STRUCTURAL INTEGRITY ASSESSMENT OF EXISTING DRAINAGE INFRASTRUCTURE ALONG UGBOWO BENIN CITY, EDO STATE. NIGERIA.

BY

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CERTIFICATION

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DEDICATION

I dedicate this work to God Almighty for his grace and guidance during this project work.

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ABSTRACT

Ugbowo Road in Benin City faces persistent flooding and drainage failure driven by rapid urbanization, poor maintenance, and structural decay. This study assessed the structural integrity and hydraulic efficiency of drainage sections at four key locations: UBTH, Adolor Junction, Uselu Shell, and Ekehuan Link Road. Through visual inspections, non-destructive rebound hammer testing, and hydraulic analysis using Manning's and Rational Methods, the research aimed to identify specific causes of failure and propose viable technical solutions.

The investigation revealed significant structural defects, including cracks, erosion, and honeycombing, with concrete compressive strengths (12.7–19.8 MPa) falling below the required 20–25 MPa standard. While hydraulic analysis confirmed that the original designs possessed sufficient capacity to handle peak discharges, their performance is currently crippled by heavy siltation, waste dumping, and poor slope alignment. Consequently, the study identified functional inefficiency and maintenance neglect, particularly at the critical Adolor Junction rather than design inadequacy as the primary drivers of drainage failure.

To restore optimal functionality and mitigate urban flooding, the study recommends the reconstruction of failing sections using 25 MPa concrete and the implementation of a rigorous maintenance regime involving routine desilting. Technical enhancements, such as the installation of trash screens and inspection chambers, should be paired with the enforcement of environmental sanitation policies. Finally, the establishment of a drainage asset management plan by the Edo State Ministry of Works and Environment is essential for the long-term monitoring and sustainability of the corridor's infrastructure.

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ACRONYMS

NDT - Non Destructive Testing

FAD - Failure Assessment Diagrams

SHM - Structural Health Monitoring

PVC - Polyvinyl Chloride

GPR - Ground Penetrating Radar

UPV - Ultrasonic Pulse Velocity

GPS - Global Positioning System

ASTM C805 - American Society for testing and materials

AASHTO - American Association of State Highway and transportation officials.

FAL – Failure assessment line.

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Benin City, serving as the administrative capital of Edo State in southern Nigeria, has increasingly faced severe urban flooding challenges, particularly during the annual rainy seasons (Adewumi & Ede, 2019). Ugbowo, a prominent district within Benin City, hosts major facilities such as the University of Benin, the University of Benin Teaching Hospital, and numerous residential, commercial, and educational institutions (Edo State Ministry of Physical Planning, 2022).

This area has experienced rapid population growth over the past two decades, driven by urbanization, economic opportunities, and the expansion of educational and healthcare services. Consequently, the pressure on existing public infrastructure, particularly drainage systems, has become immense.

Originally designed to handle lower runoff volumes corresponding to the urban structure of the 1970s and 1980s, the drainage channels in Ugbowo now find themselves overwhelmed by increased surface runoff resulting from paved surfaces, reduced natural vegetation, and altered land-use patterns (Odemwingie & Alabi, 2021).

Climate change has further aggravated this situation, with heavier and less predictable rainfall patterns contributing to flash flooding and infrastructural strain (Nwankwoala, 2015).

In addition to natural and developmental pressures, systemic challenges such as poor construction practices, substandard materials, improper design standards, inadequate maintenance, and indiscriminate disposal of solid waste into drainage channels have significantly contributed to the degradation of the drainage infrastructure (Obaseki, 2020). These infrastructural issues contribute significantly to persistent flooding, road deterioration, environmental degradation, and heightened public health risks due to stagnant water breeding grounds for diseases such as malaria and cholera (Okoye et al., 2022).

Given the increasing vulnerability of Ugbowo to flooding and the observable deterioration of its drainage facilities, it is critically important to conduct a systematic and holistic assessment of the structural integrity of these infrastructures. Such an assessment will provide vital insights into the extent of damage, identify root causes, and offer remedial strategies needed to restore functionality, enhance resilience, and protect the area's socio-economic assets against future urbanization and climatic challenges.

1.2 Problem Statement

Despite ongoing government efforts aimed at improving drainage systems across Benin City including desilting operations, construction of new drains, and establishment of storm water management programs (Edo State Flood Management Report, 2023), the effectiveness of these initiatives in ugbowo is hampered by the visibly degraded and grossly underperforming nature of many existing drainage infrastructures.

The persistence of flooding during relatively moderate rainfall events suggests that the current drainage systems are either structurally compromised, undersized, or poorly maintained (Akinbobola & Soremekun, 2021).

Field observations and media reports frequently highlight cases of collapsed culverts, silted channels, detached drain covers, misaligned precast elements, and complete structural failures along key roads and residential areas (Iwemi, 2023).

In many cases, the hydraulic capacity of the existing drains is insufficient to handle increased runoff volumes, resulting in overtopping and lateral erosion of adjacent properties.

Compounding the problem is the issue of human activities: unauthorized building over drainage channels, improper solid waste disposal, and lack of public awareness contribute to the blockage and rapid deterioration of drainage facilities (Adeleke, 2020). Additionally, the lack of regular inspection, maintenance regimes, and enforcement of environmental sanitation laws worsens the situation.

If these problems are not urgently addressed through a comprehensive assessment and strategic interventions, Ugbowo will continue to suffer escalating flood-related disasters, leading to greater economic losses, environmental degradation, public health crises, and deterioration of critical infrastructures such as roads, buildings, and utility services.

1.3 Aim and Objectives

The aim of this study is to assess the structural integrity and hydraulic performance of the existing drainage infrastructure along Ugbowo road, Benin City, to identify the causes of failure and provide recommendations for their rehabilitation and improvement.

The objectives of this research are as follows:

1. To assess and quantify the physical and structural deterioration of some section of ugbowo road’s drainage infrastructure.
2. To identify primary causes of deterioration, covering environmental, design, construction, operation, and maintenance factors.
3. To evaluate the hydraulic capacity of drainage channels against current surface run off volumes.

4. To propose sustainable solutions for recurring failures and systems resilience.

1.4 Scope of the Study

This research will be focused on the physical assessment of existing drainage channels located in the Ugbowo axis of Benin City. The investigation will include: Physical inspections to assess structural conditions such as cracking, collapse, sedimentation, blockages, biological growth, and hydraulic capacity (flow rates, blockages, flooding), Collection of photographic evidence and geotagging of critical points of failure, Review of existing documents, reports, and literature related to drainage master plans, flood management, and urban development policies.

The study will be limited to existing drainage infrastructure within Ugbowo and will not extend to the design or construction of new drains. The focus will be on diagnosis, documentation of failures, and recommendations for rehabilitation and maintenance strategies.

1.5 Justification of the Study

The justification for undertaking this research is based on several critical and interconnected reasons:

1. Reducing Flood Risks and Associated Damages: Recurrent flooding in Ugbowo leads to significant property loss, disruption of livelihoods, public health emergencies, and damage to road networks and public utilities (Omole & Longe, 2008). A detailed understanding of the structural weaknesses in the drainage system is essential for developing effective flood mitigation measures and reducing long-term economic costs.
2. Promoting Sustainable Urban Growth: Rapid urbanization in Ugbowo demands resilient and efficient infrastructural systems, including drainage facilities (UNEP, 2020). Functional drainage systems are critical components of sustainable cities, enhancing

quality of life, supporting economic productivity, and ensuring environmental sustainability.

