentration of rainwater obtained from various roofing sheets in Makurdi, Nigeria. In the study, with the help of Atomic Absorption Spectroscopy (AAS), rusted roofing sheets contained the highest levels of heavy metals, rendering the water undrinkable and further highlighting the need to use a good roof material and maintenance (Gav et al., 2018). Nicole Nawrot and Ewa Wojciechowska (2018) assess trace metal leaching from building roof tops under rainfall conditions of urban runoff pollution. Laboratory examination of the summer storm samples showed copper roofs leached heavy loads of copper (10.23 mg/dm^3) and tar paper roofs leached heavy zinc (15.52 mg/dm^3), while ceramic roofs had minimal contamination. Most of the runoff was within first-grade cleanliness standards, and materialrelated environmental impacts were observed (Nawrot and Wojciechowska, 2018). In 2014 a research evaluates the role of roof materials and lead flashing towards rainwater tank contamination in urban settings. Nine months' trace metal sampling revealed high concentrations of lead in tanks with non-coated lead flashing, and thus implies regular tank cleaning and substituting materials (Magyar et al., 2014). The research by Udo Quek and Jürgen Förster in 1993 examines heavy metal pollution of roof runoff and its contribution to urban hydrology. Zinc sheet roofs increased the concentration of metals, as runoff contained trace metals with concentrations lower than in direct rain, and this demonstrates the application of materials to reduce environmental pollution (Quek and Förster, 1993). Mirela Iulia Magyar, et al. (2008) disseminate heavy metal contamination, lead, of Melbourne rainwater tanks. Pilot roof testing on six roofs indicated that overall exceedance of Australian Drinking Water Guidelines occurred, with uncoated lead flashings contributing significantly, leading to infrastructure and policy change (Magyar et al., 2008). This study examines the leaching of five toxic metals from 14 roof products over rainfall events. Heavy leaching of high levels of metals was witnessed in certain products, but aging alleviated the extent of leaching, which attests to the importance of long-term monitoring and material selection for stormwater management (Winters et al., 2015). A study investigated heavy metal contamination of three kinds of roof runoffs during 14 rain events in 2011. Statistical results showed metal concentrations followed a normal distribution and were influenced by weather and air pollution, and had implications for stormwater management in urban areas (Zhang et al., 2011). This research describe urban soil enrichment with heavy metals due to roof runoff infiltration in Halle/Saale. Heavy metal concentration in soils resulted from long-term infiltration, and there is a need to decrease volume of runoff and metal loads to avoid contamination of soil (Gieska et al., 2000). I.F. Adeniyi and I.O. Olabanji (2005) compare physicochemical and bacteriological properties of rainwater from five roofing material sources in Ile-Ife, Nigeria. Variability in contamination was highly significant by ANOVA and correlation analysis, and no sample was drinkable by micro- and chemical contamination, indicating towards treatment requirements (Adeniyi and Olabanji, 2005). A 2015 article founded on research into rainwater tank contamination in Newcastle, Australia. Exceedance of lead, ammonia, and pH was occasional, but sludge accumulation in tanks can improve water quality with an emphasis on maintenance (Magyar et al., 2015). For the year 2005, I.O. Olabanji and I.F. Adeniyi report nine trace metal analysis in bulk freefall and roof-intercepted rainwater in Ile-Ife, Nigeria. Roof-intercepted water contained higher metal concentrations, type of material and atmospheric pollution being some of the reasons, showing material-specific water quality control measures (Olabanji and Adeniyi, 2005). This study encapsulate roof runoff contamination, with emphasis on leaching of materials and atmospheric deposition. Organic pollutants and heavy metals were invariably in excess in a meta-analysis of over 100 contaminants, prompting recommendations for smarter material choice (De Buyck et al., 2021). Susanne Galster and Brigitte Helmreich (2022) write about the copper and zinc runoff from roofs as corrostion-induced leaching that is harmful to aquatic life. Corrosion is reduced through the process of patina formation but is treated through stormwater quality improvement devices (Galster and Helmreich, 2022). This study compared the leaching of zinc and lead from roof coverings within an urban small catchment. Mass balance modeling confirmed roofs as significant sources of pollution, highlighting source-specific stormwater management (Gromaire et al., 2010). Sarah L. Pennington and Jenny Webster-Brown (2008) reported on the impact of copper roofing on Auckland stormwater runoff in New Zealand. They set up elevated copper concentrations, particularly on first flush, with geochemical modeling affirming the role of pH on the bioavailability, to which mitigation is needed (Pennington and Webster-Brown, 2008). This study simulate urban catchment runoff zinc loads using the MEDUSA2.0 model. Roof type greatly influenced it, and material substitution could reduce zinc by 30%, and low-intervention measures (Charters et al., 2022) came to light. This research investigates Chinese suburban rooftop runoff for lead, zinc, arsenic, and cadmium. Event mean concentrations were generally above standards, and atmospheric deposition was an important contributor, with source control and treatment necessary (Yu et al., 2014). O.M. Ojo (2019) establishes the effect of roof materials on the quality of rainwater harvested in Nigeria. Corrugated iron, aluminum, and asbestos roof samples were acidic with iron, lead, and phosphorus in concentrations above those of WHO, indicating treatment needs for potability (Ojo, 2019). This study compares roof runoff quality by material type in an urban setting. Asbestos roofs contained the highest health risk with highest contaminant levels, with material selection and treatment requirements emphasized (Nicholson et al., 2010). Markus Faller and D. Reiss (2005) have reported five years of metallic roofing material runoff in Switzerland. Copper, zinc, and lead release quantifiable metal ions, while aluminum, stainless steel, and titanium revealed negligible leaching, emphasizing the choice of materials for water quality (Faller and Reiss, 2005). This study writes about emissions from construction materials as a pollutant in Pennsylvania. Laboratory and field testing revealed excessive particulate and metal emission, indicating deficiencies in long-term sustainability research (Clark et al., 2006). The research evaluates the speciation of heavy metals in roof dusts using BCR sequential extraction procedure. Zinc was environmentally dangerous, whereas lead was health dangerous, particularly to children, with a remark on source-specific monitoring (Li et al., 2015). This study examines future roof-collected rainwater pollutants. 44 of 54 targeted pollutants were found, PCA and correlation analysis pinpointing the need for multi-stage sampling in city water systems (Ju et al., 2024). This research analyze trace elements of coal dust in rainwater. The household samples were found to be within Australian Drinking Water Guidelines, reflecting minimal coal dust impact but the necessity for ongoing monitoring in areas of coal (Lucas et al., 2009). Edward S. Young and William E. Sharpe (1984) assess the impact of atmospheric deposition on 40 cisterns that collect roof-catchment. Tap water and sediments with excessive concentrations of lead and copper posed health risks, and monitoring and maintenance were instituted (Young and Sharpe, 1984). This study recorded rainwater quality from various rooftops within the semi-arid region of South Africa. It was contaminated with microbes, so it needed to be treated for consumption while being acceptable for use in non-potable systems (Lihuwani et al., 2025). E.S. Nicholas and Pius O. Ukoha (2023) discuss the influence of roofing material and industrial process on rainwater quality in Southern Nigeria. Physicochemical and heavy metal content analysis showed variable quality highlighting the requirement for treatment to make rainwater safe for household use (Nicholas and Ukoha, 2023). E.S. Nicholas and P.O. Ukoha (2024) contrast roofing materials with galvanized iron tanks in Rivers State, Nigeria. Flame-AAS analysis revealed diverse water quality where some samples required purification to be consumed safely, highlighting material choice (Nicholas and Ukoha, 2024). V. Meera and M. Mansoor Ahammed (2018) discuss roof-harvested rainwater quality determinants. Contamination was largely influenced by the type of materials and dynamics in rain, with bacteriological issues requiring treatment before being used safely (Meera and Ahammed, 2018). This research assessed storage tanks, thatched roofs, and industrial processes within southeastern Nigeria. WQI analysis revealed irregular contamination, with most samples needing treatment to render them potable (Nicholas et al., 2024). R.A. Olaoye (2012) compares four Nigerian rooftop rainwater qualities. While most parameters were within WHO standards, chloride, hardness, and microbial pollution had to be disinfected for drinking (Olaoye, 2012). M.C. Enedoh (2023) discusses leaching of roof sheets in Imo State, Nigeria, through EDXRF. Metro tiles leached high concentrations of toxic metals, while zinc and aluminum were less toxic, confirming their appropriateness for use in harvesting systems (Enedoh, 2023). Olaoye and Olaniyan (2012) investigated the impact of roofing material on rainwater quality in Nigeria. pH and hardness values were most times above standard, and microbial contamination required treatment for safety purposes prior to consumption (Olaoye amd Olaniyan, 2012). JT Utsev (2013) looks at the impact of roof type on rainwater quality in Nigeria's Gboko. More recently installed roofs had less pollution, but microbial and chemical contaminants did render most samples suitable for non-potable use only after treatment (Utsev, 2013). Isoken H. Igbinosa and Isoken T. Aighewi (2017) evaluate rainwater quality in Nigeria's Edo State. Although most physicochemical parameters met World Health Organization (WHO) guidelines, high levels of lead and cadmium created health concerns requiring engineered systems and monitoring (Igbinosa and Aighewi, 2017).

