INVESTIGATING RAINWATER HARVESTING AS A STORMWATER MANAGEMENT STRATEGY IN BENIN CITY

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PLAGIARISM

This work **INVESTIGATING RAINWATER HARVESTING AS A STORMWATER MANAGEMENT STRATEGY IN BENIN CITY** by INEGBENOISE, Ofure Jesusemojie with Mat. Number ENG2102848 of the Department of Civil Engineering, Faculty of

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DEDICATION

I dedicate this project work to God Almighty, the source of all wisdom, knowledge, and strength. His grace and guidance have seen me through every stage of this academic journey.

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ABSTRACT

Benin City, Edo State, faces increasing urban flooding and water scarcity due to rapid urbanization and limited public water supply. Rainwater harvesting (RWH) offers a sustainable solution by reducing surface runoff and supplementing household water demand. This study investigates the effectiveness of RWH as a stormwater management strategy, evaluates current practices, and explores its potential to improve water availability and mitigate flooding in selected locations within Benin City.

A combination of field surveys, photographic documentation, household questionnaires, interviews, hydrological assessments, and case study reviews was employed. Field surveys focused on Upper Sakponba, Eyean Community, and Amagba Road, examining rooftop collection systems, storage tanks, and compound management such as grassing.

Questionnaires assessed household awareness, adoption, and perceived benefits of RWH. Hydrological analysis using the Rational Method estimated rooftop runoff volumes, while Lagos case studies provided insights into large-scale RWH integration with green infrastructure and flood mitigation systems.

Results show that many households practice RWH using plastic or concrete tanks, which reduces runoff and meets non-potable water demand, although adoption is limited by cost, technical knowledge, and space. Hydrological assessment confirmed that rooftop runoff can satisfy household water needs when storage is properly sized. The study recommends incorporating RWH into building codes, providing subsidies and technical training, promoting first-flush diverters and filtration units, and integrating RWH with urban stormwater measures such as retention ponds and green infrastructure.

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ACRONYMS

RHW	- Rainwater Harvesting
SUDS	- Sustainable Urban Drainage Systems
LID	- Low Impact Development
CSOs	- Combined Sewer Overflows
SWMM	- Storm Water Management Model
NiMet	- Nigerian Meteorological Agency
SUDS	- Sustainable Urban Drainage Systems
PVC	- Polyvinyl Chloride
WHO	- World Health Organization
GIS	- Geographic Information System
NGOs	- Non-Governmental Organizations
UGI	- Urban Green Infrastructure
QMRA	- Quantitative Microbial Risk Assessment
RHRW	- Roof Harvested Rain Water

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Stormwater management has become a major challenge in many urban areas around the world, especially in rapidly growing cities where infrastructure development often lags behind population growth. One of the most common consequences of poor stormwater management is urban flooding, which leads to environmental degradation, damage to infrastructure, loss of property, and health hazards. As cities expand, natural surfaces that allow water infiltration are replaced with impermeable surfaces like concrete and asphalt, increasing surface runoff and overwhelming drainage systems.

Rainwater harvesting (RWH) has emerged as a sustainable solution to address both water scarcity and stormwater management issues. It involves the collection and storage of rainwater from rooftops, paved surfaces, or other catchment areas for later use or controlled release. In addition to providing an alternative water source, RWH reduces the volume and rate of stormwater runoff, thereby mitigating the risks of urban flooding and erosion.

In many developed countries, rainwater harvesting has been integrated into urban planning policies as a climate-resilient approach to water and environmental management. However, in many developing nations, including Nigeria, the practice remains underutilized. Benin City, the capital of Edo State in southern Nigeria, experiences heavy seasonal rainfall and has faced recurring challenges related to stormwater drainage, resulting in frequent flooding of roads and residential areas. This situation is exacerbated by poor waste management, inadequate drainage infrastructure, and rapid urbanization.

Given the growing concerns over the impacts of stormwater in Benin City, investigating rainwater harvesting as a potential solution is both timely and necessary. By exploring its feasibility and effectiveness within the context of the city, this study aims to contribute to sustainable urban development and improved environmental management practices.

1.2 Statement of the Problem

Benin City, like many urban centers in Nigeria, is increasingly facing the adverse effects of poor stormwater management. During the rainy season, the city experiences significant flooding, which disrupts transportation, damages property, displaces residents, and poses serious health risks due to the spread of waterborne diseases. The underlying causes of this persistent issue include inadequate and poorly maintained drainage systems, unregulated urban development, and the absence of effective stormwater control strategies.

Despite the abundance of rainfall in the region, rainwater is often allowed to flow unchecked, contributing to surface runoff that overwhelms the city's drainage infrastructure. At the same time, there is a growing demand for clean water, particularly in residential areas, where the water supply is often inconsistent. The disconnect between excess rainfall and water scarcity highlights a missed opportunity to harness rainwater as a resource rather than treating it as a nuisance.

Rainwater harvesting presents a viable, cost-effective, and environmentally friendly approach to addressing both flooding and water scarcity. However, the adoption and implementation of RWH systems in Benin City remain limited, partly due to a lack of awareness, insufficient policy support, and limited technical expertise. There is a pressing need to evaluate how rainwater harvesting can be integrated into the city's stormwater management strategy to reduce flooding, conserve water, and promote sustainable urban living.

This study seeks to investigate the potential of rainwater harvesting as a strategic response to the stormwater challenges facing Benin City.

1.3 Aim and Objectives

The aim of this study is to investigate the potential of utilizing rainwater harvesting as a strategy for managing stormwater in Benin City.

The objectives of this study are;

a. To examine the current state of stormwater management practices in Benin City.
b. To identify the different rainwater harvesting methods.
c. To evaluate the effectiveness of rainwater harvesting in reducing stormwater runoff and mitigating urban flooding.
d. To design a rainwater harvesting system for managing storms in the study area.

1.4 Scope of Study

This study focuses on investigating the potential of rainwater harvesting (RWH) as a stormwater management strategy in Benin City, Edo State, Nigeria. The geographical scope of the study is limited to urban areas within Benin City, particularly residential and commercial zones that are most affected by stormwater runoff and flooding. The study will explore the current state of stormwater management, the prevalence of RWH systems, and the challenges associated with their adoption in the city.

The time frame for this study covers the rainy season, providing insight into how RWH systems perform in managing stormwater during periods of high rainfall. The study will assess the feasibility and effectiveness of RWH in reducing flooding and surface runoff, focusing on both technical and socio-economic aspects.

This research will not cover rural areas or other forms of stormwater management beyond rainwater harvesting, such as traditional drainage systems or green infrastructure. Additionally, the study is limited by the availability of data on existing rainwater harvesting systems and may rely on a combination of field surveys, interviews with local stakeholders, and secondary data.

1.5 Significance of the Study

This study is significant in several ways, particularly in the context of increasing urban flooding and poor drainage infrastructure in Benin City. First, it contributes to the growing body of knowledge on sustainable urban water management by exploring RWH as a viable strategy for mitigating stormwater runoff. By investigating the current practices and potential of RWH in Benin City, the study provides data-driven insights that can inform urban planning and environmental policy.

For government agencies and urban planners, the research offers practical recommendations for integrating RWH systems into drainage planning and building regulations. This could help reduce the pressure on existing stormwater infrastructure and minimize the risk of flooding in vulnerable communities. The findings may also support the development of local policies and incentives aimed at promoting environmentally friendly water management practices.

Residents, especially those in flood-prone areas, stand to benefit directly from the study. It raises awareness of alternative water sources and presents cost-effective solutions for water scarcity and stormwater control. Additionally, commercial property owners and market traders may find value in understanding how RWH can help safeguard their properties against flood damage.

The study also serves as a guide for future researchers by providing a methodological framework for assessing RWH systems in similar urban contexts. Overall, the research underscores the importance of sustainable water practices and their potential to transform urban resilience in Nigerian cities.

1.6 Justification of Study

The increasing frequency and intensity of urban flooding in Benin City necessitate the exploration of alternative stormwater management strategies. Traditional methods, such as surface drainage systems, have proven to be inadequate in addressing the growing problem of stormwater runoff due to rapid urbanization, climate change, and insufficient infrastructure maintenance. This study, by investigating rainwater harvesting as a viable stormwater management solution, aims to offer an innovative approach to alleviating the city’s flooding problems.

Rainwater harvesting provides several environmental, economic, and social benefits. By capturing and storing rainwater, the city can reduce the volume of runoff that contributes to flooding, erosion, and waterlogging. Additionally, RWH systems can help conserve potable water by providing an alternative source for non-potable uses such as irrigation, cleaning, and even household consumption, thereby easing the pressure on existing water supply systems.

Economically, the adoption of rainwater harvesting can reduce costs associated with stormwater drainage maintenance, infrastructure development, and flood damage repair. It also presents opportunities for job creation in the construction, maintenance, and operation of RWH systems. Moreover, integrating RWH into urban planning can contribute to sustainable development goals by promoting climate resilience, environmental sustainability, and improved public health.

By focusing on Benin City, this study addresses a significant gap in local knowledge and provides recommendations that can inform both policymakers and residents. The findings can help drive awareness and inspire further research into sustainable water management practices in Nigeria and similar urban settings across Africa.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction to Rainwater Harvesting

2.1.1 Definition and global usage

Rainwater harvesting (RWH) involves the collection and storage of rainwater from surfaces such as rooftops, paved areas, or other catchments for later use. This practice serves multiple purposes, including providing an alternative water source for domestic, agricultural, and industrial applications, as well as mitigating stormwater runoff and reducing the risk of flooding.

Globally, RWH has been utilized for centuries, especially in regions facing water scarcity or unreliable rainfall patterns. In ancient civilizations, such as those in the Middle East and the Indus Valley, sophisticated systems were developed to capture and store rainwater. In modern times, countries like Australia, India, and several European nations have implemented RWH systems to supplement their water supply and manage stormwater effectively.

2.1.2 Environmental and economic benefits

The adoption of RWH offers numerous environmental and economic advantages:

a. Flood Mitigation: By capturing rainwater, RWH systems reduce the volume of stormwater runoff, alleviating pressure on urban drainage systems and minimizing the risk of flooding.

b. Water Conservation: Harvested rainwater can be used for non-potable purposes such as irrigation, toilet flushing, and landscape maintenance, thereby conserving treated potable water for essential uses.
c. Cost Savings: Utilizing harvested rainwater can lead to reductions in water bills and decrease the demand on municipal water supply systems, especially during peak usage periods.
d. Groundwater Recharge: Properly managed RWH systems can facilitate the infiltration of water into the ground, replenishing groundwater aquifers and supporting the overall hydrological cycle.

2.1.3 Rainwater harvesting in Benin City

In Benin City, the capital of Edo State, Nigeria, RWH has been identified as a viable solution to address water scarcity and manage stormwater. Studies have demonstrated the feasibility of implementing RWH systems in the region:

a. Domestic Water Supply: A study was designed, and a rainwater harvesting (RWH) system was proposed for a five-member household in the Ovia North-East Local Government Area of Benin City. The system consisted of a 6 m^2 corrugated metal sheet catchment, PVC collection pipes, a filter with granular activated carbon and fine sand, and two 100-liter plastic storage drums. This setup aimed to secure a domestic water supply and mitigate water scarcity issues in the area.
b. Rural Community Water Supply: In Ogbekpen, a rural community in Edo State, a conceptual model for RWH was developed using the Storm Water Management Model (SWMM) and ArcMap 10.1 software. The model utilized daily rainfall data from 2000

to 2016, obtained from the Nigerian Meteorological Agency (NiMet), to design an RWH system tailored to the community's water supply needs.

These studies highlight the potential of RWH to enhance water availability and address stormwater challenges in Benin City and its environs.

2.2 Stormwater Management

2.2.1 Definition and importance

Stormwater management refers to the planning, analysis, and implementation of strategies aimed at controlling and utilizing surface runoff resulting from rainfall or snowmelt. Effective management is crucial in urban areas to mitigate flooding, prevent erosion, protect water quality, and enhance the sustainability of water resources. As urbanization increases, impervious surfaces like roads and buildings reduce the natural infiltration of water into the soil, leading to higher volumes and velocities of runoff. This exacerbates the risk of flooding and environmental degradation.