3. Supporting Evidence-Based Planning and Investment Decisions: Effective planning and resource allocation for drainage infrastructure improvements require accurate, field-based assessments (World Bank Urban Development Series, 2018). By providing concrete evidence of infrastructural deficiencies and priority areas for intervention, this study will assist policymakers, engineers, and urban planners in making informed decisions.

In conclusion, this study is both timely and necessary. By assessing the structural integrity of the existing drainage systems in Ugbowo, it will contribute significantly to the larger goals of flood risk reduction, infrastructure resilience, sustainable urban development, and improved quality of life for the residents of Benin City.

CHAPTER TWO

LITERATURE REVIEW

2.1 BACKGROUND OF STUDY

Ensuring the structural integrity of drainage systems is a critical factor in maintaining their ability to function safely and efficiently over their intended lifespan. In rapidly urbanizing areas like Ugbowo, drainage networks are essential to managing storm water runoff, preventing urban flooding, and safeguarding both public health and urban ecosystems. Studies by Olaniyi (2014) underscore that although significant funds have been allocated for infrastructure development in Nigeria, insufficient maintenance regimes and irregular structural inspections have caused considerable deterioration in drainage assets, leading to frequent failures and suboptimal performance. Preserving structural integrity is not merely a technical priority but a fiscal and social imperative, as failing infrastructure results in costly emergency repairs, service interruptions, and health hazards. Therefore, consistent and detailed structural assessments are indispensable to optimize asset performance, forestall catastrophic failures, and contribute positively to the resilience of urban communities.

2.2 FOUNDATIONAL PRINCIPLES AND GOALS OF STRUCTURAL INTEGRITY ASSESSMENT

Structural integrity assessment involves systematically evaluating whether existing infrastructure components can resist expected loads and environmental stresses without succumbing to failure or unacceptable damage. Lahey (1991) explains that such evaluations combine simplified analytical methods with sophisticated numerical modeling techniques, including finite element analysis, to simulate structural behavior under various operational and environmental conditions. Originally conceived for safety-critical sectors such as nuclear power plants and offshore oil platforms, these assessment approaches have evolved to address challenges faced by urban infrastructure systems like drainage networks. The primary objectives of structural integrity assessment include identification of defects such as cracks, corrosion, or material fatigue, quantification of the current condition, and forecasting of remaining service life. These evaluations enable stakeholders to prioritize maintenance and rehabilitation activities, aligning safety requirements, budgetary constraints, and long-term sustainability.

2.3 COMMON CAUSES OF STRUCTURAL FAILURES IN DRAINAGE SYSTEMS

Numerous factors contribute to the deterioration and eventual failure of drainage systems. These include:

i. Poor Construction Practices: Inadequate compaction, insufficient curing, and use of low-grade materials often result in premature failures.
ii. Obsolete Designs: Many systems were not built to accommodate current urban runoff or population density.
iii. Environmental Stressors: Fluctuating water tables, expansive soils, and erosion can weaken substructures.
iv. Improper Maintenance: Blocked outlets, siltation, and vegetation growth reduce flow efficiency and increase hydraulic pressure.
v. Material Degradation: Aging materials like concrete and metal deteriorate over time due to weathering and chemical exposure.

Figure 2.1 shows an example of a common cause of structural failures in drainage.

Figure 2.1: Common structural failure (cracking in a rectangular concrete drainage channel).

2.4 METHODS EMPLOYED IN STRUCTURAL INTEGRITY ASSESSMENT

2.4.1 Visual Inspection Supported by Non-Destructive Testing Techniques

While visual inspections remain a fundamental step in periodic infrastructure evaluation due to their simplicity and cost-effectiveness, they are inherently limited by their qualitative nature and inability to detect subsurface or latent defects. The advent and integration of advanced Non-Destructive Testing (NDT) methods have significantly enhanced the depth and reliability of structural evaluations. Techniques such as ultrasonic pulse velocity testing, acoustic emission monitoring, infrared thermography, and radiographic imaging now allow engineers to detect and characterize internal flaws like micro-cracks, voids, corrosion of reinforcement bars, delamination, and material degradation without impairing the physical integrity of drainage components. Olaniyi (2014) illustrates how the application of NDT in reinforced concrete structures can reveal deterioration levels invisible to naked eyes, facilitating more accurate condition assessments and informed maintenance decisions. Nonetheless, challenges persist, including the interpretation of complex data patterns, high initial investment costs, and the need for skilled personnel to conduct and analyze these tests effectively.

2.4.2 Integration of Safety Factors and Failure Assessment Diagrams in Integrity Evaluations

To account for the inherent uncertainties related to loading conditions, material variability, and defect characteristics, engineering assessments routinely incorporate safety factors ensuring conservative evaluations. The method of Failure Assessment Diagrams (FAD), as detailed by Kikuchi (2007), represents a sophisticated analytical framework that combines fracture mechanics principles with plastic collapse analysis to evaluate a structure's ability to safely tolerate cracks and notches. FAD allows determination of acceptable defect sizes and failure risk margins by plotting stress intensity against material strength parameters. This approach has proven useful in evaluating components such as thick-walled vessels, pipelines, and thin shells prone to stress concentration. Its adaptability makes it well-suited for assessing aging drainage infrastructure where defects are often difficult to quantify precisely. By applying FAD, engineers can prioritize maintenance efforts based on quantified risk thresholds, helping to prevent sudden failures.

Figure 2.2 shows a schematic representation of failure assessment diagrams.

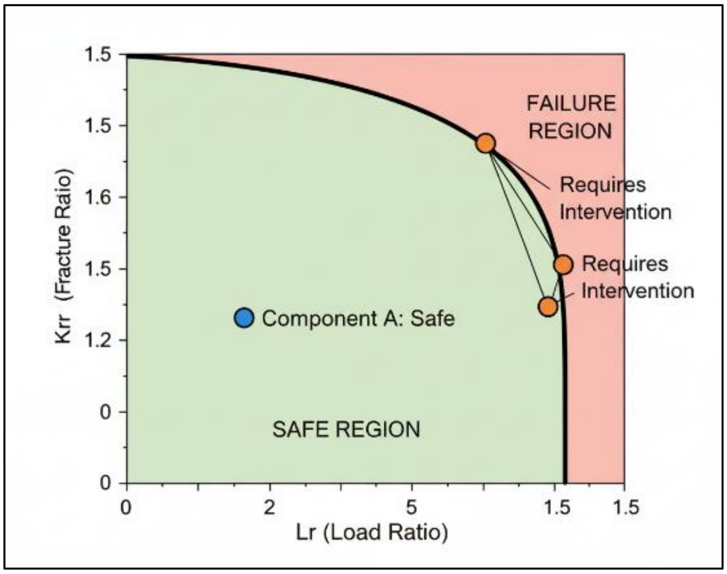

Figure 2.2: Schematic representation of failure assessment diagram showing the safe assessment region and the failure assessment line. (Source adapted from Kikuchi, 2007).

2.4.3 Risk-Based Methodologies for Structural Integrity Management

Taking a step beyond purely deterministic evaluations, risk-based structural integrity assessment incorporates probabilistic analyses to quantify the likelihood of failures and their possible consequences. Zhou and Kahraman (2015) emphasize that such frameworks are vital to optimize inspection schedules, maintenance funding allocation, and risk mitigation strategies in high-value assets including offshore installations and industrial facilities. These approaches consider the combined effects of material degradation, operational loads, environmental factors, and inspection uncertainties to produce risk-informed maintenance plans. For urban drainage infrastructure, often characterized by diverse materials, complex operational contexts, and climate variability, adopting risk-based methodologies ensures that limited resources target the most critical assets and vulnerabilities, ultimately enhancing urban resilience while optimizing expenditure.