CHAPTER THREE

METHODOLOGY

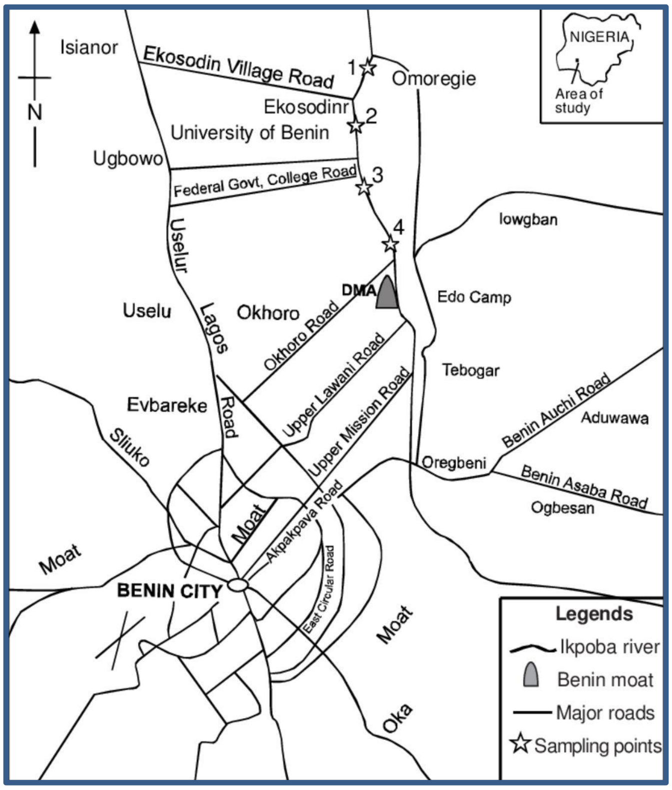
3.1 STUDY AREA

3.1.1 Overview of Ugbowo

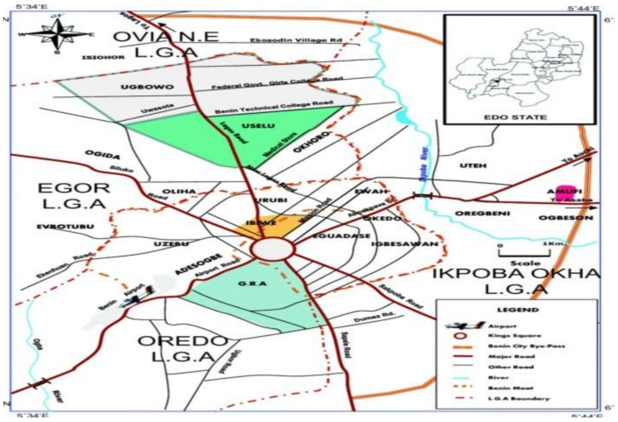
The study will be conducted in Benin City, Edo State, Southern Nigeria. Benin is located in Nigeria's humid tropical rainforest belt with two common seasons: wet season (April to October) and dry season (November to March). Mean annual rainfall between 1,700 mm and 2,000 mm is an ideal place to conduct a study on rainwater harvesting.

Ugbowo is a big Benin City township of Edo State, Nigeria, and is home to the University of Benin, thereby a town of learning and residence. Since it lies on the Ugbowo-Lagos Road, it receives moderate to high traffic, and therefore can be a source of air pollution in the atmosphere, which would accordingly affect rainwater quality. The region is supposed to possess a mixed content of roofing materials, including corrugated iron, aluminum, and modern tiles, impacting the concentration levels of contaminants in collected rainwater (Benin – Wikipedia, 2025).

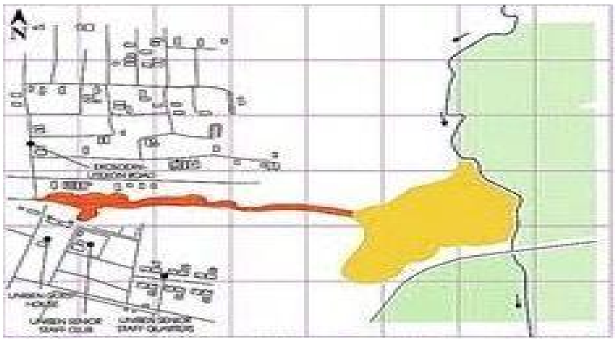
In Benin City, in particular, the study will be conducted in three neighborhoods in the Ugbowo district, viz. Ekosodin, 19th and Environs., and Oluku. They are chosen due to their distinct patterns of land use, socioeconomic differences, and the common practice of rooftop rainwater utilization for household or supplementary purposes.



Ekosodin Map



BDPA Map



Oluku Map

Figure 1: Map of Benin city

3.1.2 Ekosodin

Ekosodin, near Ugbowo, is a site for high-density student residential hostels. The use of less expensive or older roofing material, e.g., corrugated iron, can lead to higher contamination by rust and abandonment and compromise the quality harvested rainwater (Benin – Wikipedia, 2025).

3.1.3 Benin Development and Planning Area (BDPA)

The Benin Development and Planning Area (BDPA) in Ugbowo, Benin City, Edo State, Nigeria, is a peri-urban community where harvested rainwater serves as a critical water source due to limited municipal water distribution. Studies relevant to the project topic, "Water Quality Assessment of Harvested Rainwater," highlight the influence of roofing materials on rainwater quality in this region. Research conducted in nearby communities, such as Oluku and Ugbihioko, shows that rainwater harvested from corrugated iron (60%), aluminum (20%), and asbestos (10%) roofs often contains elevated levels of heavy metals (e.g., lead, copper, iron) and microbial contaminants, frequently exceeding WHO drinking water standards (Igbinosa and Aighewi, 2017). Physicochemical parameters like pH (often acidic, 4.7–5.7), turbidity, and nutrient levels vary, influenced by roofing materials and environmental factors (Igbinosa et al., 2017).