2.2.2 Traditional stormwater management approaches

Historically, stormwater management has relied on “gray infrastructure” solutions designed to quickly convey runoff away from urban areas. These include:

a. Storm Sewers and Drains: Networks of underground pipes that transport runoff to nearby water bodies.

b. Detention and Retention Basins: Structures that temporarily or permanently hold runoff, controlling the release rate to reduce downstream flooding.

c. Channelization: Modification of natural waterways to expedite the flow of water, often involving concrete lining.

While these methods effectively reduce immediate flooding risks, they can lead to unintended consequences such as degraded water quality, loss of aquatic habitats, and increased downstream erosion.

2.2.3 Sustainable stormwater management strategies

In response to the limitations of traditional methods, sustainable or “green” stormwater management practices have been developed. These approaches aim to mimic natural hydrological processes, promoting infiltration, evapotranspiration, and the reuse of stormwater. Key strategies include:

a. Green Infrastructure: Utilization of vegetation, soils, and natural processes to manage water and create healthier urban environments. Examples include green roofs, permeable pavements, and urban tree canopies.

b. Low Impact Development (LID): A land planning and engineering design approach that emphasizes conservation and use of on-site natural features to manage stormwater close to its source. Techniques involve bioretention cells, rain gardens, and swales.

c. Stormwater Harvesting: The collection and storage of stormwater for beneficial use, such as irrigation, industrial processes, or groundwater recharge. This method not only reduces runoff but also supplements the water supply.

2.2.4 Stormwater management in Benin City

Benin City, the capital of Edo State in Nigeria, faces significant challenges related to stormwater management due to rapid urbanization, inadequate drainage infrastructure, and heavy rainfall events. The city has experienced frequent flooding, leading to property damage, disruption of economic activities, and public health concerns.

Efforts to address these challenges have included the construction of drainage channels and flood control projects. However, these measures have often been reactive rather than proactive, highlighting the need for integrated and sustainable stormwater management strategies. Incorporating green infrastructure and stormwater harvesting could offer viable solutions to enhance the city's resilience to flooding and improve water resource management.

2.3 Rainwater Harvesting as a Stormwater Management Strategy

2.3.1 Integration of rainwater harvesting in stormwater management

Rainwater harvesting (RWH) serves as a sustainable approach to stormwater management by capturing and storing rainwater for later use, thereby reducing runoff volume and mitigating flood risks. This practice not only conserves water but also alleviates pressure on urban drainage systems, especially during heavy rainfall events.

Incorporating RWH into stormwater management strategies offers multiple benefits:

a. Reduction of Runoff Volume: By capturing rainwater at the source, RWH systems decrease the amount of stormwater entering drainage networks, thus reducing the likelihood of urban flooding.
b. Water Quality Improvement: Harvested rainwater, when properly treated, can be used for non-potable purposes, reducing the demand on treated municipal water and minimizing the discharge of pollutants into natural water bodies.
c. Groundwater Recharge: Some RWH systems facilitate the infiltration of collected rainwater into the ground, replenishing aquifers and sustaining groundwater levels.

2.3.2 Case studies and applications

Several studies have demonstrated the efficacy of RWH as a stormwater management tool:

a. Residential Applications: Research indicates that implementing RWH systems in residential areas can significantly reduce stormwater runoff, thereby decreasing the burden on urban drainage infrastructure.
b. Urban Infrastructure: Cities have adopted RWH in various forms, such as green roofs and permeable pavements, to manage stormwater effectively while enhancing urban aesthetics and biodiversity.

2.3.3 Challenges and Considerations

While RWH presents numerous advantages, its implementation faces certain challenges:

a. Initial Costs: The installation of RWH systems can be capital-intensive, potentially deterring widespread adoption without financial incentives or subsidies.
b. Maintenance Requirements: Regular maintenance is essential to ensure the efficiency and longevity of RWH systems, necessitating public awareness and engagement.
c. Regulatory Frameworks: The absence of comprehensive policies and guidelines can hinder the integration of RWH into existing urban planning and stormwater management practices.

Integrating rainwater harvesting into stormwater management strategies offers a sustainable solution to urban flooding and water scarcity challenges. By reducing runoff volumes, improving water quality, and replenishing groundwater resources, RWH contributes to resilient and sustainable urban environments. Addressing the associated challenges through policy development, public education, and financial support can enhance the adoption and effectiveness of RWH systems.

2.4 Case Studies on Rainwater Harvesting for Stormwater Management

Examining real-world applications of rainwater harvesting (RWH) provides valuable insights into its effectiveness as a stormwater management strategy. The following case studies highlight successful implementations in both international contexts and within Nigeria.

2.4.1 International Case Studies

2.4.1.1 Augustenborg, Malmö, Sweden

The district of Augustenborg in Malmö, Sweden, is widely regarded as a successful example of sustainable urban stormwater management. Previously plagued by frequent flooding due to outdated and insufficient drainage systems, the area underwent a major environmental transformation in the late 1990s. The city authorities implemented Sustainable Urban Drainage Systems (SUDS), which integrated various green infrastructure elements such as green roofs, open water channels, detention basins, and permeable surfaces. One of the critical components of this approach was the use of rainwater harvesting systems.

Rainwater collected from rooftops is directed into above-ground and underground storage systems. The stored water is then either used for irrigation of green spaces or gradually released into constructed wetlands and channels. This approach not only reduces the risk of flooding but also enhances groundwater recharge, urban cooling, and biodiversity in the area. The initiative led to a 50% reduction in stormwater load on the conventional sewer system and significantly improved the quality of life for residents (Villarreal & Dixon, 2005). Importantly, this case demonstrates how decentralized stormwater management, with RWH at its core, can be effective in mitigating urban flood risks while promoting sustainable living.

2.4.1.2 Guangxi Province, China – Sponge City Initiative

In China, the national "Sponge City" initiative seeks to address urban flooding and water scarcity by encouraging cities to absorb, store, and reuse rainwater like a sponge. One notable example is the implementation of Low Impact Development (LID) practices in Guangxi Province. The region integrated several green infrastructure technologies, including bioretention cells, sunken green spaces, vegetated swales, and permeable pavements. Rainwater harvesting played a vital role in this integrated system.

Studies from the Guangxi pilot projects revealed that combining bio-retention facilities with permeable pavements resulted in a reduction of surface runoff by over 70% in certain areas (Zhou et al., 2018). Harvested rainwater was channeled into underground storage tanks for use in landscaping, non-potable domestic applications, and to support nearby ecosystems during dry spells. The project not only curbed urban flooding but also improved the water quality of stormwater discharges and increased public awareness of the benefits of sustainable water use.

This case highlights the power of strategic planning and interdisciplinary design in managing urban hydrology. It further supports the idea that when rainwater harvesting is integrated into broader sustainable drainage systems, it becomes a reliable tool for urban resilience against climate-induced flooding.

2.4.1.3 Portland, Oregon, United States – Green Infrastructure Integration

Portland, Oregon, is considered a leading example in North America for its innovative use of green infrastructure and rainwater harvesting to manage stormwater. The city began facing severe combined sewer overflows (CSOs) during the 1990s, which prompted authorities to invest in a city-wide stormwater management overhaul. The City of Portland's Bureau of

Environmental Services introduced a variety of initiatives, including eco-roofs, green streets, and rainwater cistern systems across residential and commercial developments.

The “Clean River Rewards” program incentivized homeowners and businesses to disconnect their downspouts from the sewer system and instead redirect runoff to rain barrels, infiltration planters, or vegetated swales. Rainwater harvesting systems were installed to collect water for irrigation, toilet flushing, and cooling systems, thereby reducing demand on the potable water supply.

Studies show that these interventions reduced CSO events by over 90%, improved water quality in the Willamette River, and provided significant cost savings compared to traditional grey infrastructure solutions (Liptan, 2010). Importantly, Portland’s model combines public outreach, regulatory frameworks, and financial incentives, demonstrating how policy and community involvement can enhance RWH adoption.

2.4.2 Case Studies in Nigeria

2.4.2.1 Kano Metropolis, Kano State

Kano Metropolis, a densely populated urban area in northern Nigeria, has long faced challenges with water supply due to both climatic conditions and infrastructural limitations. A study conducted by Nabegu (2009) revealed the significant potential of rainwater harvesting (RWH) in addressing domestic water needs and mitigating stormwater-related challenges in this region. The research used estimated data and found that, with a collection efficiency of approximately 70%, RWH could supply up to 56 million cubic meters of water annually. This volume was projected to serve domestic water demand for approximately 280 days within the metropolitan area.

RWH systems observed in the area typically included rooftop catchments made of corrugated metal sheets, PVC gutters, and plastic or concrete storage tanks. These systems not only alleviated water scarcity but also contributed to managing stormwater runoff by capturing rain at the source and reducing surface flooding. However, the study emphasized that adoption was limited by a lack of centralized management or policy framework to coordinate largescale implementation. The findings highlighted that integrating RWH into the region's urban planning could significantly ease water scarcity while minimizing the negative effects of stormwater runoff and reducing dependence on groundwater extraction and water trucking.

2.4.2.2 Kunchi LGA, Kano State

In rural Kano, particularly in Kunchi Local Government Area, a survey of 357 households was conducted to assess the prevalence and effectiveness of RWH. The research adopted semistructured questionnaires to gather community-level data. The findings showed that about 48% of the households engaged in some form of rainwater harvesting, usually employing rudimentary systems comprising metal roofs, basic gutter networks, and large plastic storage tanks or barrels.

The harvested rainwater was primarily used for household activities such as cooking, cleaning, and watering small gardens. Significantly, the installation of these RWH systems helped to control localized flooding by preventing the accumulation of runoff on unpaved streets and residential compounds. One notable challenge was the lack of maintenance and technical know-how, which led to low harvesting efficiency and water quality issues. Nevertheless, the study illustrated how even low-cost systems can play a meaningful role in rural water security and stormwater regulation if accompanied by proper community sensitization and technical support.

2.4.2.3 Ibadan Metropolis, Oyo State

Ibadan, the capital of Oyo State, presents another compelling case of RWH application, especially within high-density neighborhoods susceptible to flooding. A study by Wahab and Ojolowo (2013) assessed 178 buildings in the Coca-Cola area of Ibadan and demonstrated how rooftop RWH systems, complemented by surface catchments and drainage control measures, significantly reduced flash floods. Systems typically consisted of aluminum roofs, integrated PVC gutter systems, and reinforced concrete storage tanks.

The analysis showed that well-designed RWH systems could capture between 90% and 100% of stormwater runoff during peak rainfall periods. This substantially reduced the volume of water flowing through the inadequate drainage channels in the neighborhood, thereby reducing urban flood events. Additionally, another study by Lucas et al. (2005) developed region-specific gutter design formulas, showing that gutters account for approximately 50% of the total cost of RWH systems in Ibadan. These case studies underscore the importance of technical customization and urban design in optimizing RWH as a flood mitigation and water supply solution.

2.4.2.4 Ikot Osurua, Akwa Ibom State

In southern Nigeria, the community of Ikot Osurua in Akwa Ibom State has also adopted RWH as a practical response to erratic water supply and localized surface flooding. Udoh and Nelson (2023) carried out a detailed study involving 220 households, combining questionnaire-based surveys with laboratory analyses of collected rainwater. The findings showed that around 77% of the households depended on rainwater for daily needs, particularly during the rainy season.

The RWH systems typically involved corrugated roofing materials, PVC or aluminum gutters, and polyethylene storage tanks. However, laboratory tests revealed that the water often exceeded safe limits for turbidity and microbial counts, emphasizing the need for basic purification before consumption. Nevertheless, by diverting rainwater from the streets and into storage systems, the community observed a notable reduction in stormwater pooling and erosion, which previously damaged local infrastructure.

These expanded case studies across different states of Nigeria illustrate the diversity of RWH implementation strategies, challenges, and benefits. They offer valuable insights into how context-specific approaches—tailored to urban or rural settings—can maximize the effectiveness of rainwater harvesting as a tool for both water security and stormwater management.

2.4.2.5 Ogbekpen Community, Edo State

The Ogbekpen rural community in Ikpoba-Okha Local Government Area of Edo State serves as a compelling example of how rainwater harvesting can be integrated into local planning to address water scarcity. A study conducted by Ogie et al. (2016) applied the Storm Water Management Model (SWMM) and ArcMap GIS software to simulate a conceptual RWH model tailored to the community's needs. Using 10 years of daily rainfall data from the Nigerian Meteorological Agency (NiMet), the research team was able to design a system that captures rooftop runoff and stores it in tanks for domestic use.