2.4.4 Advances in Structural Health Monitoring Technologies for Infrastructure Evaluation

Recent technological advancements have revolutionized structural integrity assessment through the implementation of real-time structural health monitoring (SHM) systems that continuously collect, transmit, and analyze data related to infrastructure performance. Ta et al. (2025) explore how wireless sensor networks embedded within urban drainage systems provide comprehensive monitoring of parameters such as strain, water level, flow velocity, and temperature, facilitating the early detection of blockages, structural weaknesses, and potential failures [Ta et al., 2025]. These networks reduce reliance on manual inspections, offering cost-effective and scalable solutions to monitor large drainage networks continuously. The integration of SHM with big data analytics and AI-driven predictive maintenance models streamlines infrastructure management, improves safety margins, and extends asset lifetimes. However, issues related to sensor durability, power management, data reliability, and communication infrastructure still pose challenges for widespread adoption, particularly in resource-constrained urban contexts.

2.5 CHALLENGES CONFRONTING STRUCTURAL INTEGRITY ASSESSMENT OF URBAN DRAINAGE SYSTEMS

Urban drainage infrastructures are confronted with multifarious challenges that compromise their structural integrity and operational effectiveness. Arisandi et al. (2011) highlight, through their study of Malang City’s drainage systems, that inadequate maintenance practices, limited budgetary provisions, unclear jurisdictional authority, and low public awareness collectively undermine drainage performance and accelerate infrastructure failure [Arisandi et al., 2011]. Urban growth exacerbates these issues as increasing impervious areas elevate peak runoff volumes, placing additional hydraulic loads on aging drainage components. Sediment accumulation, debris blockages, and corrosion contribute to flow restrictions and structural degradation, further diminishing system capacity. Effective structural integrity assessment must encompass hydraulic function, physical condition, and management context to inform holistic interventions that enhance system resilience and longevity.

2.6 ACCOUNTING FOR CLIMATE CHANGE IN DRAINAGE INFRASTRUCTURE ASSESSMENT AND DESIGN

Climate change poses a formidable challenge by intensifying rainfall extremes and increasing variability in hydrologic regimes, directly impacting drainage infrastructure performance. Jorgensen and Drews (2014) reviewed adaptive strategies to integrate climate change-induced uncertainties into urban drainage system planning, emphasizing the need for flexibility and robustness [Jorgensen & Drews, 2014]. Their work demonstrates how incorporating scenario analyses and flexibility metrics permits planners to quantify system adaptability to future climate conditions. Recommended measures include creating redundant drainage pathways, upsizing pipes to accommodate increased flow volumes, deploying detention or retention systems, and adopting green infrastructure solutions to mitigate runoff. Such adaptive designs enhance urban drainage system resilience, ensuring continued effectiveness in the face of evolving environmental pressures

2.7 SUSTAINABILITY AND SOCIO-ECONOMIC DIMENSIONS IN INFRASTRUCTURE INTEGRITY ASSESSMENT

Adoption of sustainability principles in urban drainage infrastructure evaluation is crucial to balance environmental stewardship, social welfare, and economic feasibility. Mawanza and Chikodzi (2023) emphasize that although sustainability frameworks have been increasingly embraced worldwide, their implementation in African urban infrastructure planning including

Nigerian contexts remains limited, thereby constraining holistic development [Mawanza & Chikodzi, 2023]. Sustainable Urban Drainage Systems (SUDS), including permeable pavements, infiltration wells, and natural detention basins, have proven effective in reducing runoff volumes, improving water quality, and enhancing urban biodiversity. Beyond technical benefits, sustainable approaches promote public engagement, equitable access, and transparent governance. Integrating social and economic factors into structural integrity assessments ensures infrastructure projects are viable and beneficial over the long term.

2.8 PARAMETERS AFFECTING DRAINAGE SYSTEM PERFORMANCE

Figure 2.3 shows the classification of key parameters affecting the drainage system performance.

Figure 2.3: Classification of key parameters influencing the structural integrity and operational performance of urban drainage systems.

2.8.1 Hydraulic and hydrological parameters

i. Drainage Capacity: This refers to the maximum volume of water that the drainage system can safely convey without causing flooding or overflow. It is vital to ensure that the system is designed and maintained to handle expected peak flows, especially during heavy rainfall events, to prevent urban flooding and property damage. (Arisandi, Sidik, & Sukarno, 2011; Christiansen & Rajab, 2011).

ii. Flow Velocity: The speed at which water moves through drainage pipes or open channels affects sediment transport, potential erosion, and the prevention of clogging. Low velocities may lead to sediment deposition, while excessively high velocities can cause erosion of the channel bed or pipe materials. (Soyinka & Siu, 2014).

iii. Inflow and Outflow Rates: Measuring the rates at which water enters and exits the drainage system is essential for understanding system balance and identifying bottlenecks or capacity limitations that can lead to flooding or surcharge conditions. (Borage & Tambe, 2014).

iv. Peak Discharge: This is the highest flow rate during rainfall or storm events. Accurately determining peak discharge helps in designing infrastructure that can cope with extreme weather, particularly under changing climate conditions that may increase the frequency of intense storms. (Okoye & Dike, 2018).

v. Runoff Volume: The volume of surface water runoff generated from the surrounding urban area influences the loading on the drainage system. Runoff is affected by factors such as impervious surfaces, soil type, and vegetation cover. (Ayoade, 2008).

vi. Channel Slope and Gradient: These geometric parameters govern the gravitational flow of water. An appropriate slope ensures efficient drainage by balancing flow velocity to minimize sedimentation without causing erosion. (Wang, 2013).

vii. Catchment Area Characteristics: Land use, surface permeability, and rainfall patterns within the drainage catchment affect hydrological inputs. Urbanization increases impervious surfaces, leading to greater runoff volumes and higher demands on drainage infrastructure. (Collins, Ramirez, & Wang, 2012).

2.8.2 Structural and material parameters

Figure 2.4 shows the common cross-sectional shapes of drainage structures.