3.1.4 Oluku

Oluku, a peri-urban settlement is said to have 60% corrugated iron roofing materials with heavily contaminated heavy metals, above threshold levels of lead and cadmium, and this means the water must be treated (Benin – Wikipedia, 2025).

3.1.5 Geographical and Demographic Context

Benin City, capital of Edo State, is a city in Nigeria's South-South geopolitical zone, and Ugbowo is one of the central neighborhoods located about 7.1 km from city center. Data on Ugbowo proper populace are not readily available, although as a university town it could be expected to have high student and workforce populace, implying increased water demand and potential risk of pollution.

Ekosodin, a community around Ugbowo, is largely renowned for housing students with over 500 buildings serving as hostels, (Benin – Wikipedia, 2025)

3.1.6 Climate and Rainfall Patterns

The climate of Benin City is a tropical savanna climate (Köppen type "Aw"), with an average annual temperature of 26.7°C and high rainfall between April and October, peaking in June and July, according to Weather Spark. Rainy season with stormy weather is best for rainwater harvesting but with a greater potential for contamination from atmospheric deposition and roof runoff, particularly the first flush, (Benin – Wikipedia, 2025).

3.1.7 Roofing Material and Contribution

Material and type of roofing material determine the quality of collected rainwater. In Oluku, Igbinosa and Aighewi carried out a study in 2017, and the results showed 60% of roofs composed of corrugated iron sheets, 20% aluminum, 10% asbestos, and 10% open space, with heavy metal contamination, particularly lead and cadmium, way above WHO standards (Igbinosa and Aighewi, 2017). Given the proximity in location and similar urban environment, Ugbowo, Ekosodin, and 19th and Environs. would likely share similar distributions of roofing materials, of which corrugated iron and aluminum are the common ones, especially for low-income or older structures.

In Ugbowo, the University of Benin closeness would mean a combination of aged and new materials like stone-coated tiles and aluminum. Ekosodin, being student hostel bearing, would have more aged corrugated iron or asbestos roofs, which rust and leach, (Ojo, 2019). 19th and Environs., the middle one, could have more variations but the higher traffic volume and industrial use would come with more atmospheric deposition, enhancing pollutant loads.

3.2 Research Methodology for Water Quality Assessment of Harvested Rainwater

3.2.1 Part 1: Study Design and Sampling

Study design and sampling will inform the design by which the representative rainwater will be collected from various roof structures for comprehensive water quality analysis. I will accomplish this by the following:

a. **Site Selection:** Ekosodin, 19th and Environs. and Oluku are selected sites. 6 residential houses with different roofing materials (e.g., corrugated iron, aluminum, asbestos, and zinc) will be sampled in order to acquire variability, through strategy compliance by (Nicholas and Ukoha, 2023).

b. **Roofing Materials Characterization:** Roofing materials will be described by condition, age, and type (e.g., rust or coated) from in situ observations and household questionnaires, as outlined by (Utsev, 2013). This will include documentation of the presence of lead flashing or other components that influence contamination, as documented by (Magyar et al., 2014).

c. **Sampling Strategy:** Roof runoff rainwater will be sampled at least three different events of rainfall to capture temporal variability, employing the multi-stage sampling strategy of (Ju et al., 2024). At least 6 samples will be obtained, 1 sample per event, employing clean pre-sterilized polyethylene bottles to avoid external contamination, as suggested by (Adeniyi and Olabanji, 2005).

d. **Storage System Evaluation:** Storage vessel samples will be collected (e.g., plastic tanks, galvanized iron tanks) to evaluate their impact on water quality, as directed by Nicholas et al. (2024). Storage conditions, such as cleaning frequencies, will be documented in terms of evaluating the impact of sediment accumulations, as detailed by (Magyar et al., 2015).

e. **Control Samples:** Bulk bulk free-falling rainwater samples (roof-intercepted not) will be collected from all the sites to act as a point of reference baseline, as it was performed by (Olabanji and Adeniyi, 2005). This will allow for disconnecting the role of roofing materials towards contamination.

f. **Preserving samples:** The samples will be preserved at the time of collection by being stored in a field cooler that is portable and held under 4°C and reported to the laboratory within 24 hours, according to standard procedures provided by (Olaoye and Olaniyan, 2012).

3.2.2 Part 2: Laboratory Analysis

Laboratory analysis will be geared towards determining the physicochemical and microbial rainwater parameters sampled for analysis acceptability for domestic consumption. I will conduct the following:

a. **Physicochemical Analysis:** This will be measured using standard methods, as outlined by (Olaoye and Olaniyan, 2012). pH will be determined by using a calibrated pH meter, turbidity with a turbidimeter, and total hardness and chloride by titration methods, according to standard HCl titration method (Enedoh, 2023). Heavy metal levels, i.e., lead (Pb), zinc (Zn), cadmium (Cd), iron (Fe), and copper (Cu), will be determined by Flame Atomic Absorption Spectrophotometry (Flame-AAS), as employed by (Nicholas and Ukoha, 2024). Standard solution calibration will ensure accuracy, and detection limits will be determined according to (Quek and Förster, 1993).

b. **Microbiological Analysis:** Total coliforms, fecal coliforms, and Escherichia coli will be enumerated by the membrane filtration technique, based on (Lihuwani et al., 2025). The samples will undergo incubation at appropriate temperatures (35–37°C for total coliforms, 44.5°C for fecal coliforms) for detecting microbial contamination.

c. **Quality Control:** Stringent quality-control measures will be followed. All equipment will be calibrated and the analysis conducted in a secure area.

3.2.2.1 Physical Properties

The physical properties tests: temperature, pH, turbidity, total suspended solids, and colour are critical for assessing the suitability of harvested rainwater for domestic use and its environmental impact (Enedoh, 2023).

1. Temperature

Aim

To measure the temperature of harvested rainwater to assess its suitability for potable use.

Apparatus/Equipment

i. Digital pH meter with temperature probe (e.g., Hach HQ40d)
ii. Deionized water for rinsing
iii. Lint-free cloth for probe cleaning
iv. Field notebook and pen for documentation
v. Cooler for sample storage (if needed post-measurement)

Procedure

Temperature will be measured in situ using a calibrated digital pH meter with a temperature probe, recording values in degrees Celsius (°C). This aligns with assessing physical properties of harvested rainwater to ensure compliance with WHO guidelines (Olaoye and Olaniyan, 2012).

Precautions

i. Calibrate the temperature probe with standards at 0°C and 50°C before use to ensure accuracy (Olaoye and Olaniyan, 2012).
ii. Avoid touching the probe to container walls or bottoms to prevent false readings (Olaoye and Olaniyan, 2012).
iii. Conduct measurements under stable weather conditions to minimize external influences (Olaoye and Olaniyan, 2012).
iv. Rinse the probe with deionized water and store in a protective case to prevent damage and contamination (Olaoye and Olaniyan, 2012).

v. Perform blank measurements with deionized water to verify probe accuracy, recalibrating if deviations exceed 0.2°C (Olaoye and Olaniyan, 2012).

2. **pH**

Aim

To measure the pH of harvested rainwater to assess its acidity or alkalinity, which is influenced by roofing materials and atmospheric deposition (Ojo, 2019).

Apparatus/Equipment

i. Digital pH meter with glass electrode (e.g., Hach HQ40d)
ii. pH buffer solutions (pH 4, 7, and 10) for calibration
iii. Deionized water for rinsing
iv. Lint-free cloth for electrode cleaning
v. Field notebook and pen for documentation
vi. Cooler for sample storage (if needed post-measurement)

Procedure

pH will be determined using a digital pH meter with a glass electrode, ensuring accurate assessment of rainwater quality from different roofing materials (Olaoye and Olaniyan, 2012).