The simulations revealed that an average household could harvest up to 2,500 liters of water per month during peak rainy periods, significantly reducing the community's dependence on boreholes and river sources. Additionally, the system helped alleviate minor flooding incidents during heavy downpours by redirecting runoff into managed storage systems. This study underscores the duality of RWH, as a water provision and flood mitigation measure, and demonstrates how technology (GIS and hydrological models) can enhance planning in rural Nigerian settings.

2.5 Rainwater Harvesting Practices in Benin City

In Benin City, a more urbanized context, a study conducted by Oke & Oyegun (2012) evaluated the potential of rainwater harvesting both as a flood/storm mitigation strategy and as an alternative source of water supply. The researchers analyzed rainfall trends, roof catchment areas, and runoff coefficients to estimate the volume of harvestable rainwater from residential buildings.

Their findings showed that a standard roof surface area of 120 m^2 could yield an average of 745.9 cubic meters of water annually, given Benin's average annual rainfall of 2,000–2,200 mm. Importantly, they emphasized that if even 30% of urban households adopt RWH systems, stormwater loads on the city's overburdened drainage systems could be significantly reduced, thereby lowering flood risks during peak rainy periods.

2.5.1 Design and implementation of RWH systems

A study conducted in the Ovia-North East Local Government Area of Benin City focused on designing and constructing a RWH system for domestic use. The system comprised a 6 m^2 corrugated metal roof catchment area, PVC collection pipes, a filtration unit with granular activated carbon and fine sand, and two 100-liter plastic storage drums. This setup demonstrated the feasibility of small-scale RWH systems in providing supplementary water for households.

2.5.2 Water quality assessments

Assessments of harvested rainwater quality in Benin City have revealed variations in physicochemical and biological parameters across different locations and seasons. A study evaluating rainwater from various parts of the city found that while some samples met World Health Organization (WHO) standards, others exhibited elevated levels of contaminants, particularly during the onset of the rainy season. These findings underscore the importance of proper treatment and storage practices to ensure the safety of harvested rainwater for domestic use.

2.5.3 Potential for flood mitigation

Beyond serving as an alternative water source, RWH has been identified as a strategy for flood mitigation in Benin City. By capturing and storing rainwater, RWH systems can reduce surface runoff, thereby alleviating pressure on urban drainage infrastructure during heavy rainfall events. This dual benefit enhances the resilience of urban areas to both water scarcity and flooding challenges.

2.6 Summary of Key Findings and Research Gap

2.6.1 Key findings

2.6.1.1 International case studies

a. Augustenborg, Sweden: The integration of Sustainable Urban Drainage Systems (SUDS) with RWH significantly reduced stormwater load by 50%, improved biodiversity, urban cooling, and enhanced quality of life (Villarreal and Dixon, 2005).
b. Guangxi, China: The “Sponge City” initiative demonstrated that combining RWH with Low Impact Development (LID) technologies reduced surface runoff by over 70%.

Stored rainwater was successfully used for landscaping and non-potable domestic purposes (Zhou et al., 2018).

c. Portland, USA: A mix of eco-roofs, rain cisterns, and policy incentives (e.g., the Clean River Rewards program) led to a 90% reduction in combined sewer overflows (Liptan, 2010). Rainwater harvesting was effectively used for irrigation, toilet flushing, and cooling systems.

2.6.1.2 Nigerian case studies

a. Kano Metropolis: RWH could meet domestic water demand for up to 280 days annually if efficiently implemented (Nabegu, 2009). However, the absence of a centralized policy limits scalability.

b. Kunchi LGA: 48% of surveyed households practiced RWH, reducing localized flooding. Low technical knowledge and poor system maintenance hindered efficiency.

c. Ibadan Metropolis: RWH systems helped reduce flash floods and stormwater pressure on inadequate drainage. Technical customizations and cost-effective design (Lucas et al., 2005) were emphasized.

d. Ikot Osurua: 77% of households used rainwater. Though water quality was often poor, RWH reduced erosion and infrastructure damage (Udoh and Nelson, 2023).

e. Ogbekpen Community: Simulated models showed that households could harvest up to 2,500 liters/month, reducing dependence on river sources and minimizing minor flooding (Ogie et al., 2016).

f. Benin City: Studies found RWH could yield up to 745.9 m^3/year per building, and if adopted by 30% of households, could substantially reduce flood risk (Oke and Oyegun, 2012). The quality of water varied seasonally, requiring treatment.

2.6.2 Identified research gaps

a. Limited Real-World Monitoring: Most studies rely on simulations or estimated values rather than post-implementation performance data. Long-term monitoring of actual water yield, system reliability, and cost-effectiveness is lacking.
b. Insufficient Water Quality Assessment: In many Nigerian case studies (e.g., Kano, Ibadan, Ogbekpen), focus is placed on quantity and infrastructure, with minimal data on microbial and chemical water quality, which is critical for domestic safety.
c. Adoption Barriers Unexplored: There is a lack of research on social, economic, and institutional barriers that hinder widespread adoption of RWH, including perceptions, maintenance behavior, and financial feasibility at community levels.
d. Policy Integration Gaps: Absence of robust regulatory frameworks or supportive incentives for implementing RWH, particularly in Nigerian cities, limits institutional commitment. Unlike Portland or Malmö, Nigerian cities often lack incentive schemes or clear implementation guidelines.
e. Lack of Comparative Evaluation: There is little cross-analysis of RWH outcomes across different climatic zones and urban forms within Nigeria, which would help tailor strategies more effectively.

2.6.3 Addressing research gaps

a. Bridging the Local Data Deficit for Benin City: Most existing Nigerian RWH studies focus on cities like Kano, Ibadan, and Abeokuta, with limited detailed research on Benin City. Your study fills this geographic gap by investigating RWH specifically in flood-prone urban and peri-urban areas of Benin City, providing much-needed local data on runoff conditions, community practices, and the potential for stormwater management.

b. Combining Technical Analysis with Public Perception: Many previous studies either focused solely on technical modeling (e.g., Ogbekpen, Kano) or lacked sufficient community engagement. Your study integrates field surveys, questionnaires, and interviews to capture the perspectives of residents, planners, and business owners, addressing the gap in understanding behavioral and socio-economic drivers of RWH adoption.

c. Addressing Lack of Implementation Frameworks: Studies in Kano and Ibadan highlighted the absence of centralized management and regulatory enforcement for widespread RWH adoption. Your study includes a policy and regulatory review of urban planning laws and environmental policies in Benin City and Nigeria at large. This provides a foundation for identifying reforms or institutional support mechanisms that could facilitate large-scale RWH integration.

d. Incorporating Water Quality Considerations: Past studies (e.g., Ikot Osurua and Abeokuta) pointed to concerns about water quality, with limited emphasis on mitigation strategies. Your research acknowledges this and proposes community awareness and basic treatment recommendations (like filtration or storage hygiene) to ensure that harvested rainwater is not just collected but safe for use.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

The research will focus on Benin City, Edo State, located within the humid tropical climatic zone of southern Nigeria. The city receives an annual rainfall of approximately 2,000 mm, concentrated between April and October. Selected neighborhoods prone to flooding will be studied, including both residential and mixed-use areas.

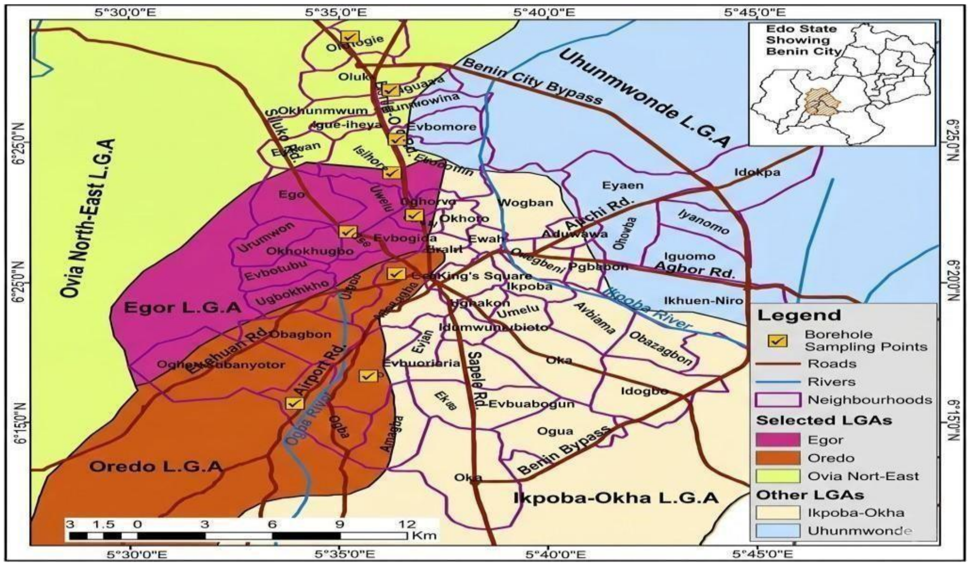

Fig 3.1 Map of Benin City.

3.2 Research Design

A mixed-methods research design is adopted for this study, combining both qualitative and quantitative approaches. This design is considered appropriate given the need to collect both measurable data and subjective perceptions regarding rainwater harvesting and stormwater management. Quantitative data will be gathered through structured questionnaires, while qualitative insights will be obtained through interviews, site observations, and case study reviews. This combination is expected to provide a more comprehensive and balanced understanding of the practical and perceptual aspects of RWH systems in Benin City.

3.3 Data Collection and Procedures

3.3.1 Field surveys

Field surveys are expected to play a crucial role in this research, as they offer firsthand insights into existing stormwater management conditions, the application of RWH systems, and the potential for further implementation.

3.3.2 Data collection through observation

On-site observations are planned to evaluate drainage conditions, the extent of stormwater accumulation, and existing water management practices. Observational checklists will be used to record details on roof structures, drainage pathways, slope, catchment size, and signs of waterlogging. Observations will also include noting the presence and functionality of RWH systems, such as gutters, storage tanks, or redirection pipes.

3.3.3 Photographic documentation

Photographic evidence will be collected during site visits to support visual analysis. Photographs will capture drainage infrastructure, surface runoff paths, and installed RWH components. These visuals are intended to enhance the quality of documentation, verify field notes, and supplement qualitative assessments.

3.4 Questionnaires and Interviews

To gain diverse perspectives on rainwater harvesting (RWH) as a stormwater management strategy in Benin City, a combination of structured questionnaires and semi-structured interviews will be employed.

All participants will be assured of the confidentiality of their responses. Names and identities will not be disclosed in any reports, presentations, or publications resulting from this research. Participation will be entirely voluntary, and all responses will be collected anonymously.

The primary aim of this data collection is to assess the awareness, perception, and adoption of RWH systems among various groups affected by stormwater runoff. The feedback gathered is expected to be instrumental in:

a. Understanding local attitudes and practices toward RWH,
b. Identifying existing challenges related to stormwater management,
c. Gauging the feasibility of broader adoption of RWH systems, and
d. Informing recommendations for improved urban water strategies.

3.4.1 Target audience identification

Participants will be selected across different stakeholder groups, including:

a. Residents of flood-prone areas
b. Urban planners and environmental officials
c. Commercial facility managers
d. Market women and small business owners

This diverse pool is intended to ensure a range of perspectives from individuals both directly and indirectly affected by stormwater runoff and rainwater harvesting.

3.4.2 Questionnaire design

The questionnaire comprises both closed- and open-ended questions. Topics to be covered include:

Awareness and Perception of Rainwater Harvesting

a. Have you heard of rainwater harvesting before?
b. How well do you understand how rainwater harvesting works?
c. Do you consider RWH an effective method for managing rainwater in cities like Benin?

Challenges Associated with Stormwater Runoff

a. What major stormwater-related problems do you face in your area (e.g., flooding, erosion)?
b. How often do these problems occur after rainfall?
c. In your view, what has been the most challenging part of managing stormwater?

Personal Benefits of Rainwater Harvesting

a. Has using harvested rainwater reduced your dependency on other water sources?
b. What uses do you put harvested rainwater to in your household or business?
c. Would you recommend RWH to others in your community?

These questions will be administered across various demographic groups, including urban planners, engineers, water management officials, residential homeowners, and market shop owners affected by surface runoff.

3.5 Case Study Review

This research will include a review of existing rainwater harvesting (RWH) systems in urban settings outside Benin City, with a focus on cities that share similar climatic and socioeconomic characteristics.