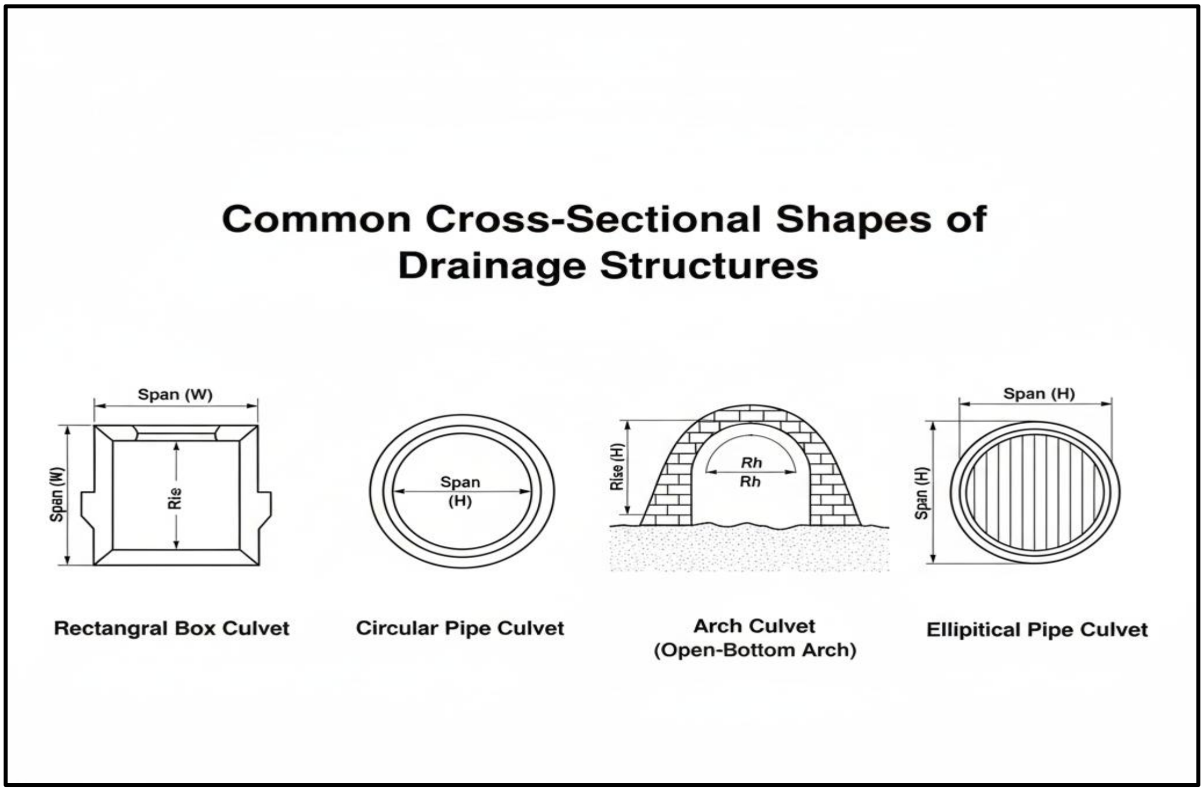

Figure 2.4: Common cross-sectional geometries of urban drainage structures.

i. Pipe/Channel Material: Common materials include concrete, PVC, metal, and sometimes clay. Material selection impacts durability, resistance to corrosion and chemical attack, and maintenance needs. For example, concrete is strong but can crack, whereas metals may corrode, especially in aggressive environments. (Rajab & Smith, 2010).

ii. Pipe Diameter and Cross-Sectional Area: These influence the hydraulic capacity. Larger diameters can carry more water but may be more costly and challenging to install. Correct sizing is crucial to balance costs and performance. (Tambe, 2014).

iii. Wall Thickness: Thickness affects the pipe’s ability to withstand internal pressures from water and external pressures from soil, traffic loads, and other environmental forces. Insufficient thickness can lead to structural failure. (Suresh & Patel, 2016).

iv. Condition of Joints and Seals: Properly functioning joints and seals prevent leakage and infiltration, which can undermine soil stability and reduce pipe efficiency. Damaged joints may also allow ingress of roots or debris, contributing to system blockages. (Christiansen & Rajab, 2011).

v. Surface Wear and Corrosion Levels: Wear due to abrasion by sediment-laden flows and corrosion from chemical agents deteriorate the pipe surface over time. These degrade hydraulic performance and structural strength. (Borage & Tambe, 2014).

vi. Cracks, Deformations and Displacements: Visible defects such as cracks or bending indicate stress, material fatigue, or ground movement and can be precursors to more severe failures. Monitoring these defects helps prioritize maintenance. (Collins et al., 2012).

vii. Load-Bearing Capacity: The ability of drainage elements to resist applied loads (soil weight, traffic, dynamic forces) without excessive deformation or failure is fundamental to structural integrity. (Olawale & Kareem, 2019).

2.8.3 Environmental and operational parameters

i. Sediment and Debris Accumulation: Sediment buildup reduces effective flow area, increases chances of blockages, and exacerbates flooding risks. Regular removal is essential for maintaining system function. (Arisandi et al., 2011).

Figure 2.5 shows an example of sediment and debris accumulation in drainage systems.

Figure 2.5: Example of severe sediment and debris accumulation compromising the flow capacity of an urban drainage channel.

ii. Water Quality Indicators: The presence of pollutants like acids, salts, and organics in conveyed water can accelerate corrosion or biological degradation, impacting material longevity. (Wang, 2013).

iii. Flooding Frequency and Extent: The frequency and spatial extent of flooding events linked to drainage system capacity and condition serve as practical performance metrics. (Okoye & Dike, 2018).

iv. Maintenance History and Frequency: The quality, regularity, and methods of maintenance activities impact the ongoing performance and lifespan of the infrastructure. (Borage & Tambe, 2014).

v. Blockage Incidents and Causes: Understanding the nature and causes of blockages, such as litter, vegetation growth, or sedimentation, helps inform targeted interventions. (Collins et al., 2012).

vi. External Environmental Conditions: Soil type affects pipe support and settlement, groundwater levels influence buoyancy and corrosion potential, and climatic factors like temperature variation impact material expansion and contraction.

2.8.4 Performance and safety parameters

i. Structural Integrity Index: This is a composite measure derived from inspections, testing, and analysis that quantifies the overall condition of the drainage system components. (Suresh & Patel, 2016).

ii. Serviceability: This parameter assesses the system's functional adequacy, indicating whether it meets drainage demands without interruptions or failures. (Christiansen & Rajab, 2011).

iii. Risk of Failure or Collapse: Probability analysis based on structural condition and external loading predicts potential failure scenarios, helping to prioritize repair or replacement. (Olawale & Kareem, 2019).

iv. Life Expectancy and Remaining Useful Life: Estimations based on current wear, material properties, and operating conditions inform asset management and planning for renewal. (Tambe, 2014).

v. Resilience to Extreme Weather Events: The ability to maintain function or recover quickly after events such as heavy rains or floods is critical under increasing climatic variability.

2.8.5 Design and geometrical parameters

i. Alignment and Layout: The spatial arrangement, length, and connectivity of the drainage network affect hydraulic performance and ease of maintenance. (Collins et al., 2012).

ii. Inlet and Outlet Design: Efficient design of collection points and discharge structures minimizes flow disruption, sediment accumulation, and facilitates maintenance access. (Rajab & Smith, 2010).

iii. Slope and Depth of Installation: These affect flow energy, structural stability, and protection from surface loads or temperature extremes. (Suresh & Patel, 2016).

iv. Vacuum or Gravity Drainage Type: Determines design and operational considerations, gravity systems rely on natural slope, whereas vacuum systems use mechanical pumping, influencing structural and maintenance requirements. (Wang, 2013).

2.8.6 Socio-technical and management parameters

i. Institutional Support and Governance: Effective organizational arrangements ensure Proper responsibility, funding, and enforcement of maintenance protocols. (Christiansen & Rajab, 2011).

ii. Community Awareness and Involvement: Public participation in the upkeep and monitoring of drainage reduces littering and blockages, enhancing system sustainability. (Arisandi et al., 2011).

iii. Economic Resources Available for Maintenance: Adequate budget allocation influences the capacity for timely repairs and upgrades. (Borage & Tambe, 2014).

iv. Technological Adoption: Use of modern monitoring tools, asset management software, and inspection methods improves assessment accuracy and maintenance efficiency. (Okoye & Dike, 2018).

v. Regulatory Compliance: Adherence to codes and standards ensures minimum quality, safety, and performance across the infrastructure lifecycle. (Olawale & Kareem, 2019).

2.9 MAINTENANCE AND POLICY CONSIDERATIONS

Sustained performance of drainage systems depends not just on design and materials but also on governance and community engagement. Key insights from reviewed studies include:

i. Preventive Maintenance: Regular desilting, cleaning, and joint sealing prevent premature failures.
ii. Asset Management Systems: Digital inventory and tracking systems help authorities schedule inspections and repairs efficiently.
iii. Institutional Frameworks: Enforcing building codes and integrating urban planning with drainage design reduces the likelihood of structural overload.
iv. Stakeholder Involvement: Local participation in monitoring and minor maintenance increases longevity and reduces costs.