Precautions

i. Calibrate the pH meter with buffer solutions at pH 4, 7, and 10 before each session (Olaoye and Olaniyan, 2012).
ii. Rinse the electrode with deionized water and blot with a lint-free cloth between samples to prevent cross-contamination (Olaoye and Olaniyan, 2012).

iii. Immerse the electrode fully in the sample, avoiding contact with container walls or sediment (Olaoye and Olaniyan, 2012).
iv. Allow the reading to stabilize for 1–2 minutes before recording (Olaoye and Olaniyan, 2012).
v. Store the electrode in a storage solution or deionized water, recalibrating if drift exceeds 0.2 pH units (Olaoye and Olaniyan, 2012).

3. **Turbidity**

Aim

To assess the cloudiness of harvested rainwater caused by suspended particles from roofing materials or atmospheric deposition (Enedoh, 2023).

Apparatus/Equipment

i. Turbidity meter (e.g., Hach 2100Q)
ii. Calibration standards (0 NTU, 10 NTU, 100 NTU)
iii. Deionized water for rinsing
iv. Clean sample vials with caps
v. Lint-free cloth for cleaning
vi. Field notebook and pen for documentation

Procedure

Turbidity will be measured using a turbidity meter to evaluate the impact of roofing materials on rainwater clarity, aligning with WHO standards (Enedoh, 2023).

Precautions

1. Calibrate the turbidity meter with standards at 0 NTU, 10 NTU, and 100 NTU before each session (Enedoh, 2023).
2. Fill sample vials without air bubbles and wipe with a lint-free cloth to prevent interference with light transmission (Enedoh, 2023).
3. Avoid exposing samples to sunlight to prevent algal growth or particle settling (Enedoh, 2023).
4. Take readings within 30 minutes of collection to minimize changes in suspended particle stability (Enedoh, 2023).
5. Rinse sample vials with deionized water and store the meter in a protective case (Enedoh, 2023).

3.2.2.2 Chemical Properties

The chemical properties tests: BOD, COD, heavy metals, and nutrient levels are crucial for assessing the organic and inorganic contamination in harvested rainwater (Magyar et al., 2008). These tests evaluate the potential environmental impact on receiving waters and compliance with WHO standards.

1. **Biochemical Oxygen Demand (BOD)**

Aim

To determines the organic load in harvested rainwater, which can be influenced by organic matter deposited on roofs or leached from materials like tar paper (Nicholas and Ukoha, 2024).

Apparatus/ Equipment

- i. BOD incubator (e.g., Lovibond ET 108) set at 20°C
- ii. Dissolved oxygen (DO) meter with probe
- iii. 300 mL BOD bottles with glass stoppers
- iv. Pipettes and volumetric flasks
- v. Deionized water for dilution
- vi. Nutrient buffer solution (e.g., phosphate buffer)
- vii. Field notebook and pen for documentation
- viii. Cooler for sample storage

Procedure

BOD will be measured over five days using a BOD incubator and dissolved oxygen meter to assess the organic contamination in rainwater collected from various roofing materials (Nicholas and Ukoha, 2024).

Precautions

- i. Calibrate the DO meter with air-saturated water before use (Nicholas and Ukoha, 2024).
- ii. Fill BOD bottles to overflow without air bubbles to prevent oxygen contamination (Nicholas and Ukoha, 2024).
- iii. Store samples at 4°C and begin incubation within 6 hours of collection (Nicholas and Ukoha, 2024).
- iv. Maintain the incubator at 20°C ± 1°C for 5 days to ensure consistent microbial activity (Nicholas and Ukoha, 2024).

v. Use sterile techniques and avoid sunlight exposure to prevent photo-oxidation (Nicholas and Ukoha, 2024).

2. Chemical Oxygen Demand (COD)

Aim

To determine the total oxygen required to oxidize organic and inorganic matter in harvested rainwater (Galster and Helmreich, 2022).

Apparatus/Equipment

1. COD digestion apparatus (e.g., Hach DRB200)
2. COD vials with pre-measured dichromate reagent
3. Spectrophotometer (e.g., Hach DR3900) set at 620 nm
4. Pipettes and volumetric flasks
5. Deionized water for dilution
6. Heating block or oven for digestion
7. Field notebook and pen for documentation
8. Cooler for sample storage

Procedure

COD will be measured using a COD digestion apparatus and spectrophotometer, focusing on contaminants leached from roofing materials (Nicholasuksi and Ukoha, 2024).

Precautions

i. Calibrate the spectrophotometer with a blank COD vial before use (Nicholas and Ukoha, 2024).
ii. Handle COD reagents with gloves in a well-ventilated area to avoid exposure to toxic chemicals (Nicholas and Ukoha, 2024).
iii. Add samples to COD vials without air bubbles to ensure accurate digestion (Nicholas and Ukoha, 2024).
iv. Maintain digestion temperature at 150°C ± 2°C for 2 hours (Nicholas and Ukoha, 2024).
v. Cool vials to room temperature before measurement and dispose of used vials as per safety protocols (Nicholas and Ukoha, 2024).

3. Heavy Metals

Aim

To measure heavy metals (e.g., lead, zinc, copper, cadmium) in harvested rainwater, as roofing materials like uncoated lead flashing or zinc sheets are significant sources of metal contamination (Olabanji and Adeniyi, 2005).

Apparatus/Equipment

1. Atomic Absorption Spectrophotometer (e.g., PerkinElmer AAnalyst 400) or EDXRF (e.g., Thermo Scientific Niton XL3t)
2. Standard metal solutions for calibration
3. Nitric acid for sample digestion
4. Deionized water for rinsing
5. Pipettes and volumetric flask
6. Field notebook and pen for documentation

7. Cooler for sample storage

Procedure

Heavy metal concentrations will be analyzed using Atomic Absorption Spectrophotometry or Energy Dispersive X-ray Fluorescence (Olabanji and Adeniyi, 2005).

Precautions

i. Calibrate the instrument with standard metal solutions before analysis (Olabanji and Adeniyi, 2005).
ii. Digest samples with nitric acid in a fume hood to ensure safety and complete metal extraction (Enedoh, 2023).
iii. Rinse equipment with deionized water between samples to prevent cross-contamination (Olabanji and Adeniyi, 2005).
iv. Analyze samples within 24 hours of collection, storing at 4°C if delayed (Enedoh, 2023).
v. Dispose of digested samples as hazardous waste per safety protocols (Enedoh, 2023).

4. **Nutrient Levels**

Aim

To determine the nutrient levels (e.g., phosphorus, nitrogen) in harvested rainwater (Karczmarczyk et al., 2020).

Apparatus/Equipment

i. Spectrophotometer (e.g., Hach DR3900) for colorimetric analysis
ii. Ion chromatograph (e.g., Thermo Scientific Dionex) for precise nutrient quantification
iii. Standard nutrient solutions (e.g., phosphate, nitrate)

iv. Deionized water for dilution
v. Pipettes and volumetric flasks
vi. Field notebook and pen for documentation
vii. Cooler for sample storage

Procedure

Nutrient concentrations will be measured using colorimetric methods or ion chromatography, as used in studies of roof runoff (Nicholson et al., 2010).

Precautions

i. Calibrate the spectrophotometer or ion chromatograph with standard solutions before use (Nicholson et al., 2010).
ii. Filter samples to remove particulates before analysis to ensure accuracy (Karczmarczyk et al., 2020).
iii. Rinse equipment with deionized water between samples to avoid cross-contamination (Nicholson et al., 2010).
iv. Analyze samples within 24 hours, storing at 4°C if delayed (Karczmarczyk et al., 2020).
v. Dispose of chemical reagents as per safety protocols (Nicholson et al., 2010).