3.5.1 Case selection criteria

Case studies will be selected based on the documented success of implemented RWH systems, the availability of credible documentation, and their relevance to urban stormwater management. Both Nigerian cities and selected locations in sub-Saharan Africa will be considered as sources.

3.5.2 Document and literature analysis

Government publications, peer-reviewed academic journals, technical reports, and policy briefs will be reviewed. These materials will provide insight into best practices, system designs, and the socio-political support mechanisms that influence the successful adoption of RWH technologies.

3.5.3 Comparative framework

Data gathered from Benin City will be compared with findings from the selected case studies. This comparison aims to identify performance gaps and highlight successful practices that could be adapted to the local context.

As part of the methodology, this research will examine Lagos State as a national case study. Particular attention will be given to flood-prone neighborhoods such as Ikorodu and parts of

Ajah, where targeted RWH interventions have reportedly contributed to reduced surface runoff. The review will focus on policy documents, environmental reports, and project briefs that detail the retrofitting of buildings with rooftop collection systems connected to underground storage tanks or modular soakaway systems.

This case is selected due to its urban similarity to Benin City and the availability of empirical documentation on outcomes. The analysis will serve two purposes: (1) to understand how RWH has been strategically implemented within Nigeria’s urban planning context, and (2) to extract adaptable lessons that can inform effective implementation in Benin City. Information will be sourced from academic publications, government environmental strategy documents, and third-party evaluations by NGOs.

3.6 Hydrological Assessment

A basic hydrological assessment will be conducted to estimate stormwater runoff volumes from rooftops in the selected study areas. The Rational Method will be applied as a simplified approach to calculate the volume of water that can potentially be harvested during peak rainfall events. This calculation will be based on key parameters such as rainfall intensity (I), rooftop surface area (A), and runoff coefficient (C). The method will provide a theoretical estimation of the quantity of rainwater that could be captured and stored, helping to evaluate the potential effectiveness of both existing and proposed rainwater harvesting systems as tools for stormwater management.

3.7 Design of Rainwater Harvesting System for Stormwater Management

As part of the methodological framework, a rainwater harvesting (RWH) system will be conceptually designed to demonstrate how stormwater can be effectively managed within selected areas of Benin City. This design process will serve to provide a contextual model that aligns with local environmental conditions, building patterns, and socio-economic factors.

3.7.1 Design objectives

The primary objective of the design will be to outline a sustainable, scalable RWH system that can collect and store rooftop runoff, thereby reducing surface flooding and supplementing non-potable water needs. The system will be conceptualized for application in both residential and commercial settings commonly found in Benin City.

3.7.2 Design considerations

Several considerations will guide the system design:

a. Local Climatic Conditions: The average annual rainfall of Benin City and rainfall intensity patterns will be considered to estimate stormwater availability.

b. Building Typology: Common roof types, slopes, and surface areas in the study area will be referenced to ensure design applicability.

c. Water Demand Patterns: Typical non-potable uses, such as toilet flushing, irrigation, and washing, will influence the sizing of storage components.

d. Materials Availability: Locally available materials like PVC pipes, galvanized roofing, and reinforced concrete will be prioritized in the system design.

e. Affordability and Maintenance: The system will be designed to require minimal maintenance and offer cost-effective solutions for low- to middle-income users.

3.7.3 Design parameters

The following parameters will be used in the conceptual design:

a. Catchment Area (A): The roof surface area (in square meters) will be used to estimate the volume of water that can be captured.

b. Runoff Coefficient (C): A standard coefficient (typically ranging from 0.7 to 0.9 for metal roofs) will be used to account for losses due to evaporation and inefficiencies.

c. Rainfall Intensity (I): Local rainfall data (mm/hr) sourced from meteorological records will inform the volume of water expected during rainfall events.

d. Runoff Volume (Q): Part of rainfall that becomes surface water flow, and it is calculated by

$$Q = C \times A \times P$$

Where Q = run off volume

C = Runoff coefficient

A = Catchment area

P = Precipitation (i.e., rainfall depth)

e. Filtration and First Flush Diverters: The design will integrate basic filtration units and first flush systems to improve water quality before storage.

3.7.4 Conceptual layout

The proposed RWH system will include the following components:

a. Catchment Surface (e.g., pitched metal roofing)

b. Gutter System (for channeling water)

c. Downpipes (PVC or iron)

d. First Flush Diverter (to discard the initial contaminated runoff)

e. Filtration Unit (mesh or sediment trap)

f. Storage Tank.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the findings obtained from the field surveys, questionnaires, interviews, and supporting data collection methods described in Chapter Three. The aim is to analyse the current state of rainwater harvesting (RWH) practices in selected locations within Benin City and assess their potential as a stormwater management strategy.

The results are organised in accordance with the study objectives, beginning with the field survey observations, which include photographic documentation and site descriptions. The locations covered — Upper Sakponba, Eyean Community (Ikpoba Hill), and Amagba (Ugbor Road) — were purposively selected based on their varying urban layouts, socio-economic settings, and the prevalence of rainwater harvesting practices in the areas.

For each site, visual evidence from photographs is used alongside measured or estimated building parameters such as roof area, drainage characteristics, and water storage capacity. Where applicable, hydrological estimations are made to determine potential runoff volumes, and these are compared against existing storage infrastructure to assess efficiency.

The discussion integrates these findings with insights from the literature reviewed, highlighting consistencies and gaps between theory and practice. This combined analysis serves to evaluate the effectiveness, limitations, and future potential of rainwater harvesting systems within the socio-environmental realities of Benin City.

4.1 Field Survey of Existing RWH and Stormwater Management Practices

4.1.1 RWH practice in Upper Sakponba

The Upper Sakponba area was selected for field investigation primarily because of its established culture of rainwater harvesting. Many households in this neighborhood have, over time, adopted the practice of collecting rainwater from rooftops and storing it in largecapacity tanks for domestic use. This adoption is due to the fact that there is no public water supply and the high cost of alternative sources, such as boreholes and water vendors.

During the site visit, rooftop catchment systems were observed to be mostly composed of corrugated metal sheets with varying roof surface areas, channeling rainfall through gutter systems into storage tanks. The tanks were predominantly plastic types with capacities ranging from 500 to 2,000 liters, strategically positioned close to buildings for easy access. Some households demonstrated additional ingenuity by raising their tanks slightly above ground level to facilitate gravity-fed water discharge.

Figure 4.1 below illustrates a traditional yet highly functional method of rainwater harvesting observed in the Upper Sakponba area of Benin City. Although the system was specifically designed to capture and store rainwater directly from the roof of a residential building, providing a source of domestic water, it is also an effective approach to stormwater management. Rainwater falling onto the corrugated roofing sheets is first collected by a gutter installed along the roof edge. The runoff is then channelled through a funnel-shaped connector, which directs the flow into a downpipe. The blue section of the pipe serves as the primary conduit for the water, while the grey section continues the flow downwards toward the designated storage facility.

Fig. 4.1 Rainwater harvesting system observed in Upper Sakponba, Benin City. The left image shows a locally fabricated funnel and PVC pipe assembly attached to the roof gutter, designed to channel rainwater downward. The right image shows the receiving concrete well (5,000 litres of water storage capacity), where harvested water is collected for various domestic uses.

The storage component, visible on the right side of the image, consists of a large cylindrical concrete tank with a tightly fitted lid. This cover plays a critical role in preventing contamination by debris, insects, and other pollutants, while also reducing water loss through evaporation. The tank’s considerable size suggests it is capable of holding a substantial quantity of water, making it a reliable source for household use throughout periods of reduced rainfall. Water stored in such tanks is often used for domestic purposes, including washing, cooking, cleaning, and, when treated, for drinking. From a stormwater management perspective, this rainwater harvesting setup provides significant benefits. Capturing water at the rooftop level, reduces the volume of stormwater entering open drains and streets during heavy rainfall events, thereby alleviating pressure on existing drainage systems. The storage of rainwater also delays the release of water into the surrounding environment, which helps to moderate peak flows and reduces the likelihood of flooding. Furthermore, in densely built-up areas such as Upper Sakponba, where impermeable surfaces are common, this practice mitigates the risk of erosion, limits surface runoff, and contributes to improved environmental resilience. Overall, the rainwater harvesting system in Upper Sakponba demonstrates how traditional designs can be adapted to serve dual purposes, providing a sustainable water source while playing an active role in managing stormwater. In later sections of this study, the roof area of the observed building will be measured, and together with rainfall data from Benin City, an estimate of the potential volume of water that can be harvested at this site will be calculated. This will provide a quantitative basis for assessing the system’s effectiveness in addressing both water scarcity and stormwater-related challenges.

4.1.2 RWH practice in Eyean

The images below depict a modernized yet simple rainwater harvesting system in Eyean Community, Ikpoba Hill, Benin City. Unlike the traditional concrete tanks observed at Upper Sakponba, this system utilizes a large plastic (polyethylene) storage tank, which is directly connected to the roof’s gutter network through PVC downpipes. The design follows a straightforward concept: rainfall striking the roof is directed into gutters, which channel the water through the vertical PVC downpipe into the storage tank. This type of tank is often preferred for its lightweight, durability, and resistance to corrosion compared to concrete structures.

Fig. 4.2 Rainwater harvesting system observed in Eyean, Benin City.

From the first image, it can be observed that the tank inlet is sealed except for the pipe connection, which helps to reduce contamination by minimizing dust, debris, and insect entry. The outlet tap at the lower section of the tank (second image) allows easy access to the stored water, as demonstrated by the bucket being filled. This stored water can be used for domestic purposes such as washing, cleaning, and, in some cases, drinking after appropriate filtration and treatment.

From a stormwater management perspective, this system plays a critical role in reducing runoff volume during heavy rainfall events. Instead of allowing rainwater to flow directly onto the ground—potentially causing erosion, localized flooding, or strain on drainage systems—the harvesting system captures and stores it for later use. This reduces peak flow rates, supports water conservation efforts, and ensures a supplementary water source during dry spells. The use of a sealed plastic tank also minimizes water loss through seepage and prevents mosquito breeding, thereby improving public health outcomes**.**

4.1.3 RWH practice at Amagba Road

During the field survey at Amagba Road, it was observed that some residential buildings have incorporated a modern RWH system into their design. The system consists of roofmounted gutters connected to vertical downpipes, which channel rainwater away from the building's walls and foundations. According to the property owner, this setup serves a dual purpose: first, it helps mitigate stormwater runoff by directing rainwater into designated drainage; secondly, it protects the building's exterior by preventing rainwater from directly washing down the walls, thereby reducing erosion at the foundation and prolonging the lifespan of the paint. This approach reflects an integration of stormwater management with building maintenance considerations, demonstrating how functional infrastructure can also contribute to property preservation.

Fig. 4.3 Modern rainwater harvesting system at a residential building in Amagba Road.

During the site observation at Amagba Road, a complete roof gutter and downspout system was identified. This system is designed to effectively capture, channel, and safely discharge rainwater from the building roof. The installation comprises several interlinked components, each serving a specific function to ensure efficient water flow, structural stability, and protection of the building's walls and foundation. The key components observed are described and illustrated in Fig. 4.4.

Fig. 4.4 Cross-sectional view of a gutter system display with components labeled.

a. Gutter

   i. This is the long horizontal trough that collects rainwater from the roof.

   ii. It channels the water towards the downspout to prevent it from dripping off the roof edges and eroding the ground below.

b. Gutter bracket
   i A support piece that holds the gutter in place against the fascia board.

   ii It ensures the gutter remains level and stable, even when full of water.

c. Gutter joiner

    i. A connector used to join two lengths of gutter together.
    ii. It helps extend the guttering system while maintaining a watertight seal. d. 135° inside corner
    iii. A specially angled section that allows gutters to turn around inside roof corners at 135 degrees.
    iv. Commonly used for building designs where the roofline has an inward corner.

d. Downspout

    i. The vertical pipe that carries water from the gutter down to the ground or drainage system.
    ii. Prevents water from splashing down directly from the roof.

e. 65° Pipe side elbow

    i. A bent section of the downspout with a 65-degree angle.
    ii. Allows redirection of water flow, often used at the bottom to guide water away from the building's foundation.

4.1.3.1 Roof gutter system

A roof gutter system is a network of channels, pipes, and fittings installed to manage roof runoff, preventing uncontrolled water flow that could damage walls, foundations, or surrounding landscaping. The system typically includes gutters (horizontal troughs), downspouts (vertical pipes), elbows, brackets, joiners, and other fittings that ensure water is efficiently transported from the roof to a designated discharge or storage point.