2.10 SYNTHESIS AND IDENTIFICATION OF KNOWLEDGE GAPS

While the reviewed literature offers extensive insights and tools for structural integrity assessment of drainage infrastructure, several critical gaps remain particularly relevant to the localized context of Ugbowo, Benin City: There is a shortage of empirical studies and validated models that reflect the specific materials, construction practices, and climatic conditions prevalent in Nigerian urban contexts. Integration of climate change impact projections into structural assessment and design frameworks tailored to resource-constrained cities is underdeveloped. The implementation, performance evaluation, and scalability of SHM systems using wireless sensor networks remain sparse within developing urban infrastructure. Existing sustainability assessment models often lack incorporation of socio-economic realities and stakeholder engagement practices pertinent to local governance structures. Addressing these gaps will provide significant contributions towards enabling more effective, resilient, and sustainable infrastructure management in Ugbowo and similar urban environments.

2.11 CRITICAL REVIEW OF EXISTING RESEARCH AND APPLICATIONS RELATED TO DRAINAGE INFRASTRUCTURE ASSESSMENT

Numerous studies have been conducted globally and within Nigeria to assess the structural integrity and performance of drainage infrastructure in urban environments. A review of these works reveals critical insights into common failure modes, causes of degradation, and the methodologies employed in evaluating drainage systems. This section synthesizes findings from fifteen key studies relevant to the structural assessment of drainage systems, with a focus on how they inform the present investigation along Ugbowo Road in Benin City.

A recurring theme across the literature is the structural inadequacy of drainage systems in rapidly urbanizing areas. For instance, Ebohon et al. (2018) and Igbinosa & Aighewi (2017), in separate studies on Benin City, highlighted how urban encroachment, silting, and poor construction practices have rendered many drainage channels ineffective. These studies specifically noted that inadequate maintenance and outdated structural designs contribute to frequent system failures and urban flooding, emphasizing the relevance of site-specific assessments like the one proposed in this study.

Several authors also explored the relationship between drainage failure and material quality. Mohammed & Adeyemi (2019), in a study conducted in Kano, revealed that the compressive strength of concrete used in existing drainage systems often fell below acceptable standards. Similarly, Olukanni & Akinyemi (2016) emphasized the role of substandard materials and poor workmanship in the collapse of roadside drains in Ogun State, which led to road pavement degradation.

Other studies focused on visual and non-destructive assessment techniques. Akinyemi & Olorunfemi (2020) utilized a visual rating system in Ibadan to classify drainage conditions, identifying surface defects, joint failures, and sedimentation as major indicators of structural decline. Patel et al. (2016) advanced this further by advocating for non-destructive testing (NDT) methods such as Ground Penetrating Radar (GPR) and Ultrasonic Pulse Velocity (UPV), which allow for the detection of internal flaws without compromising the structure.

Hydraulic inefficiencies and outdated designs are another major concern raised in the literature. Nnaji & Oduguwa (2016) and Ajayi et al. (2021) demonstrated that many drainage systems in Nigerian cities were designed decades ago and have not been upgraded to accommodate increased runoff due to urban expansion and climate variability. Their studies in Ilorin and Lagos used GIS and flow capacity analysis to reveal that most systems are structurally overburdened and hydraulically undersized.

Geotechnical considerations have also received attention in the literature. Akinpelu et al. (2020) explored the impact of poor subsoil conditions on culvert failures, showing that soil subsidence and lack of foundational support often led to cracking and settlement of concrete structures. This underscores the importance of including geotechnical investigations in structural integrity assessments.

In studies comparing formal and informal urban settlements, Olowu & Olatunji (2021) found that unregulated settlements often experience more frequent drainage system failures due to the absence of planning and lack of enforcement of construction standards. Their findings reinforce the need for regulatory compliance and infrastructure monitoring, especially in areas like Ugbowo that are undergoing rapid transformation

From a policy and maintenance standpoint, Asamudo & Okafor (2015) and the Nigerian Society of Engineers (2020) observed that preventive maintenance is either non-existent or irregular in most Nigerian urban centers. They stressed the need for asset management systems, regular inspections, and stakeholder participation to sustain drainage infrastructure over time. These arguments are supported by the World Bank (2019), which advocates a shift from reactive to proactive infrastructure management in African cities.

In northern Nigeria, Ibrahim & Musa (2020) identified structural deterioration in over 40% of urban drains in Kaduna due to poor design sizing, aging materials, and construction oversight lapses. Oke & Adedeji (2014) echoed similar observations in Lagos, documenting structural issues such as longitudinal cracking, scouring, and disjointed sections, all of which pose serious threats to structural stability.

Collins and colleagues (2017) investigated the application of recycled crushed Portland cement concrete as a sub-base material in drainage layers, concluding that such sustainable materials can maintain or enhance structural performance while reducing environmental impacts associated with quarrying and waste disposal [Collins et al., 2017].

Francisco et al. (2024) utilized multi-objective evolutionary algorithms combined with hydraulic network modeling to optimize stormwater drainage upgrades in Tianjin Eco-City, illustrating how computational optimization can enhance flow capacity and reduce flood risk under varied scenarios [Francisco et al., 2024].

Hui et al. (2018) conducted extensive reviews of wireless sensor network technologies deployed for urban drainage monitoring in cities worldwide. They highlighted innovations in sensor fusion, energy harvesting, and data analytics that have improved early detection of blockages and flow irregularities, enabling timely maintenance interventions [Hui et al., 2018].

Ma et al. (2025) proposed a fuzzy logic model integrating hydraulic, technical, and operational indicators to assess drainage system performance comprehensively. Their methodology provides a practical tool for prioritizing maintenance and rehabilitation interventions under uncertainty [Ma et al., 2025].

Jian et al. (2018) developed predictive deterioration models using statistical and machine learning methods to estimate the failure probabilities of drainage pipes, supporting condition-based maintenance strategies that preempt structural failures [Jian et al., 2018].

Christiansen and Rajab (2011) introduced quantitative metrics to measure the flexibility and adaptability of urban drainage systems, offering decision-support mechanisms to plan for future uncertainties and infrastructure upgrades [Christiansen & Rajab, 2011].

Borage and Tambe (2014) highlighted the requisite integration of sustainability metrics into urban infrastructure projects' planning and evaluation, emphasizing the incorporation of ecological footprints, social acceptability, and economic viability [Borage & Tambe, 2014].

Vidanaarachchi et al. (2016) examined socio-political and institutional challenges facing sustainable urban drainage implementation in tropical cities, identifying key governance and capacity-building obstacles [Vidanaarachchi et al., 2016].

Moriwaki and Kato (2013) investigated the role of machine learning algorithms in structural health monitoring technologies applied to timber and concrete infrastructures, demonstrating significant advancements in automated damage detection accuracy and reliability [Moriwaki & Kato, 2013].

Fernández et al. (2003) reviewed the validation process of probabilistic fracture mechanics codes for nuclear structural integrity, demonstrating the applicability of risk-informed assessment approaches to critical infrastructure maintenance methods applicable to urban drainage infrastructure management [Fernández et al., 2003].

Collectively, these studies form a comprehensive foundation for understanding the challenges and best practices associated with drainage infrastructure assessment. They highlight the urgent need for localized studies that combine structural, hydraulic, and geotechnical evaluations. Despite the breadth of existing research, a gap remains in location-specific assessments tailored to unique environmental, geotechnical, and urban planning conditions such as those found along Ugbowo Road in Benin City. This underscores the necessity and timeliness of the current study.