3.2.2.3 Biological Properties

The biological properties tests (total microbial content, coliform counts, and pathogen detection) are essential for assessing the safety of harvested rainwater for potable use, as roofing materials and atmospheric deposition can introduce microbial contamination (Lihuwani et al., 2025).

1. **Total Microbial Content**

Aim

To measure the total microbial content in harvested rainwater (Lihuwani et al., 2025).

Apparatus/Equipment

1. Autoclave (e.g., Tuttnauer 2540M) for sterilization
2. Membrane filtration unit (e.g., Millipore) with 0.45 µm filters
3. Nutrient agar plates (e.g., Oxoid)
4. Petri dishes
5. Incubator set at 37°C
6. Pipettes and sterile diluent (e.g., 0.9% saline solution)
7. Sterile forceps and gloves
8. Field notebook and pen for documentation
9. Cooler for sample storage

Procedure

Total microbial content will be measured using membrane filtration and nutrient agar plates, as applied in studies of rainwater quality in Nigeria (Lihuwani et al., 2025).

Precautions

i. Sterilize equipment in the autoclave at 121°C for 15 minutes to prevent cross-contamination (Lihuwani et al., 2025).

ii. Wear sterile gloves and work in a laminar flow hood to minimize airborne contaminants (Lihuwani et al., 2025).

iii. Filter samples within 2 hours of collection, storing at 4°C if delayed (Lihuwani et al., 2025).

iv. Use sterile saline for dilutions and avoid touching the filter surface (Lihuwani et al., 2025).

v. Incubate plates at 37°C ± 1°C for 24–48 hours in the dark and dispose of materials as biohazard waste (Lihuwani et al., 2025).

2. **Coliform Count**

Aim

To quantify the total and fecal coliforms in harvested rainwater (Lihuwani et al., 2025).

Apparatus/Equipment

1. Sterile multiple-tube fermentation tubes (10 mL, 1 mL, 0.1 mL volumes)
2. Lauryl Tryptose Broth (LTB) or MacConkey Broth for presumptive test
3. Brilliant Green Lactose Bile Broth (BGLBB) or EC Broth for confirmatory test
4. Durham tubes for gas production detection
5. Incubator set at 35°C and 44.5°C for fecal coliforms
6. Pipettes and sterile diluent (e.g., 0.9% saline solution)
7. Sterile gloves and forceps
8. Field notebook and pen for documentation
9. Cooler for sample storage

Procedure

Coliform counts will be determined using the Most Probable Number (MPN) technique with fermentation tubes (Lihuwani et al., 2025).

Precautions

i. Sterilize glassware and broth media at 121°C for 15 minutes (Lihuwani et al., 2025).
ii. Wear sterile gloves and work in a clean area to minimize contamination (Lihuwani et al., 2025).
iii. Inoculate tubes within 2 hours of collection, storing at 4°C if delayed (Lihuwani et al., 2025).
iv. Incubate tubes at 35°C ± 0.5°C for total coliforms and 44.5°C ± 0.2°C for fecal coliforms, checking for gas production (Lihuwani et al., 2025).
v. Dispose of used tubes and media as biohazard waste, avoiding aerosol inhalation (Lihuwani et al., 2025).

Pathogen Detection

Aim

To determine specific pathogens (e.g., Escherichia coli, Salmonella, Pseudomonas) in harvested rainwater (Igbinosa and Aighewi, 2017). This ensures the rainwater's safety for potable use.

Apparatus/Equipment

1. Autoclave for sterilization
2. Selective media (e.g., MacConkey agar for E. coli, XLD agar for Salmonella)
3. Biochemical test kits (e.g., API 20E for identification)
4. Incubator set at 37°C
5. Pipettes and sterile diluent
6. Sterile petri dishes and gloves
7. Field notebook and pen for documentation

8. Cooler for sample storage

Procedure

Pathogen detection will use selective media and biochemical tests, as employed in Nigerian rainwater quality assessments (Igbinosa and Aighewi, 2017).

Precautions

i. Sterilize all equipment at 121°C for 15 minutes (Lihuwani et al., 2025).
ii. Use sterile gloves and a laminar flow hood to prevent contamination (Lihuwani et al., 2025).
iii. Process samples within 2 hours, storing at 4°C if delayed (Igbinosa and Aighewi, 2017).
iv. Use selective media specific to target pathogens to ensure accurate identification (Lihuwani et al., 2025).
v. Dispose of cultures as biohazard waste per safety protocols (Igbinosa and Aighewi, 2017).

3.2.3 Part 3: Data Analysis and Interpretation

Data analysis and interpretation will be combined with laboratory data in attempting to compare water quality to a standard and conclude on important contaminant factors. I will achieve this by:

a. **Data Compilation:** Physicochemical and microbial data will be compiled into a database for statistical analysis, following the approach of (Igbinosa and Aighewi, 2017). The results will be segregated based on roofing material, storage type, and rain event.

b. **Water Quality Index (WQI) Calculation:** A Water Quality Index shall be computed using the Arithmetic Weightage Index Model to categorize water samples as excellent, good, or unfit for use. pH, turbidity, heavy metals, and microbial concentration will be weighted according to World Health Organization (WHO) and Nigerian Drinking Water Quality Standards.

Arithmetic Weightage WQI model. (Brown et al., 1970; Tyagi et al., 2013). Steps:

i. Constant of proportionality k

$$k = \frac{1}{\sum 1/Sn} \qquad \text{Eq. (3.2)}$$

K is proportionality constant

ii. Perimeter weightage Wn

$$Wn = \frac{k}{Sn} \qquad \text{Eq. (3.1)}$$

Where Wn = perimeter weightage; k = constant for proportionality; Sn = standard value (WHO guideline).

iii). Quality rating Qn

$$Qn = 100\ (\frac{Vn - Vi}{Sn - Vi}) \qquad \text{Eq. (3.3)}$$

Where Qn = quality rating, Vn = laboratory test result of parameters, Vi = ideal value of parameter (it is zero for all parameters except pH which is equal to 7.0 and dissolved oxygen which is equal to 14.6mg/L)

iv). Overall WQI

$$\text{WQI} = \frac{\sum (Qn\, x\, Wn)}{\sum (Wn)} \qquad \text{Eq. (3.4)}$$

Interpreted against thresholds:

0–25: Excellent

26–50: Good

51–75: Poor

76–100: Very poor

> 100: Unsuitable

c. **Reference to Standards:** Comparison with World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) standards will be used to ascertain potability, as mandated by (Olaoye and Olaniyan, 2012). Excesses of the heavy metals or microbial load will be highlighted as a health risk.
d. **Reporting and Recommendations:** Tabulation of results will be included in the final report in the form of levels of contamination, most important factors determining, material selection recommendations, treatment regimens, and system maintenance recommendations. Results will be shared with stakeholders as part of informing policy and public health interventions.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of laboratory analyses conducted on harvested rainwater from 3 communities in Benin; Ekosodin, BDPA, and Oluku. Water samples were collected using direct rainfall collection and rooftop catchment collection methods and the physicochemical and microbial parameters were analyzed.