In rainwater harvesting, the roof gutter system plays a critical role as the first collection point in the process. When rain falls on a roof, the gutters channel the water toward downspouts, which can be connected to storage tanks, cisterns, or infiltration systems instead of directing water to storm drains. This setup enables the captured water to be stored for domestic, agricultural, or environmental uses. By integrating a roof gutter system into RWH design, the efficiency of water capture is increased, losses from spillage are reduced, and the harvested water remains cleaner, as gutters can be fitted with leaf guards and firstflush devices to minimize debris and contamination.

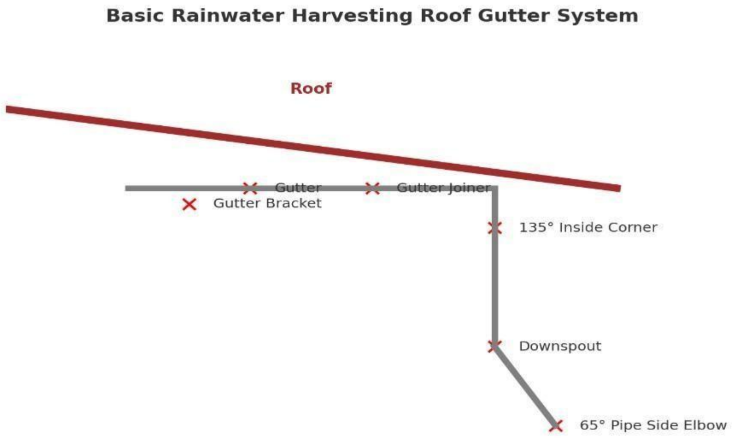

Fig. 4.5 Basic roof gutter system.

4.1.3.2 Integration of the roof runoff channeling to the public drainage system

From the building configuration shown (pitched roof fitted with gutters and vertical downpipes), rooftop runoff can be systematically collected and conveyed in a controlled manner to the public drainage network as part of an integrated rainwater harvesting (RWH) system.

During rainfall events, precipitation falling on the roof surface is intercepted by the installed gutters positioned along the roof edges. These gutters collect runoff and direct it into vertical downpipes attached to the exterior walls of the building. Rather than allowing uncontrolled discharge at ground level, the downpipes can be connected to a structured conveyance system designed to regulate flow before discharge into the public drain.

At the base of each downpipe, a first-flush diverter should be installed to remove initial contaminants and debris. Thereafter, runoff is directed into a storage tank (surface or underground), which serves as a temporary retention facility. This storage component performs a critical stormwater management function by reducing immediate runoff volume and attenuating peak discharge during heavy rainfall events in Benin City.

When the storage tank reaches full capacity, excess water is discharged through a designed overflow pipe. This overflow pipe should be laid underground with an appropriate gradient (approximately 1–2% slope) to ensure gravity-driven flow. The pipe should be constructed of durable PVC material and properly sealed to prevent leakage.

The terminal end of the overflow pipe should be directly connected to the public drainage channel through a controlled outlet structure. This outlet may include:

a. A screened discharge point to prevent debris entry into the public drain.
b. A small energy dissipation chamber or splash pad to reduce erosion and scouring.
c. A non-return valve (where necessary) to prevent backflow during high drainage levels.

By channeling excess roof runoff through a controlled pipe system into the public drainage network, the building avoids surface ponding, minimizes soil erosion around the foundation, and reduces the sudden influx of storm water into municipal drains.

4.1.4 Grassing of the compound as a stormwater control measure

In many residential buildings in Benin City, compounds are fully paved with concrete or interlocking blocks. While this improves accessibility, it significantly increases surface runoff because impervious surfaces prevent water infiltration. As a result, rainwater flows rapidly out of the compound into public drains, contributing to flooding.

Grassing works best when combined with rooftop rainwater harvesting and serves as an effective stormwater control measure because it reduces the volume and speed of rainwater flowing out of the premises. Unlike fully paved surfaces, grassed areas are permeable and allow rainwater to infiltrate into the soil. The root system improves soil structure and increases water absorption capacity, while the grass cover slows surface runoff by increasing surface friction. This reduces peak discharge into public drains, minimizes erosion, and decreases the likelihood of localized flooding. When incorporated into residential compounds in Benin City, grassing significantly lowers surface runoff and complements rooftop rainwater harvesting systems.

Grassed areas reduce rainwater outflow through the following mechanisms:

a. Increased Infiltration: Grass-covered soil allows rainwater to infiltrate into the ground rather than flowing directly into drains. The root system creates pore spaces that enhance soil permeability.
b. Reduced Runoff Velocity: Grass acts as surface roughness, slowing down the speed of flowing water. Slower runoff reduces erosion and peak discharge into public drainage systems.

c. Temporary Surface Storage (Depression Storage): Uneven grassed surfaces hold small volumes of water temporarily before infiltration occurs. This delays runoff and reduces peak flow.

d. Evapotranspiration: Grass absorbs water through its roots and releases moisture back into the atmosphere, reducing total runoff volume.

4.2 Questionnaire Results

A total of 30 households were surveyed in Benin City to assess their demographic characteristics, awareness, practices, perceptions, and willingness towards rainwater harvesting (RWH) as a stormwater management strategy. The responses were analyzed and presented under the following sections.

Household Survey Questionnaire Results

Section A: Demographic Information

The ages of respondents ranged from 20 to 65 years, showing a wide distribution across youth, middle-aged, and elderly groups. In terms of gender, 16 respondents were male while 14 were female, giving a fairly balanced representation.

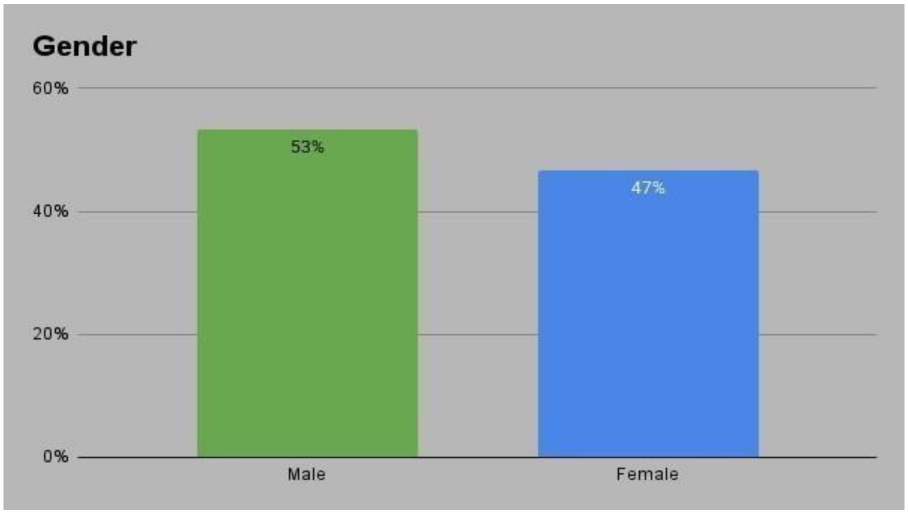

Fig. 4.6 Gender distribution of respondents.

The educational background of respondents revealed that 2 had no formal education, 5 had primary education, 12 had secondary education, and 11 had attained tertiary education. This suggests that the majority had sufficient literacy levels to understand water management practices.

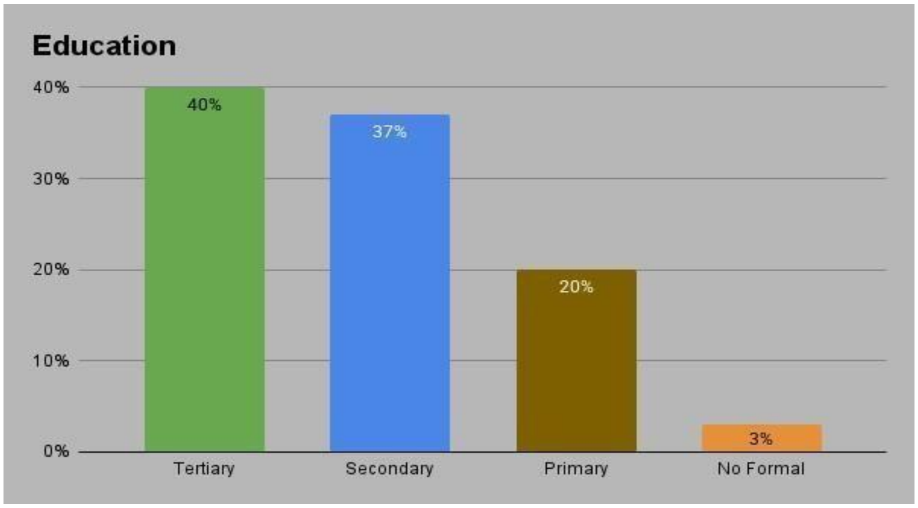

Fig 4.7 Educational background of respondents. Household sizes ranged between 3 to 8 members, which is typical for the urban setting of Benin City.

Section B: Awareness of RWH

Out of the 30 respondents, 23 indicated that they had heard of rainwater harvesting, while 7 reported having no prior knowledge of it.

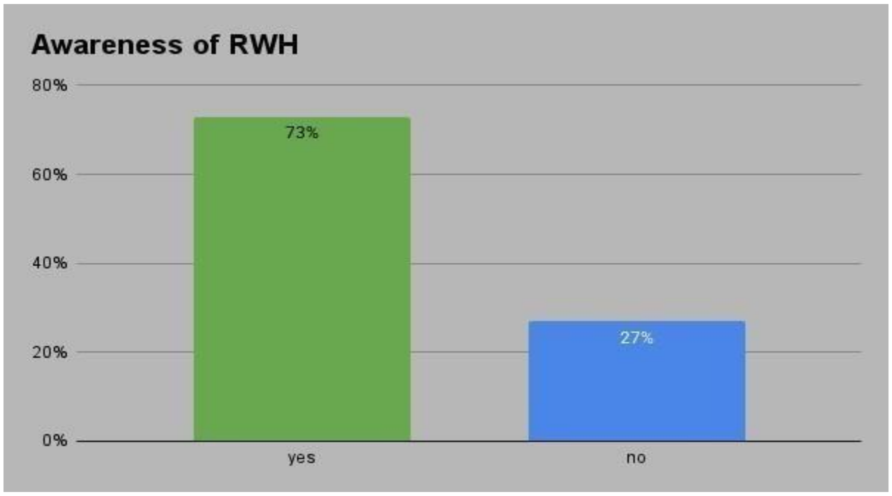

Fig 4.8 Awareness of RWH among respondents.

When asked about their source of information, respondents mentioned radio (6), television (5), school (4), community meetings (3), and other means such as neighbors or social media (5).

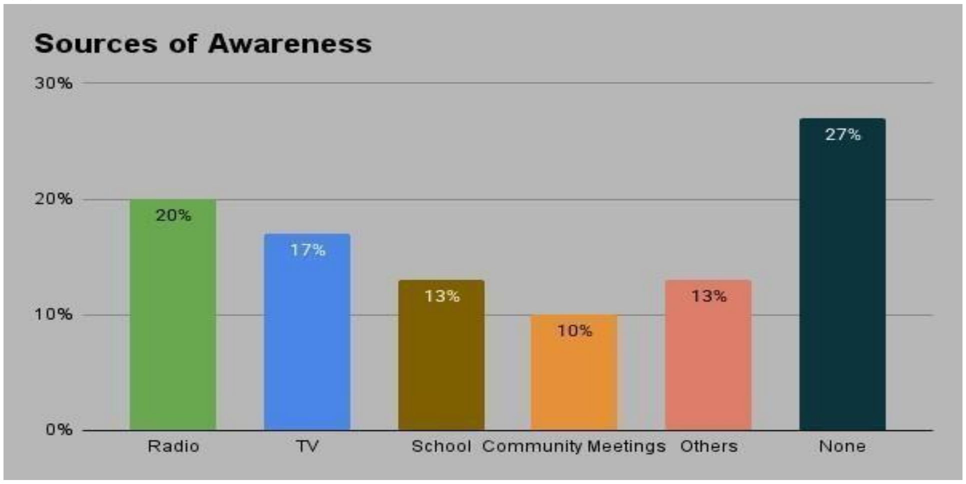

Fig 4.9 Sources of awareness of RWH among respondents.