2.12 EMERGING TECHNIQUES AND INNOVATIONS IN STRUCTURAL INTEGRITY ASSESSMENT

2.12.1 Application of Machine Learning and Advanced Data Analytics in SHM

Machine learning (ML) techniques have demonstrated increasing utility in structural health monitoring by enabling automated classification of defect signatures, anomaly detection, and reliability assessment from complex sensor data. Moriwaki and Kato (2013) describe how supervised and unsupervised learning models such as neural networks, support vector machines, and clustering algorithms improve the accuracy, robustness, and interpretability of structural damage diagnostics. Integration of ML with sensor networks facilitates real-time, adaptive monitoring solutions scalable to large urban drainage infrastructures, enabling prioritized intervention planning.

2.12.2 Probabilistic Modeling and Risk Assessment Frameworks

Probabilistic methods, including Bayesian inference and advanced fracture mechanics models, enhance traditional deterministic assessment by explicitly incorporating uncertainties related to variable loads, material properties, and inspection data. Fernández et al. (2003) emphasize that probabilistic fracture mechanics codes enable reliability-based maintenance planning, optimizing the trade-off between safety and economic costs in aging structures. Extending these models to drainage infrastructure allows for risk-tiered maintenance scheduling that aligns with asset criticality and budgetary constraints.

2.12.3 Advancements in Wireless Sensor Networks and IoT for Urban Drainage Monitoring

Recent progress in low-power electronics, digital communication protocols, and Internet-of-Things (IoT) integrations have overcome many barriers associated with traditional wired monitoring systems. Hui et al. (2018) outline how wireless sensor networks (WSNs) provide flexible, scalable, and cost-effective platforms capable of continuously monitoring key parameters such as water quality, flow rates, structural vibrations, and blockage indicators. Such networks improve situational awareness, facilitate predictive maintenance, and contribute to comprehensive urban water management strategies.

Figure 2.6 shows a wireless sensor network architecture for structural health monitoring of drainage infrastructure.

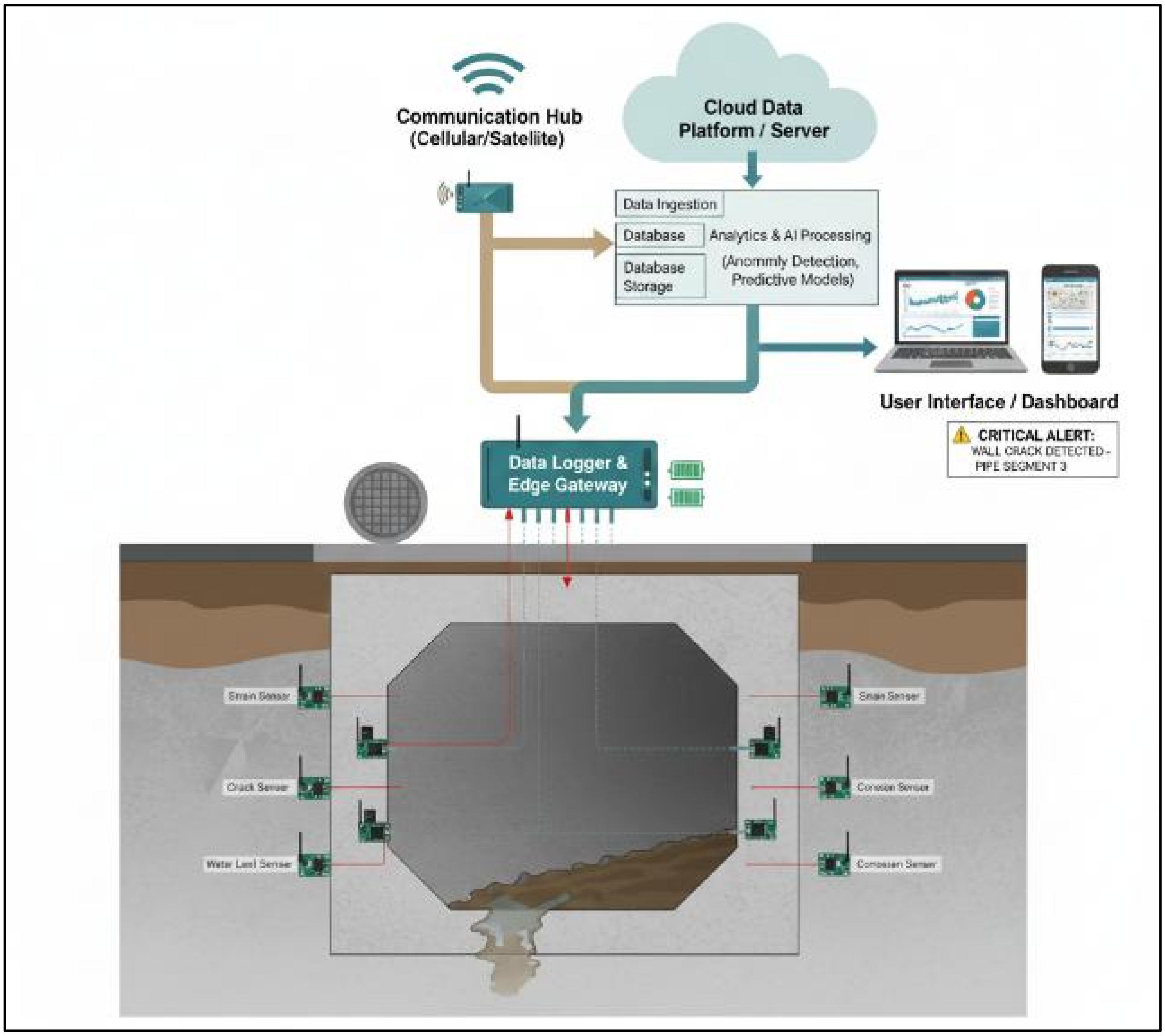

Figure 2.6: Schematic diagram illustrating a typical wireless sensor network architecture for structural health monitoring of drainage infrastructure.

This chapter, replete with a detailed review and critical analysis of existing knowledge and emerging trends, lays the conceptual and methodological groundwork necessary to undertake a thorough structural integrity assessment of the drainage infrastructure in Ugbowo, Benin City. The insights gleaned herein inform the research design and strategic objectives of the ensuing study.

CHAPTER THREE

METHODOLOGY

3.1 STUDY AREA

Ugbowo Road is a major arterial road in Benin City, Edo State, and Southern Nigeria. It's a critical transportation corridor, connecting the city center with its western suburbs and serving as a primary access route to the University of Benin and its teaching hospital. The road cuts across a diverse urban landscape, primarily within the Oredo and Egor Local Government Areas. Its drainage infrastructure is crucial for flood control and urban resilience.

Ugbowo lies approximately between latitude 6.3900°N and 6.4100°N and longitude 5.5900°E and 5.6200°E. The area experiences a tropical climate, characterized by a distinct wet season (April–October) and dry season (November–March). The average annual rainfall in the area is around 2000 mm, and mean monthly temperatures range from 23℃ to 28℃ (Enaruvbe and Atafo, 2018). These climatic conditions place significant hydraulic and thermal stresses on the drainage infrastructure, accelerating material degradation and increasing the risk of hydraulic overloading in the selected sections. This study focuses on selected critical sections of the existing drainage infrastructure along roads in ugbowo benin city, rather than the entire stretch,

The areas surrounding Ugbowo Road's selected sections are densely populated, featuring a vibrant mix of residential buildings, numerous businesses, and bustling roadside markets. The road is particularly notable for hosting major institutions like the University of Benin and the University of Benin Teaching Hospital (UBTH), which generate substantial traffic and pedestrian movement. Benin City's population, estimated at about 1.75 million (United Nations, 2016), contributes to high volumes of stormwater runoff from extensive impervious surfaces along the road corridor.