4.2 physicochemical and microbial analyses results from harvested rainwater in ekosodin

Table 4.1: physicochemical and microbial analyses results from harvested rainwater in ekosodin

parameters	Standard units	Direct rainfall	Rooftop catchment	WHO standards	interpretation
pH		6.8	6.7	6.5 - 8.5	Within range; slightly acidic but acceptable.
EC	MS/cm	65	68	< 1000	Very low — indicates low ionic content and minimal dissolved solids.
Sal.	g/L	0.036	0.035	< 0.5	Excellent; very fresh water.
Col.	Pt.Co	ND	0.7	< 15	Excellent.
Turbidity	NTU	ND	0.4	< 5	Excellent clarity; rooftop sample slightly higher due to roof dust.
TSS	Mg/l	ND	1.1	< 30	Well below limit; low suspended solids.
TDS	Mg/l	50	49	< 500	Excellent — very low dissolved solids.
COD	Mg/l	9.9	8.7	< 10	Within limit; low organic

					load.
HCO_3	Mg/l	22.9	22.5	No specific limit	Typical for rainwater; safe.
Na^+	Mg/l	0.55	0.54	< 200	Normal levels; no health risk.
K^+	Mg/l	0.20	0.17	< 12	Normal levels; no health risk.
Ca^{2+}	Mg/l	3.12	2.18	< 75	Normal levels; no health risk.
Mg^{2+}	Mg/l	1.85	1.72	< 50	Normal levels; no health risk.
Cl^-	Mg/l	30.3	28.5	< 250	Very low; safe.
P	Mg/l	0.052	0.045	< 5	Very low; no eutrophication risk.
NH_4–N	Mg/l	0.663	0.061	< 0.5	Slightly high for direct rainwater, could indicate atmospheric nitrogen or pollution.
NO_2	Mg/l	0.005	0.005	< 1.0	Excellent; no contamination
NO_3	Mg/l	0.022	0.022	< 10	Excellent; no contamination
SO_4	Mg/l	0.012	0.11	< 250	Excellent.
Fe^{3+}	Mg/l	0.413	0.555	< 0.3	Slightly above standard — may cause metallic taste. Likely from roofing material or atmospheric dust.
Mn^{2+}	Mg/l	0.123	0.131	< 0.2	Safe.
Zn^{2+}	Mg/l	0.203	0.225	< 3.0	Safe.
Cu^{2+}	Mg/l	0.202	0.112	< 0.5	Safe.
Cr^{3+}	Mg/l	ND	0.052	< 0.05	safe
Cd^{2+}	Mg/l	ND	0.016	< 0.003	slightly above permissible limit
Ni^{2+}	Mg/l	ND	0.013	< 0.02	safe
Pb^{2+}	Mg/l	ND	0.023	< 0.01	slightly above permissible limit
V	Mg/l	ND	0.07	< 0.1	safe

THC	Mg/l	ND	ND	< 100	
Hardness	Mg/l	15.8	12.6	< 100 (soft); < 300 (acceptable)	Soft water — good.
Total heterotrophic bacterial counts	CFU/ML	0×10^3	3×10^3	< 100	Rooftop sample shows bacterial contamination from roof and dust; direct rainfall sterile.
Total coliform counts	CFU/ML	0×10^3	0×10^3	0	No coliforms.
Total E coli counts	CFU/ML	0×10^3	0×10^3	0	No E coli
Tentative isolates		NIL	NIL		----

a) **Physicochemical Quality:** Both samples are soft, fresh, and low in dissolved solids. Direct rainwater shows excellent quality chemically, while rooftop rainwater shows slightly elevated metals (Fe, Cd, Pb) and microbial load — typical for harvested water that contacts roofs and gutters. Trace metals like Pb and Cd in rooftop water are concerning. Lead (0.023 mg/L) and Cadmium (0.016 mg/L) exceed WHO limits (0.01 and 0.003 mg/L respectively).

b) **Microbiological Quality:** Direct rainfall is sterile (0 counts), indicating clean atmospheric rain. Rooftop catchment shows 3,000 cfu/mL heterotrophic bacteria, suggesting contamination from roof dust, bird droppings, and debris. Though no coliform or E. coli were detected, high heterotrophic counts make it unsuitable for direct drinking without treatment.

i. **Direct Rainwater (Ekosodin):** Excellent quality — chemically and bacteriologically safe for most purposes including drinking after basic filtration.
ii. **Rooftop Harvested Rainwater:** Slightly contaminated with metals and bacteria; not fit for direct consumption, but usable for domestic and non-potable purposes after treatment.

4.3 Physicochemical and Microbial Analysis results from harvested rainwater in BDPA.

Table 4.2: Physicochemical and Microbial Analysis results from harvested rainwater in BDPA.

parameters	Standard units	Direct rainfall	Rooftop catchment	WHO standards	interpretation
pH		6.8	6.5	6.5 - 8.5	Within range; slightly acidic but acceptable.
EC	MS/cm	80	68	< 1000	Very low — indicates low ionic content and minimal dissolved solids.
Sal.	g/L	0.036	0.031	< 0.5	Excellent; non saline
Col.	Pt.Co	ND	0.8	< 15	Excellent; clear water.
Turbidity	NTU	ND	0.5	< 5	Excellent clarity; clear water
TSS	Mg/l	ND	1.0	< 30	low suspended solids.
TDS	Mg/l	40	34	< 500	Excellent — very low dissolved solids.
COD	Mg/l	10.2	8.8	< 10	Acceptable; low organic load.
HCO_3	Mg/l	22.5	21.0	No specific limit	Normal range; safe.
Na^+	Mg/l	0.53	0.45	< 200	Normal levels; no health risk.
K^+	Mg/l	0.21	0.18	< 12	Normal levels; no health risk.
Ca^{2+}	Mg/l	3.11	2.17	< 75	Normal levels; no health risk.
Mg^{2+}	Mg/l	1.89	1.71	< 50	Normal levels; no health risk.

Cl^-	Mg/l	30.2	28.1	< 250	Excellent; safe. No salinity risk
P	Mg/l	0.051	0.042	< 5	Safe.
NH_4–N	Mg/l	0.064	0.060	< 0.5	Slightly high but acceptable, could indicate atmospheric nitrogen or pollution.
NO_2	Mg/l	0.005	0.005	< 1.0	Excellent; no contamination
NO_3	Mg/l	0.021	0.020	< 10	Excellent; no contamination
SO_4	Mg/l	0.011	0.010	< 250	Excellent.
Fe^{3+}	Mg/l	0.410	0.556	< 0.3	Slightly above standard — possible leaching from roof or pipes.
Mn^{2+}	Mg/l	0.124	0.131	< 0.2	Within limits.
Zn^{2+}	Mg/l	0.201	0.223	< 3.0	Safe.
Cu^{2+}	Mg/l	0.102	0.110	< 0.5	Safe.
Cr^{3+}	Mg/l	ND	0.051	< 0.05	Slightly above limit. May come from roof corrosion.
Cd^{2+}	Mg/l	ND	0.017	< 0.003	Above limit – toxic metal; unsafe if ingested.
Ni^{2+}	Mg/l	ND	0.010	< 0.02	Within limit.
Pb^{2+}	Mg/l	ND	0.024	< 0.01	Exceeds permissible limit – indicates contamination from roofing materials.
V	Mg/l	ND	0.008	< 0.1	safe
THC	Mg/l	ND	ND	< 100	------
Hardness	Mg/l	15.5	12.5	< 100 (soft); < 300 (acceptabl	Soft water — good.

				e)	
Total heterotrophic bacterial counts	CFU/ML	0×10^3	3×10^3	< 100	Rooftop sample shows bacterial contamination from roof and dust; indicates roof and air borne bacteria.
Total coliform counts	CFU/ML	0×10^3	0×10^3	0	No coliforms
Total E coli counts	CFU/ML	0×10^3	0×10^3	0	No E. coli
Tentative isolates		NIL	Enterobacter sp. Bacillus sp.		Presence of microbial contamination

a) **Physicochemical Quality:** Both samples are chemically good with low conductivity, TDS, and salinity, showing that the water is soft, clean, and low in dissolved solids. The direct rainfall has all parameters within standard limits except slightly high Fe (0.41 mg/L). The rooftop catchment sample shows minor contamination with Fe, Cr, Cd, and Pb — typically from metal roofing sheets or atmospheric deposits.