On whether they believed RWH could reduce flooding, 20 respondents answered “Yes,” 4 said “No,” and 6 were “Not sure.” This indicates a strong perception of RWH as a potential stormwater management tool.

Section C: Current Practices of RWH

Of the total respondents, 18 households currently practice RWH while 12 do not.

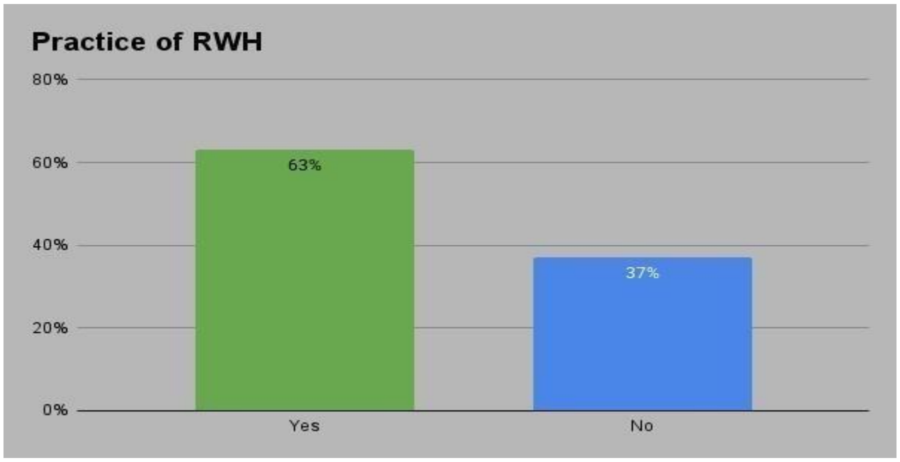

Fig 4.10 Current practice of RWH.

The main uses of harvested rainwater were reported as drinking (2), cooking (3), washing (6), gardening (4), and other domestic uses (3). This shows that households generally use harvested water for non-drinking purposes due to quality concerns.

Regarding storage facilities, the most common were plastic tanks (9), drums (5), and concrete tanks (3), while 1 household reported using improvised methods. However, 12 households had no storage facility, indicating a significant limitation to effective harvesting.

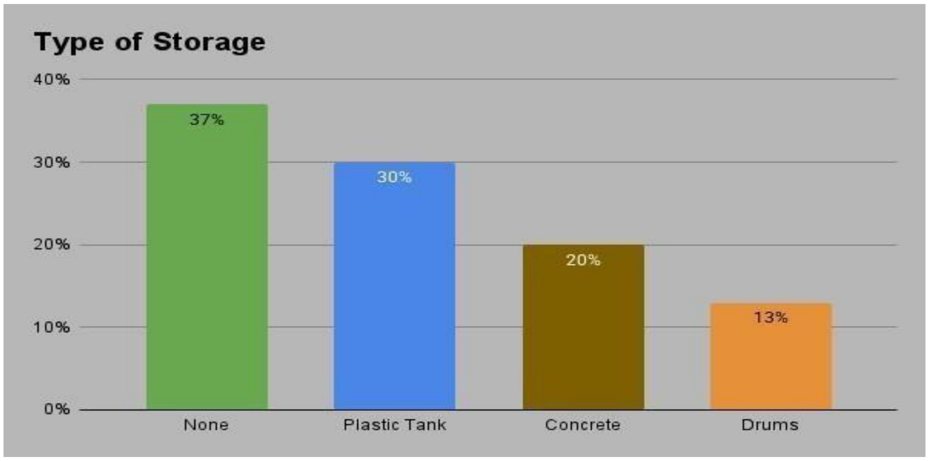

Fig 4.11 Types of RWH storage facilities.

Respondents highlighted several encouragement factors that could improve adoption: government subsidy (8), affordable tanks (6), awareness and training (5), and demonstration of benefits (3).

On the other hand, barriers identified included high cost of storage facilities (8), lack of knowledge (5), limited space (3), and other constraints (2).

Section D: Perceptions and Recommendations

Respondents identified key benefits of RWH, such as reducing flooding, providing supplementary water in the dry season, lowering water bills, and access to clean water. When asked whether RWH should be made compulsory in building plans, 21 respondents supported the idea, 2 opposed, and 7 were unsure. This suggests a generally positive attitude towards mainstreaming RWH into urban planning.

Finally, respondents made recommendations including government subsidy for storage facilities, more awareness campaigns, integration with urban drainage systems, and involvement of non-governmental organizations (NGOs) in community sensitization.

4.3 Case Study Review

4.3.1 Rainwater Quality and Safety: Ikorodu, Lagos

Access to potable water remains a major challenge in Lagos State, particularly in the Ikorodu area, where most residents rely on self-supplied water sources such as wells, boreholes, rivers, and rainwater (Longe et al., 2010; Balogun et al., 2017). According to the Millennium Development Goals report (WHO/UNICEF JMP, 2012), Nigeria narrowly met the target for improved drinking water but still showed limited or no progress in sanitation facilities, with much of the improvement restricted to urban areas. In Lagos, many households remain without access to pipe-borne treated water, making roof-harvested rainwater (RHRW) a critical alternative. However, the dependency on untreated RHRW poses significant risks, particularly due to microbial contamination.

Studies conducted in Ikorodu highlight that harvested rainwater is highly vulnerable to contamination from sediment, pollutants, saline intrusion, and pathogens from both natural and man-made sources (Pu, 2016; Obianyo, 2019; Ekwueme and Agunwamba, 2020; Guiamel and Lee, 2020). The presence of harmful microorganisms such as *Escherichia coli, Campylobacter spp., Cryptosporidium spp.,* and *Salmonella spp.* has been confirmed in rainwater tanks in similar contexts worldwide (Lye, 2002; Schets et al., 2010; Whelan et al., 2014). These pathogens increase the health risks associated with consuming untreated rainwater and highlight the urgent need for effective treatment and monitoring.

A pilot study in Ikorodu employed Quantitative Microbial Risk Assessment (QMRA) to estimate the risks posed by exposure to pathogenic *E. coli* in RHRW. The study used data collected from 125 households through structured questionnaires alongside laboratory enumeration of microbes in harvested water samples. This dual approach provided a comprehensive understanding of both household practices and the microbial quality of harvested rainwater. The results indicated that untreated RHRW presented a significant health risk, particularly in areas with poor sanitation, thereby confirming the transmission potential of pathogens through domestic water use (Soller et al., 2010; Abia et al., 2016).

One of the key problems identified in Ikorodu was the absence of adequate disinfection methods and community awareness of the risks associated with untreated rainwater. Despite its widespread use for domestic purposes such as cooking, washing, and sometimes drinking, households often neglect basic water safety practices. Furthermore, storage systems were vulnerable to contamination due to poor maintenance and environmental exposure.

To address these challenges, the QMRA findings emphasized the importance of awareness campaigns, low-cost household disinfection techniques, and improved storage practices**.** Community education on boiling water, adopting filtration systems, and using first-flush diverters on rooftops were highlighted as immediate interventions that could reduce microbial risks. At the policy level, the study called for government agencies and local authorities to support rainwater harvesting initiatives by establishing guidelines for safe collection, storage, and treatment.

This case study is significant for Benin City because it illustrates how a rapidly urbanizing Nigerian city with limited access to pipe-borne water relies heavily on RWH, but also faces challenges related to contamination and safety. By learning from Ikorodu’s experience, Benin City can adopt **more** structured and regulated RWH strategies**,** ensuring that harvested water not only supplements supply but also meets health and safety standards.

4.3.2 Urban Green Infrastructure and Flood Resilience: Lagos

Lagos State has increasingly adopted urban green infrastructure (UGI) strategies—such as bioswales, permeable pavements, detention basins, and green roofs—to mitigate the impacts of frequent flooding. While these initiatives are not always designed as direct rainwater harvesting systems, they serve as functional complements by reducing surface runoff, enhancing infiltration, and creating opportunities for water capture and reuse.

For example, bioswales and permeable pavements slow down stormwater, allowing it to percolate or be diverted into underground storage units. This principle can be combined with rooftop RWH in Benin City, where harvested rainwater can be directed into similar storage systems for both household and community use. Similarly, detention basins not only act as temporary flood buffers but can also be retrofitted with storage tanks for domestic water supply, a model that can be adopted in Benin City.

The Lagos experience shows that urban flood resilience and water security should not be treated in isolation. By linking RWH with UGI, Benin City could achieve dual benefits:

a. Enhanced RWH efficiency: Green infrastructure reduces peak runoff, meaning harvested water can be captured more effectively without overwhelming storage systems.
b. Flood mitigation: Even where storage capacity is exceeded, permeable pavements and bioswales can safely absorb excess water, reducing the burden on drainage networks.
c. Scalability and Policy Alignment: Lagos's policy direction toward integrated green–grey systems offers a precedent for Edo State, where similar frameworks could incentivize household and community-level RWH.

In this sense, Lagos demonstrates how stormwater management innovations can provide an enabling environment for RWH to thrive. If adopted in Benin City, such integration would not only improve water availability but also reduce urban flooding, making RWH a central component of sustainable urban infrastructure.

4.3.3 Detention Ponds in Lagos State

In response to recurring floods in areas such as Ajah, Lekki, Victoria Island, and Ikoyi, the Lagos State Government has adopted detention ponds as part of its stormwater management strategy.

This approach highlights the dual roles of detention ponds:

a. Flood mitigation: By capturing excess stormwater, the detention pond prevents immediate overwhelming of the drainage network, reducing the incidence of flash floods caused by lagoon backflow and persistent rainfall.
b. Water storage and controlled release: Detention ponds act as temporary reservoirs, storing large volumes of stormwater and enabling its gradual release after flood risk has reduced. This controlled release prevents downstream flooding and protects surrounding communities.

For Benin City, where heavy rainfall often results in severe surface runoff and overwhelmed drainage, the Lagos detention pond model offers a scalable solution. By strategically siting such ponds in flood-prone zones, stormwater could be both harvested and stored, serving as a resource rather than a hazard. If combined with rooftop RWH systems, detention ponds could act as community-level buffers, storing surplus runoff that exceeds household storage capacity and complementing existing drainage infrastructure. Key integration points include:

a. Community-level ponds: Establishing detention ponds in flood-prone neighborhoods (e.g., Ugbowo, Sapele Road, and Upper Sakponba) to store excess stormwater during heavy rains.
b. Linking with rooftop RWH: Households could direct overflow from their tanks and drums into community ponds, creating a multi-tiered harvesting network.
c. Policy integration: Just as Lagos has incorporated ponds into its state flood management strategy, Benin City's urban planning could adopt similar policies to integrate retention ponds as part of new drainage projects.

d. Climate resilience: With changing rainfall patterns, detention ponds can provide a reliable storage buffer that reduces flood risks and enhances water availability.

4.3.4 The Nest Development in Lagos: A Model of Modern RWH

Another major advancement in Lagos State's approach to sustainable water management is "The Nest," a 100,000 square-foot mixed-use development built in 2019 by Green Architects Nigeria. The project was internationally recognized with the 2019 LEAF Award for Best Water Efficiency due to its innovative integration of rainwater harvesting (RWH), greywater recycling, and other water-saving technologies.

The Nest incorporates a rooftop rainwater harvesting system that channels rainfall into storage tanks for reuse in irrigation and toilet flushing. By reducing dependence on municipal supply, the system effectively demonstrates how rainwater can be converted from runoff into a sustainable resource. In addition, the development also employs a greywater recycling system, where wastewater from sinks and showers is treated and reused for irrigation and toilet flushing, further reducing water demand.