Figure 3.1 to 3.3 shows the map of the study area, topographic map and also the drainage investigation points.

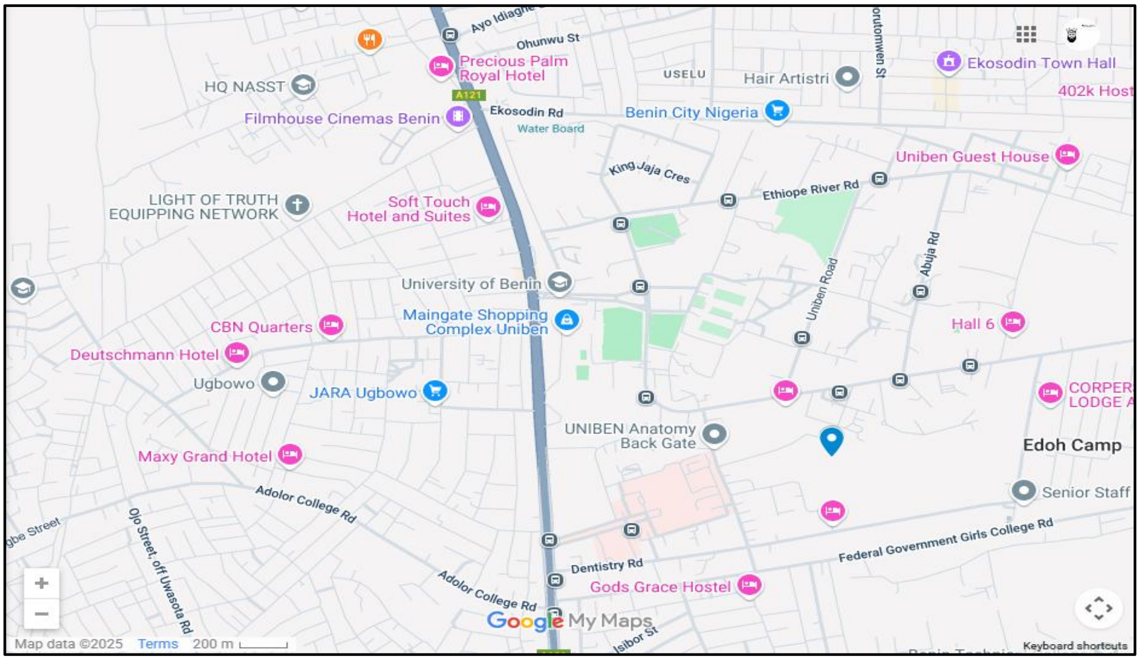

Figure 3.1: Map of Ugbowo showing the road infrastructure (Google maps).

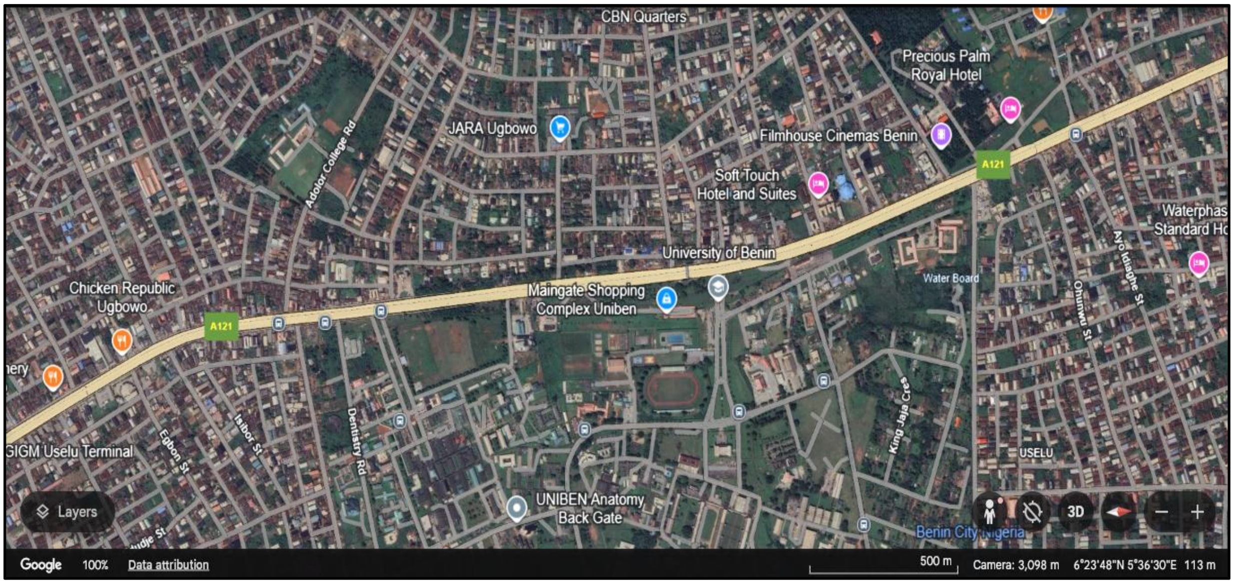

Figure 3.2: Google Imagery showing the Topographic Map of Ugbowo (Google Earth Pro, 2025).