b) **Microbial Quality:** Direct rainfall is completely sterile (no bacterial growth). Rooftop sample contain 3000 cfu/mL heterotrophic bacteria — very high. It also contains Enterobacter species: opportunistic bacteria found in soil and dust; and Bacillus species: spore-forming bacteria from soil or air. Though not pathogenic at low levels, their presence means the water is not safe for drinking without disinfection.

i. **Direct Rainfall Water (BDPA):** Excellent quality, low salinity, soft, and chemically safe. Suitable for drinking and domestic use after simple filtration.

ii. **Rooftop Catchment Water (BDPA):** Poor quality due to presence of heavy metals (Cd, Pb, Cr) and microbial contamination (Enterobacter sp., Bacillus sp.). Not safe for drinking. Can be used for domestic, agricultural, and cleaning purposes after basic filtration and disinfection.

4.4 Physicochemical and Microbial Analyses results from harvested rainwater in Oluku.

Table 4.3: Physicochemical and Microbial Analyses results from harvested rainwater in Oluku.

parameters	Standard units	Direct rainfall	Rooftop catchment	WHO standards	interpretation
pH		6.7	6.6	6.5 - 8.5	slightly acidic but acceptable.
EC	MS/cm	70	79	< 1000	Very low clean and low ionic content.
Sal.	g/L	0.035	0.032	< 0.5	Excellent; fresh water
Col.	Pt.Co	ND	0.9	< 15	Excellent
Turbidity	NTU	ND	O.7	< 5	Very clear; rooftop slightly higher due to dust
TSS	Mg/l	ND	1.2	< 30	low suspended solids.
TDS	Mg/l	45	41	< 500	Excellent — very low dissolved solids.
COD	Mg/l	10.3	8,9	< 10	Acceptable; low organic pollution
HCO_3	Mg/l	22.3	22.0	No specific limit	Normal range; safe.
Na+	Mg/l	0.63	0.62	< 200	Normal levels; no health risk.
K+	Mg/l	0.23	0.20	< 12	Normal levels; no health risk.
Ca2+	Mg/l	3.13	2.16	< 75	Normal levels; no health risk.
Mg2+	Mg/l	1.87	1.73	< 50	Normal levels; no health risk.
Cl-	Mg/l	30.4	28.3	< 250	Excellent; safe. No salinity risk
P	Mg/l	0.053	0.044	< 5	Very low.
NH_4–N	Mg/l	0.066	0.062	< 0.5	Acceptable, atmospheric source possible
NO_2	Mg/l	0.006	0.005	< 1.0	Excellent; no contamination

NO_3	Mg/l	0.023	0.020	< 10	Excellent; no contamination
SO_4	Mg/l	0.013	0.010	< 250	Excellent.
Fe^{3+}	Mg/l	0.411	0.557	< 0.3	Slightly above standard — May cause mild taste possible
Mn^{2+}	Mg/l	0.126	0.130	< 0.2	Within limits.
Zn^{2+}	Mg/l	0.200	0.222	< 3.0	Safe.
Cu^{2+}	Mg/l	0.103	0.100	< 0.5	Safe.
Cr^{3+}	Mg/l	ND	0.050	< 0.05	Slightly above permissible limit
Cd^{2+}	Mg/l	ND	0.016	< 0.003	Above limit – potentially toxic if consumed regularly
Ni^{2+}	Mg/l	ND	0.012	< 0.02	Within limit.
Pb^{2+}	Mg/l	ND	0.026	< 0.01	Exceeds permissible limit – indicates contamination from roofing corrosion.
V	Mg/l	ND	0.009	< 0.1	safe
THC	Mg/l	ND	ND	< 100	-----
Hardness	Mg/l	15.7	12.4	< 100 (soft); < 300 (acceptable)	Soft water — good.
Total heterotrophic bacterial counts	CFU/ML	0×10^3	3×10^3	< 100	Rooftop contaminated-likely from roof dust or bird droppings. No E. coli or coliforms detected, so no fecal contamination
Total coliform counts	CFU/ML	0×10^3	0×10^3	0	No coliforms
Total E coli	CFU/ML	0×10^3	0×10^3	0	No E. coli

counts					
Tentative isolates		NIL	NIL		No Tentative isolates

a) **Physicochemical Quality:** Both samples show very low TDS, EC, and salinity, meaning they are soft, fresh, and chemically clean. The direct rainfall sample meets almost all WHO and NSDWQ standards, except for slightly high iron (0.411 mg/L) — a minor issue likely from atmospheric dust. The rooftop catchment sample has slightly higher concentrations of Fe, Cd, Pb, and Cr, typical of metal roof corrosion and environmental deposition.

b) **Microbiological Quality:** Direct rainwater is completely sterile. Rooftop sample contains 3000 cfu/mL heterotrophic bacteria, showing microbial buildup on roof surfaces. However, absence of coliform and E. coli indicates no fecal contamination, only environmental bacteria.

i. **Direct Rainwater (Oluku):** Excellent quality; meets most WHO and NSDWQ limits. It can be used for drinking and domestic purposes after minimal treatment (e.g., filtration, boiling).

ii. **Rooftop Catchment (Oluku):** Poor quality due to metal leaching and microbial contamination. Unsafe for drinking without filtration + disinfection. Acceptable for domestic and agricultural use after basic treatment

4.5 Water Quality Index calculation using Arithmetic Weightage Index Model

4.5.1 Rooftop catchment from Ekosodin

Table 4.4: Water Quality Index calculation using Arithmetic Weightage Index Model

S/N	Parameter	Sn	Vn	1/Sn	$Wn = \frac{k}{Sn}$	$Qn = 100\ (\frac{Vn-Vi}{Sn-Vi})$	Qn x Wn
1	pH	8.5	6.7	0.118	${}^{2.14}/_{8.5} = 0.25$	$100[\frac{6.7-7}{8.5-7}]$ = -20	-6.4
2	Turbidity	5	0.4	0.2	${}^{2.14}/_{5}$ =0.428	$100[\frac{0.4-0}{5-0}]$ = 8	4.352
3	TSS	30	1.11	0.033	${}^{2.14}/_{30} = 0.071$	$100[\frac{1.11-0}{30-0}]$ = 3.7	0.3367
4	TDS	500	49	0.002	${}^{2.14}/_{500} = 0.00428$	$100[\frac{49-0}{500-0}]$ = 9.8	0.53312
5	Cl	250	28.5	0.004	${}^{2.14}/_{250} = 0.00856$	$100[\frac{28.5-0}{250-0}]$ = 11.4	0.1254
6	COD	10	8.7	0.1	${}^{2.14}/_{10} = 0.214$	$100[\frac{8.7-0}{10-0}]$ = 87	17.2956
7	Hardness	100	12.6	0.01	${}^{2.14}/_{100} = 0.0214$	$100[\frac{12.6-0}{100-0}]$ = 12.6	0.3427
$\sum$				0.467	0.99724		16.58552

$$K = \frac{1}{\sum {}^{1}/_{Sn}} = \frac{1}{0.467} = 2.14$$

$$WQI = \frac{\sum Qn\ x\ Wn}{\sum Wn} = \frac{16.58552}{0.99724} = 16.63$$

Interpretation according to Arithmetic Weightage WQI Scale: EXCELLENT.