How the Nest Works

a. Rainwater Harvesting

   i. Rainwater is collected from the roof surface whenever it rains.
   ii. The water flows through gutters and downpipes into a filtration system, which removes debris, dust, and contaminants.
   iii. After filtration, the rainwater is stored in large underground or overhead storage tanks.

    iv. The stored rainwater is then pumped through a separate plumbing network for non-potable uses, such as irrigation of landscaped areas (with drought-tolerant plants) and flushing toilets.

b. Greywater Recycling

    i. Wastewater from sinks, showers, and laundry (but not from toilets or kitchens) is collected separately.
    ii. This greywater passes through an on-site treatment system, which may include filtration, sedimentation, and biological treatment.
    iii. Treated greywater is disinfected and stored in holding tanks.
    iv. Like rainwater, it is reused for toilet flushing and irrigation, reducing demand for fresh water.

c. Water-Saving Fixtures and Appliances

    i. Dual-flush toilets, low-flow showerheads, and faucet aerators ensure that less water is wasted at the point of use.
    ii. Appliances like dishwashers and washing machines are chosen for their high water efficiency ratings (e.g., Energy Star certified).

d. Water-Wise Landscaping

    i. Outdoor areas are designed with drought-resistant plants, which require minimal irrigation.
    ii. Irrigation demand is primarily met through harvested rainwater and recycled greywater.

e. Integrated Building Design
    i. All these systems are integrated into the building’s design and plumbing, meaning that the municipal water supply is only used as backup.
    ii. The development achieves about 50% water savings annually, reducing demand from the Lagos Water Corporation by 50,000 gallons per year.

4.3.4.1 Positive Impact on RWH in Lagos

The Nest demonstrates how rainwater harvesting can be successfully integrated into modern architecture and urban development. Unlike traditional household-level storage practices, this project shows the commercial and large-scale application of RWH in buildings, aligning water conservation with real estate value, urban liveability, and sustainability. It highlights the fact that RWH is not only a rural or household intervention but can be embedded into urban infrastructure and smart building design.

4.3.4.2 Integration into Benin City’s RWH Strategy

The Nest provides a model that can be replicated in Benin City to improve local RWH practices. Lessons that can be applied include:

a. Incorporation into new developments: Just as The Nest made RWH central to its design, new residential estates, office complexes, and public buildings in Benin can adopt rooftop RWH with dedicated tanks for irrigation and sanitation.

b. Policy incentives: Benin’s planning authorities could mandate or encourage the installation of RWH and greywater systems in new constructions, reducing pressure on public water infrastructure.

c. Community-scale replication: Schools, hospitals, and government buildings in Benin could integrate similar RWH and greywater systems, cutting costs and setting a public example.

d. Urban resilience and sustainability: By reducing demand on Benin's already strained water supply while also lessening stormwater runoff, such systems would enhance both water security and flood control in the city.

e. Economic and social benefits: Similar to Lagos, integrated RWH systems could increase property values, create green jobs in construction and maintenance, and make Benin a more attractive and sustainable city for residents and investors.

4.4 Hydrological Assessment

A hydrological assessment is a crucial step in evaluating the potential for rainwater harvesting and understanding stormwater dynamics in a given area. This assessment involves estimating the volume of runoff generated from various catchment surfaces during rainfall events. In this study, the focus is on rooftop runoff, as roofs provide a convenient and relatively clean source of rainwater for collection. The hydrological assessment provides insights into the quantity of water that can be harvested, which is essential for designing appropriate storage systems and flood mitigation strategies.

The Rational Method is employed as a simplified approach to estimate stormwater runoff volume. This method uses the formula:

$$\mathrm{Q} = \mathrm{C} \times \mathrm{A} \times \mathrm{P}$$

Where Q represents the run off volume (m^3 or liters), C denotes runoff coefficient representing the proportion of rainfall that actually runs off the surface (0.8 for typical rooftops), A is the catchment area (m^2), and P signifies rainfall depth (m).

For the purposes of this study, annual rainfall data for Benin City are used, which averages approximately 2000 mm (2 m). This allows for an overall estimation of potential rainwater harvesting throughout the year.

Notes:

a. The hydrological assessment not only provides an estimate of potential water yield but also highlights the variability of runoff depending on roof size, material, and slope.
b. The runoff coefficient is critical as it accounts for losses due to infiltration, evaporation, and minor spillage. Roof materials such as corrugated metal sheets, tiles, or concrete may have slightly different coefficients, but 0.8 is generally accepted for standard residential rooftops.
c. Annual runoff estimates can inform decisions regarding the sizing of storage tanks, distribution systems, and overflow management, which are all critical for maximizing the efficiency of rainwater harvesting systems.
d. Conducting this assessment across multiple locations allows for a comparative understanding of which areas contribute most significantly to stormwater reduction and can guide prioritization in stormwater management planning.

4.4.1 Runoff Estimation for Upper Sakponba Roof

Figure 4.1 illustrates a moderately sized roof with an estimated catchment area of 120 m^2 (Direct measurement). Using a runoff coefficient of 0.8 and an annual rainfall of 2 m, the theoretical annual runoff is calculated as:

$$\mathrm{Q} = 0.8 \times 120 \times 2 = 192\mathrm{m}^3/\mathrm{year}$$

This estimation demonstrates that even medium-sized rooftops can make a meaningful contribution to local stormwater management. The potential runoff is sufficient to support non-potable applications, including garden irrigation, cleaning, and small-scale household water storage. Given its moderate size, a standard rainwater harvesting system with a storage tank of 10–20 m^3 would likely capture a significant portion of the runoff, thereby reducing reliance on external water sources. Furthermore, this rooftop presents an opportunity for community demonstration programs, highlighting how small-scale rainwater harvesting can contribute to flood mitigation. Consideration of roof slope and material is essential, as these factors influence the efficiency of water capture and flow towards gutters and storage tanks.

4.4.2 Runoff Estimation for Eyean Roof

Figure 4.2 illustrates the Eyean rooftop, estimated at 150 m^2. Applying the same runoff coefficient (0.8) and annual rainfall (2 m), the theoretical annual runoff is:

$$\mathrm{Q} = 0.8 \times 150 \times 2 = 240\mathrm{m}^3/\mathrm{year}$$

The higher volume of runoff indicates that this roof has greater potential to support rainwater harvesting for household and small-scale community applications. A storage system of 20–30 m^3 would be sufficient to capture a substantial portion of the runoff, optimizing water availability during both wet and dry seasons. Proper guttering and first-flush systems are recommended to maintain water quality and collection efficiency. The rooftop also demonstrates how even moderate expansions in roof area can significantly enhance annual water yield, reinforcing the value of targeting larger rooftops in urban stormwater management.

4.4.3 Runoff Estimation for Amagba Roof

Figure 4.3 presents the large modern rooftop at Amagba Road, with an estimated catchment area of 200 m². Using a runoff coefficient of 0.8 and annual rainfall of 2 m, the theoretical annual runoff is:

$$\mathrm{Q} = 0.8 \times 200 \times 2 = 320\mathrm{m}^3/\mathrm{year}$$

The substantial runoff volume from this roof underscores its critical role in urban stormwater management and rainwater harvesting potential. Effective collection and storage would require significant infrastructure, potentially incorporating multiple large storage tanks or an integrated underground system. Proper design considerations—including gutter layout, overflow management, and filtration—are essential to optimize water capture and maintain quality. The roof’s large catchment area highlights the disproportionate contribution of larger buildings to reducing surface runoff and mitigating localized flooding, emphasizing the importance of incorporating such sites in urban water resource planning strategies.

4.4.4 Seasonal Variations and Peak Rainfall Considerations

While annual runoff estimates provide a useful overview of potential water yield, it is essential to account for the seasonal distribution of rainfall in Benin City. Rainfall is typically concentrated in the wet season, during which intense storms can generate substantial volumes of runoff over short periods. Such peak events may exceed the capacity of standard rainwater harvesting systems if these are not adequately designed. For instance, a 50 mm rainstorm on the Amagba Road roof (~500 m^2) could generate up to 20 m^3 of water in a single event, underscoring the importance of properly designed gutters, downspouts, and overflow channels to prevent water loss and structural damage.

Seasonal variability also influences the availability of harvested water. While the wet season may produce excess runoff, dry periods require sufficient storage to maintain water availability throughout the year. Optimizing tank size based on seasonal rainfall patterns is therefore critical for ensuring a reliable water supply. Additionally, the temporal distribution of rainfall affects the efficiency of rainwater harvesting; larger rooftops capture proportionally more runoff during intense storms, whereas smaller roofs may require supplemental storage or collection strategies to maximize water yield.

4.4.5 Limitations of the Hydrological Assessment

Although the Rational Method offers a practical approach for estimating runoff, certain limitations must be acknowledged. The runoff coefficient ($C = 0.8$) is generalized for typical rooftops, and variations in roof material, slope, and maintenance can affect actual runoff, introducing some uncertainty into the estimates. Spatial variability of rainfall across different parts of Benin City may also result in deviations from predicted yields, as local microclimates and shading effects are not accounted for in this simplified assessment. Furthermore, the calculations assume ideal collection efficiency, without considering losses from first-flush diversion, evaporation, leakage, or debris blockage, meaning real-world yields may be lower than theoretical values.

4.4.5 Implications for RWH and Stormwater Management

Despite these limitations, the hydrological assessment provides a solid foundation for planning rainwater harvesting systems in Benin City. The findings highlight the importance of prioritizing larger rooftops to maximize water collection and integrating storage capacity with seasonal rainfall patterns to ensure year-round availability. The assessment also underscores the potential for urban flood mitigation through the reduction of surface runoff entering drainage networks.

4.5 Conceptual Design of a RWH System (Five Households)

The design of the RWH system for selected households in Benin City will be guided by local climatic conditions, building typology, water demand patterns, materials availability, affordability, maintenance considerations, and household population. The conceptual design will follow these steps:

Step 1: Define Assumptions

a. Non-potable water demand: 50 L/person/day
b. Annual rainfall: 2 m
c. Runoff coefficient: 0.8
d. Roof areas (estimated for illustration): Household 1 = 100 m², Household 2 = 80 m², Household 3 = 60 m², Household 4 = 40 m², Household 5 = 20 m²

e. Population: Household one = 9, Household two = 7, Household three = 5, Household four = 3, and Household five = 1

f. Storage: sized to meet 7 days of water demand

Step 2: Calculate Annual Water Demand

$$\mathit{Annual\ Demand} = \frac{\text{population} \times 50 \times 365}{1000}$$

Household	**Population**	**Annual Demand (m^3)**
1	9	164.25
2	7	127.75
3	5	91.25
4	3	54.75
5	1	18.25

Table 4.1. Annual water demand calculation

Step 3: Estimate Annual Runoff from Roof

Using the roof surface area (catchment area, A), rainfall data (P), and runoff coefficient (C), calculate the theoretical annual runoff (Q) for each household.

$$Q = C \times A \times P$$

Household	**Roof Area (m^2)**	**Annual Runoff Q (m^3/year)**
1	100	160
2	80	128
3	60	96
4	40	64
5	20	32

Table 4.2. Annual runoff calculation

Observation: For all households, the roof runoff roughly meets their annual non-potable water demand, with minor adjustments possible by slightly increasing roof area or optimizing tank storage.

Step 4: Determine Storage Tank Size Assume **7** days

of storage for dry periods:

$$Vtank = \frac{\text{population} \times 50 \times 7}{1000}$$

Household	Daily Demand (L)	Tank Volume (m³)
1	450	3.15
2	350	2.45
3	250	1.75
4	150	1.05
5	50	0.35

Table 4.3. Storage size calculation

Note: Tanks may be slightly oversized to accommodate peak rainfall events.

Step 5: System Components

For all households, the RWH system will include:

a. Catchment Surface: Pitched metal roof

b. Gutter System: Collects water from the roof to downpipes

c. Downpipes: PVC or iron pipes to the storage tank

d. First Flush Diverter: Removes first runoff to prevent contamination
e. Filtration Unit: Mesh or sediment trap
f. Storage Tank: Sized per household water demand and dry period coverage.

Step 6: Observations

a. Larger households with higher populations require bigger catchment areas and slightly larger tanks.
b. The proposed RWH system can meet most or all of the annual non-potable water demand for each household.
c. Seasonal variations are addressed by storage tanks sized for 7–14 days of water use, while first-flush and filtration systems improve water quality.
d. Locally available materials such as PVC pipes, galvanized roofing, and reinforced concrete storage tanks make the system cost-effective and easy to maintain.

4.5.1 Step-by-Step Operation and Installation of RWH Components

a. Catchment Surface (Pitched Metal Roofing)

i. **Installation:** The roof is constructed or identified as the main water collection surface. A pitched metal roof is ideal because the slope allows rainwater to flow naturally toward the gutters.
ii. **Function:** Rainwater first contacts the roof. The metal surface ensures minimal absorption, rapid runoff, and reduced contamination. The roof slope directs water efficiently to the collection points.

b. Gutter System

i. **Installation:** Gutters are attached along the edges of the roof where water flows. They are typically made of PVC, aluminum, or galvanized steel and are slightly sloped toward the downpipes.

ii. **Function:** The gutters collect rainwater from the roof and channel it toward the downpipes, preventing water from spilling over the sides. Proper installation ensures even flow and reduces erosion around the building foundation.

c. Downpipes (PVC or Iron)

i. Installation: Downpipes connect the gutters to the storage system. They are vertically aligned from the gutter outlet to the base or to the tank inlet. Multiple downpipes may be used for large roofs to manage high volumes of water. **ii. Function:** Downpipes convey collected water from the gutters directly to the storage system while maintaining flow velocity and minimizing spillage or overflow.

d. First Flush Diverter

i. Installation: Installed in the downpipe system before the water reaches the storage tank. It can be a small chamber or pipe designed to capture the initial runoff. **ii. Function:** The first few liters of runoff (which may contain dust, bird droppings, and debris accumulated on the roof) are diverted and discarded. This protects the storage tank from contamination and improves water quality.

e. Filtration Unit (Mesh or Sediment Trap)

i. **Installation:** Positioned between the downpipe and the storage tank. A fine mesh or sediment trap captures leaves, twigs, and larger debris. Regular cleaning is required to maintain efficiency.

ii. **Function:** Ensures that water entering the tank is free of particulate matter, reducing sediment accumulation and protecting pump and outlet systems. This unit can be integrated with the first flush diverter or installed separately.

f. Storage Tank

i. **Installation:** The tank is placed on a stable, level base near the house. Materials can include reinforced concrete, plastic, or metal. Inlet pipes from the filtration unit are connected at the top, and overflow pipes are installed to safely divert excess water.

ii. **Function:** Stores harvested rainwater for household use. Water can be drawn via tap or pump for non-potable uses such as irrigation, washing, or toilet flushing. The tank may also include a covered lid to prevent contamination and mosquito breeding.

4.5.2 Flow Summary

Rain hits the roof → 2. Water flows into gutters → 3. Conveyed by downpipes → 4. First flush diverter discards initial contaminants → 5. Filtration unit removes debris → 6. The storage tank collects clean water for use.

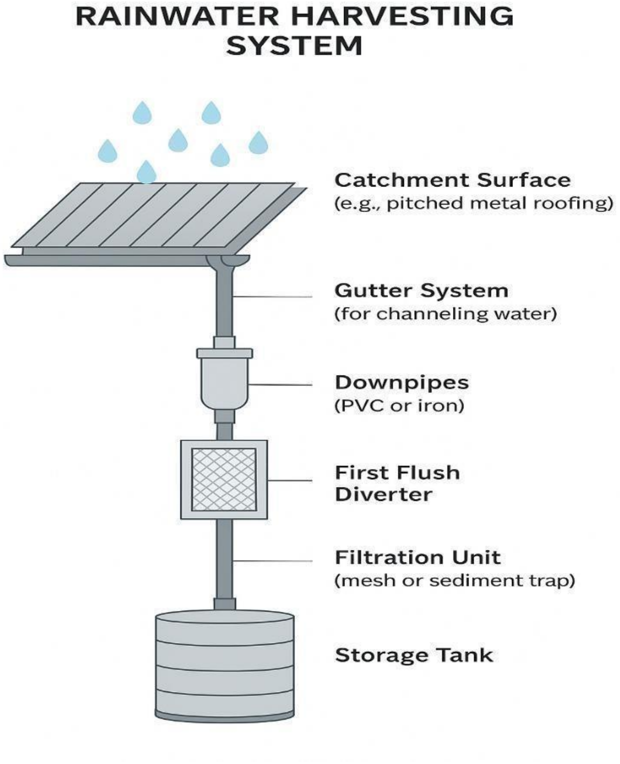

Fig 4.12. Rainwater harvesting system.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This study investigated rainwater harvesting (RWH) as a potential stormwater management strategy in Benin City, Edo State. Field surveys, questionnaires, interviews, hydrological assessments, and case study reviews revealed both opportunities and challenges for RWH implementation.

Key conclusions are:

a. **Existing RWH Practices are Prevalent but Limited in Scale:** Many households in Upper Sakponba, Eyean Community, and Amagba Road practice RWH for domestic purposes, primarily using plastic or concrete tanks connected to roof gutters. While these systems reduce runoff and mitigate localized flooding, storage capacities are often insufficient to meet seasonal water demand.

b. **Awareness and Knowledge Affect Adoption:** A majority of respondents were aware of RWH and its benefits, yet adoption was constrained by cost, lack of technical knowledge, and limited space. Households with better education and larger roof areas were more likely to adopt RWH systems.

c. **Stormwater Management Benefits:** RWH contributes to reducing surface runoff, preventing erosion, and minimizing damage to properties. Properly designed RWH systems can complement municipal drainage, particularly in flood-prone urban areas.

d. **Technical Feasibility Confirmed:** Hydrological assessment using the Rational Method demonstrated that average rooftop runoff can meet non-potable water demand for households when adequately sized storage tanks are provided. The analysis confirmed that even small-scale RWH systems could significantly alleviate water stress and reduce stormwater volume entering drainage systems.

e. **Integration with Policy and Urban Planning is Essential:** Case studies from Lagos and other urban areas show that integrating RWH with green infrastructure, retention ponds, and urban planning improves efficiency and sustainability. Current local policies in Benin City do not fully incentivize or mandate RWH adoption, limiting its wider application.

f. **Challenges Remain**: Key barriers include high installation costs, poor maintenance practices, lack of awareness, contamination risks, and limited technical support. Without policy interventions and community engagement, large-scale adoption of RWH remains constrained.

5.2 Recommendations

Based on the findings, the following recommendations are proposed for promoting RWH as a sustainable stormwater management strategy in Benin City:

a. **Policy and Regulatory Support:**

  i. Incorporate RWH provisions in building codes and urban planning regulations.
  ii. Provide incentives such as subsidies or tax breaks to encourage householdlevel RWH adoption.
  iii. Enforce minimum storage requirements for new constructions in flood-prone areas.

b. Awareness and Capacity Building:

i. Conduct community sensitization programs highlighting the benefits of RWH for water supply and flood reduction.

ii. Provide technical training on system installation, maintenance, and water treatment. iii. Promote school-based RWH awareness campaigns to instill sustainable practices.

c. Design and Technical Improvements:

i. Encourage installation of first-flush diverters, screens, and filtration units to improve water quality.

ii. Use locally available materials to reduce costs and ensure easy maintenance.

iii. Design storage tanks to accommodate seasonal rainfall variability and peak stormwater runoff.

d. Integration With Urban Stormwater Management:

i. Combine RWH systems with green infrastructure such as retention ponds, bioswales, and permeable pavements to enhance flood mitigation.

ii. Encourage community-level collection systems where individual household rooftops are insufficient.

iii. Monitor and maintain existing drains to complement RWH systems.

e. Research and Monitoring:

i. Conduct continuous water quality testing to ensure harvested rainwater meets health standards.
ii. Document and evaluate RWH adoption rates and effectiveness in reducing urban flooding.
iii. Explore opportunities for commercial-scale RWH integration in public and institutional buildings.

f. Collaboration and Funding:

i. Foster partnerships between government agencies, NGOs, and the private sector to fund RWH projects.
ii. Encourage micro-financing schemes to support households with limited resources.
iii. Establish demonstration sites to showcase best practices and practical benefits.

g. Promotion of Grassing in Residential Compounds:

i. Encourage homeowners to incorporate grassed or permeable surfaces within their compounds to enhance infiltration and reduce surface runoff.
ii. Promote the integration of grassing with rooftop rainwater harvesting systems to improve overall storm water management efficiency.
iii. Provide guidelines on compound design, including partial paving and vegetated areas, to minimize excessive runoff into public drains.

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Appendix A

Sample Questionnaire: Public Perception and Experience with Rainwater Harvesting (RWH) in Benin City

Instructions:

Please answer the following questions honestly. Your responses are strictly confidential and will be used solely for academic research purposes. No personal names or identifying information will be disclosed. The aim of this questionnaire is to evaluate the level of awareness, perceptions, challenges, and personal experiences related to rainwater harvesting (RWH) as a stormwater management strategy in Benin City.

Section 1: Awareness and Perception of Rainwater Harvesting

1. Have you heard of rainwater harvesting before?

   ☐ Yes

   ☐ No

   ☐ Not sure

2. How well do you understand how rainwater harvesting works?

   ☐ Very well

   ☐ Somewhat

   ☐ A little

   ☐ Not at all

3. Do you consider rainwater harvesting an effective method for managing rainwater in cities like Benin?

☐
Yes

☐ No

☐ Not sure

Section 2: Challenges Associated with Stormwater Runoff

4. What major stormwater-related problems do you face in your area? *(Select all that apply.)*

☐ Flooding

☐ Erosion

☐ Stagnant water

☐ Overflowing gutters/drains

☐ Damage to buildings/roads

☐ None

5. How often do these problems occur after rainfall?

☐ Always

☐ Occasionally

☐ Rarely

☐ Never

6. In your view, what has been the most challenging part of managing stormwater in your area?

☐
☐ Poor drainage systems
Lack of public awareness

☐ Government negligence

☐ Inadequate infrastructure

☐ Others (please specify): ________________

Section 3: Personal Benefits of Rainwater Harvesting

7. Has using harvested rainwater reduced your dependency on other water sources?

☐ Yes, significantly

☐ Yes, to some extent

☐ No difference

☐ I do not use harvested rainwater

8. What uses do you put harvested rainwater to in your household or business? *(Select all that apply.)*

☐ Drinking

☐ Cooking

☐ Washing clothes

☐ Cleaning floors/surfaces

☐ Gardening/irrigation

☐ Flushing toilets

☐
☐ Industrial or commercial use

9. Would you recommend rainwater harvesting to others in your community?

☐ Yes

☐ No

☐ Not sure

APPENDIX B

Key Informant Interview with Responses

Interviews were recorded and transcribed, providing valuable insights into the practices, challenges, and perspectives regarding rainwater harvesting, which complement the data gathered from the household questionnaires and field observations.

Section A: Government Agencies

Q1. How would you describe the major stormwater management challenges in Benin City?

A1. *Well, the main challenge is poor drainage design, and also the lack of maintenance. Many drains are blocked by waste, leading to frequent flooding during heavy rainfall.*

Q2. How effective are the current drainage and flood control measures? ***A2.*** *Some areas have functional drains, but generally, the system is inadequate and overwhelmed during storms.*

Q3. Is rainwater harvesting part of government policies or programs? ***A3.*** *Well, as of now, rainwater harvesting is not yet fully integrated, but it is increasingly being discussed as a sustainable option.*

Q4. What do you see as the benefits and challenges of city-wide rainwater harvesting adoption? ***A4.*** *Some benefits include flood reduction, water supply in dry seasons, and effective drainage functionality. Some challenges include the cost of storage tanks and a lack of awareness.*

Q5. What type of support should the government provide to encourage adoption? ***A5.*** *The government can provide subsidies for tanks, technical training, and awareness campaigns.*

Section B: Community Leaders

Q1. What are the most common flooding problems here?

A1. *Well, some common problems include flooding in streets, damage to properties, and when heavy rain falls, it can disrupt movements.*

Q2. How do residents cope with flooding?

A2. *Most of the people living here use sandbags, dig small channels, or some can go so far as raising their houses.*

Q3. Are there households practicing rainwater harvesting?

A3. Yes, a few families use plastic tanks or drums to harvest rainwater.

Q4. How do community members view rainwater harvesting?

A4. *Most of them see it as useful for saving water, but some still don't trust the cleanliness of harvested water.*

Q5. What barriers exist to adoption?

A5. *Some of the main barriers are the cost of tanks, lack of knowledge, and space limitations in some compounds.*

Section C: NGOs / Civil Society

Q1. What interventions has your NGO done in water/flood management in Benin City? ***A1.*** *We have carried out awareness campaigns on sanitation, small drainage clean-ups, and advocacy for flood risk reduction.*

Q2. Do you support rainwater harvesting?

A2. *On this, I can only say on a small scale – we have trained communities on how to collect and store water safely.*

Q3. What are the major challenges?

A3. *Funding, lack of community participation, and resistance to new methods.*

Q4. How do residents respond to rainwater harvesting?

A4. *Interest is growing, especially when they see it reduces their water bills, but adoption is still low.*

Q5. What opportunities exist for partnerships?

A5. *NGOs can partner with the government for training, while communities can provide local buy-in.*