4.5.2 Rooftop catchment from BDPA

Table 4.5: Rooftop catchment from BDPA

S/N	Parameter	Sn	Vn	1/Sn	$Wn = \frac{k}{Sn}$	$Qn = 100\ (\frac{Vn-Vi}{Sn-Vi})$	Qn x Wn

1	pH	8.5	6.5	0.118	$^{2.14}/_{8.5}$ = 0.25	$100[\frac{6.5-7}{8.5-7}]$ = -33.33	- 8.3325
2	Turbidity	5	0.5	0.2	$^{2.14}/_{5}$ =0.428	$100[\frac{0.5-0}{5-0}]$ = 10	4.28
3	TSS	30	1.0	0.033	$^{2.14}/_{30}$ = 0.071	$100[\frac{1.0-0}{30-0}]$ = 3.33	0.23643
4	TDS	500	34	0.002	$^{2.14}/_{500}$ = 0.00428	$100[\frac{34-0}{500-0}]$ = 6.8	0.0291
5	Cl	250	28.1	0.004	$^{2.14}/_{250}$ = 0.00856	$100[\frac{28.1-0}{250-0}]$ = 12.5	0.0962
6	COD	10	8.8	0.1	$^{2.14}/_{10}$ = 0.214	$100[\frac{8.7-0}{10-0}]$ = 88	18.832
7	Hardness	100	12.5	0.01	$^{2.14}/_{100}$ = 0.0214	$100[\frac{12.6-0}{100-0}]$ = 12.5	0.2675
∑				0.467	0.99724		15.21633

$$K = \frac{1}{\sum {}^{1}/_{Sn}} = \frac{1}{0.467} = 2.14$$

$$WQI = \frac{\sum Qn \; x \; Wn}{\sum Wn} = \frac{15.21633}{0.99724} = 15.26$$

Interpretation according to Arithmetic Weightage WQI Scale: EXCELLENT.

4.5.3 Rooftop catchment from Oluku

Table 4.6: Rooftop catchment from Oluku

S/N	Parameter	Sn	Vn	1/Sn	$Wn = \frac{k}{Sn}$	$Qn = 100\ (\frac{Vn-Vi}{Sn-Vi})$	Qn x Wn
1	pH	8.5	6.6	0.118	$^{2.14}/_{8.5}$ = 0.25	$100[\frac{6.6-7}{8.5-7}]$ = -26.67	- 6.6675
2	Turbidity	5	0.7	0.2	$^{2.14}/_{5}$ = 0.428	$100[\frac{0.7-0}{5-0}]$ = 14	5.992

3	TSS	30	1.2	0.033	$^{2.14}/_{30} = 0.071$	$100[\frac{1.2-0}{30-0}] = 4$	0.284
4	TDS	500	41	0.002	$^{2.14}/_{500} = 0.00428$	$100[\frac{41-0}{500-0}] = 8.2$	0.035096
5	Cl	250	28.3	0.004	$^{2.14}/_{250} = 0.00856$	$100[\frac{28.3-0}{250-0}] = 5.66$	0.04845
6	COD	10	8.9	0.1	$^{2.14}/_{10} = 0.214$	$100[\frac{8.9-0}{10-0}] = 89$	19.096
7	Hardness	100	12.4	0.01	$^{2.14}/_{100} = 0.0214$	$100[\frac{12.4-0}{100-0}] = 12.4$	0.26536
∑				0.467	0.99724		19.00

$$K = \frac{1}{\sum {}^{1}/_{Sn}} = \frac{1}{0.467} = 2.14$$

$$WQI = \frac{\sum Qn \ x \ Wn}{\sum Wn} = \frac{19.00}{0.99724} = 19.05$$

Interpretation according to Arithmetic Weightage WQI Scale: EXCELLENT.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study assessed the quality of harvested rainwater in three communities in Benin City-Ekosodin, BDPA, and Oluku-in order to determine its suitability for domestic use. The study focused on evaluating the physical, chemical, and biological characteristics of harvested rainwater, determining its Water Quality Index (WQl), assessing its suitability for domestic use, and providing recommendations for safe utilization.

Firstly, the study assessed the physical, chemical, and biological quality of harvested rainwater in the selected communities. The results showed that most of the physicochemical parameters such as pH, electrical conductivity, turbidity, total dissolved solids, and major ions were within acceptable limits recommended by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ). However, rooftop-harvested rainwater showed slightly higher concentrations of some heavy metals and microbial contaminants due to contact with roofing materials and environmental pollutants.

Secondly, the Water Quality Index (WQI) of the harvested rainwater samples was calculated using the Arithmetic Weightage Index Model. The results indicated that directly collected rainwater from Ekosodin, BDPA, and Oluku had WQl values that fall within the “excellent” water quality category, indicating that the water is generally suitable for drinking and domestic purposes after minimal treatment.

Thirdly, the study evaluated the suitability of harvested rainwater for domestic uses. The findings revealed that directly collected rainfall is generally safe for domestic activities such as drinking, cooking, washing, and bathing after basic purification methods such as boiling or filtration.

However, rooftop-harvested rainwater may require additional treatment due to possible contamination from roofing materials, dust, bird droppings, and atmospheric pollutants.

Finally, the study provided recommendations for the safe use and management of harvested rainwater in Benin City. Proper maintenance of roof catchment systems, installation of first-flush devices, regular cleaning of storage tanks, and basic treatment methods such as filtration and disinfection are necessary to ensure safe usage of harvested rainwater.

Overall, the study demonstrates that harvested rainwater can serve as a reliable alternative water source in Ekosodin, BDPA, and Oluku, especially in areas where public water supply is limited.

However, appropriate treatment and proper maintenance of rainwater harvesting systems are essential to ensure that the water remains safe for domestic consumption.

5.2 Recommendations

Based on the results and observations from this study, the following recommendations are made:

(i) To Individuals and Households:

a. Avoid direct consumption of untreated rooftop rainwater. Always filter, boil, or disinfect before drinking or cooking (WHO, 2022).

b. Clean roof catchments and gutters regularly to remove dust, leaves, and bird droppings that may introduce microbial contamination (Adekola et al., 2019).

c. Install first-flush diverters to discard the initial portion of rainwater that often contains roof debris and contaminants (Abdullahi et al., 2020).

d. Use non-toxic roofing materials (such as coated zinc or aluminum sheets) that are less prone to corrosion and heavy-metal leaching (Daoud et al., 2019).

e. Regularly inspect and maintain storage tanks to prevent algae growth and bacterial proliferation (NSDWQ, 2015).

(ii) To Community Associations and Corporate Organizations:

a. Promote community awareness programs on the benefits and safe handling of harvested rainwater (Okoye et al., 2019).

b. Encourage collective installation of water treatment units, such as sand filters, activated carbon filters, or UV sterilizers, in residential clusters (Srinivasamoorthy et al., 2008).

c. Support local research and periodic testing of harvested water to ensure ongoing safety compliance (Amoatey & Bani, 2011).

(iii) To Government and Agencies of Government.

a. Develop and enforce regulations on rainwater harvesting system standards, especially regarding roofing materials and storage facilities (FGN, 2018).

b. Integrate rainwater quality monitoring into existing public health and environmental programs to prevent long-term heavy-metal exposure (WHO, 2022).

c. Subsidize or provide incentives for households adopting safe rainwater treatment systems (FGN, 2018).

d. Encourage public sensitization campaigns through media and local health centers on proper rainwater harvesting and handling (Adekola et al., 2019).

e. Support further scientific research on atmospheric pollution and its effect on rainfall quality in urban and peri-urban environments. (Daoud et al., 2019).

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