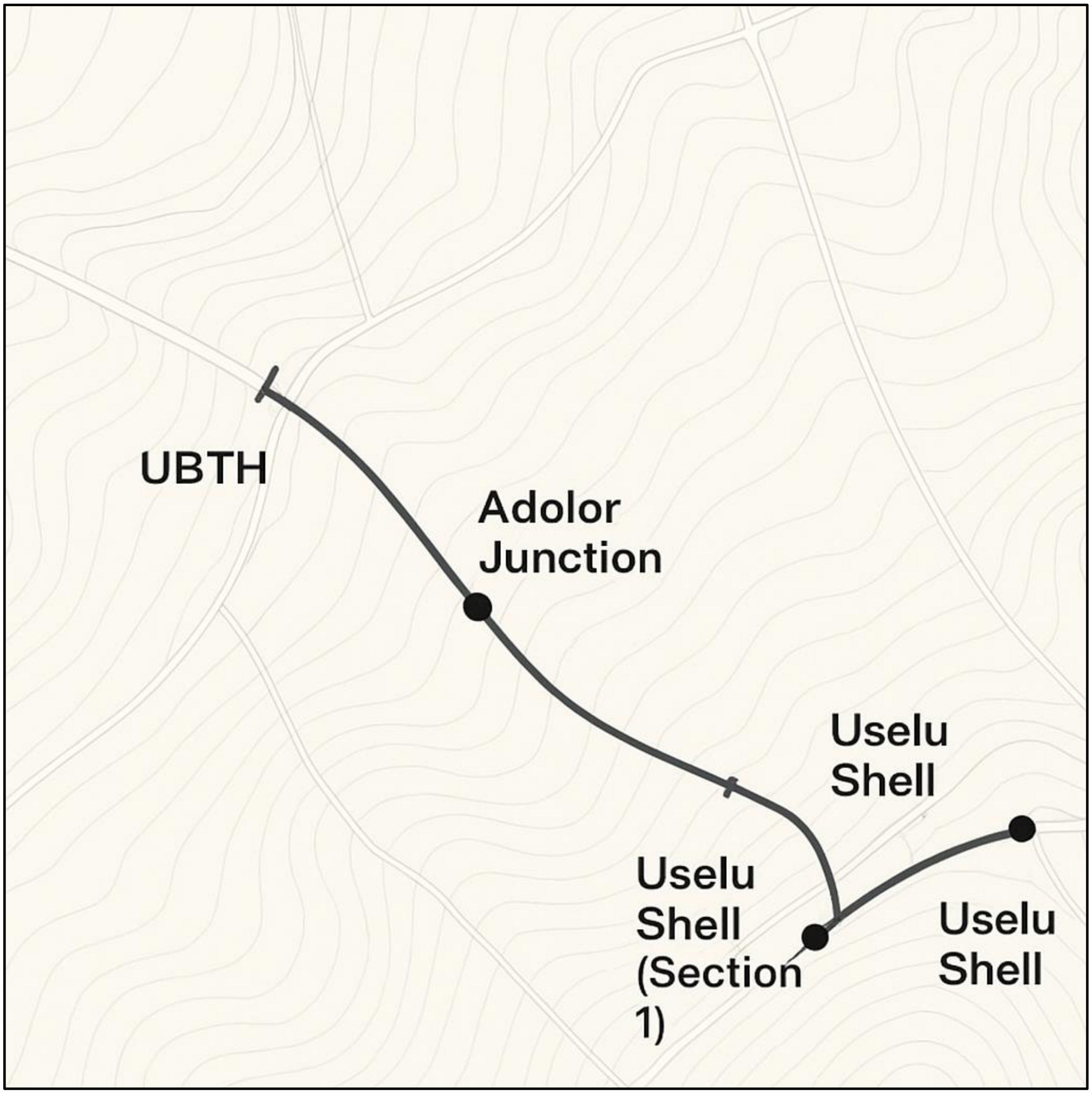

Figure 3.3: Geospatial representation of the drainage sections showing drainage investigation points.

3.2 DESIGN OUTLINE AND METHODOLOGICAL FRAMEWORK

This research adopts a systematic mixed-method approach, incorporating both qualitative assessments and quantitative evaluations. The study was structured in two primary phases:

i. **Structural Condition Assessment:** Focusing on material deterioration and visible signs of distress.
ii. **Hydraulic Capacity Evaluation:** Examining the flow characteristics of the system to determine functionality under rainfall events.

The methodological framework integrates field observations, non-destructive testing (NDT) and hydraulic simulation via Manning's formula. Each phase was tailored to provide a comprehensive insight into both the mechanical performance and flow capacity of the drainage infrastructure, ultimately facilitating the identification of failure causes and the proposal of rehabilitation strategies.

3.3 DATA COLLECTION

Data collection involved a combination of primary and secondary data sources to ensure a holistic assessment of the drainage infrastructure.

3.3.1 Primary Data Collection

Primary data was collected through direct field investigations and observations.

3.3.1.1 Physical Inspection and Structural Assessment

A systematic visual inspection served as the first-level diagnostic tool for detecting physical signs of degradation in drainage channels, culverts, manholes, and associated structures. Observations will focus on:

a) **Surface Cracking:** Surface cracking was identified and documented, including longitudinal, transverse, and map cracking, with notes on the type, extent, and severity of the cracks.

b) **Concrete Surface Deterioration:** Spalling and delamination of concrete surfaces was assessed, with documentation of the extent of damage and potential structural implications.

c) **Reinforcement Condition:** Exposed or corroded reinforcement was identified through signs such as rust stains and concrete bulging, to assess the integrity of the structure.

d) **Structural Movement:** Signs of settlement or joint displacement was noted, which could indicate structural instability or movement.

e) **Biological Growth:** Biological growth, such as vegetation or moss, were documented, as it may indicate prolonged water retention and potential maintenance issues.

f) **Sedimentation and Debris:** Sedimentation and debris accumulation was quantified and documented, including the volume and type of material, to assess the impact on drainage functionality.

g) **Erosion:** Erosion along channel banks or beds was assessed, with documentation of the extent and potential causes of erosion.

h) **Structural Instability:** Sections exhibiting partial or complete collapse, bowing, or bulging was identified, which could indicate structural instability and require immediate attention.

The entire inspection followed a systematic route along the drainage system. High-resolution photographic evidence and geotagging using a GPS-enabled device to document all observed structural defects and hydraulic performance issues, accurately pinpointing their locations. Data was documented to ensure consistency, completeness and providing a baseline for non-destructive testing.

3.3.1.2 Non-Destructive Testing (NDT) using rebound hammer

To quantitatively evaluate concrete strength without causing damage, a Schmidt Rebound Hammer was used, standardized under ASTM C805.

Procedure:

a) Test locations based on visible damage or representativeness from the visual inspection was selected
b) Each test surface was cleaned to remove debris, laitance or other substance that could affect the test results.
c) The rebound hammer was positioned perpendicular to the test surface to ensure accurate and reliable readings.
d) A minimum of three impacts was performed per test point, recording each rebound number.

e) The average rebound number for each location was computed for further evaluation and analysis.

Formula: The rebound number was interpreted using calibration charts provided by the manufacturer or derived from:

$$f_c = aR + b \tag{3.1}$$

Where:

f c = Estimated compressive strength of concrete (MPa)

R = Rebound number

a, b = Empirical constants from calibration data

Figure 3.4: Schmidt rebound hammer used for surface hardness testing.

3.3.1.3 Field data collection for hydraulics

Physical measurements was conducted to establish the hydraulic characteristics of the drainage system:

a) Channel dimensions (width, depth and slope)
b) Blockages or obstructions (e.g., solid waste, vegetation, collapsed sections) and their estimated volume or impact.

Slope (S) was also determined. All values was recorded for hydraulic calculation.

3.3.2 Secondary Data Collection

Secondary data was collected to provide context, support primary investigations, and aid in understanding the underlying causes of deterioration. This includes:

a) **Review of Existing Documents and Reports:** A comprehensive review of the project's foundational materials was successfully executed utilizing publicly accessible online repositories and relevant government planning portals. This strategic approach allowed for the systematic identification and analysis of key documentation essential for establishing the strategic context and design constraints of the current drainage project.
b) **Literature Review:** A comprehensive review of academic literature, research papers, and technical reports on drainage infrastructure assessment, deterioration mechanisms (environmental, design, construction, operation, and maintenance factors), hydraulic modeling, and rehabilitation techniques will be conducted. This will provide theoretical frameworks, best practices, and insights into common causes of failure in similar contexts.

3.4 HYDRAULIC PERFORMANCE EVALUATION

3.4.1 Hydraulic Capacity Calculation

The capacity of the drainage channels was calculated using Manning's Equation:

$$Q = \left(\frac{1}{n}\right) \times A \times R^{\frac{2}{3}} \times S^{\frac{1}{2}} \qquad (3.2)$$

Where:

Q = discharge (m^3/s)

n = Manning's roughness coefficient (assigned based on channel material and condition, considering observed blockages)

A = cross-sectional area (m^2)

R = hydraulic radius = A/P, with P = wetted perimeter

S = slope of the channel

Estimated peak discharge (QP) from storm water was then calculated using the Rational Method:

$$Qp = CIA \qquad (3.3)$$

Where:

c= runoff coefficient (dimensionless) was based on land use characteristics of the drainage area)

I = rainfall intensity (mm/hr) was derived from historical rainfall data or design storm intensity)

A = catchment/drainage area (ha) was determined from available maps or approximate delineation)

A comparison of QP with Q provided insight into the sufficiency of the current drainage system to handle current surface runoff volumes.

3.5 DATA ANALYSIS AND INTERPRETATION

3.5.1 Structural Data Interpretation

a) Rebound values was analyzed statistically (mean, standard deviation) to assess variability in concrete strength across the drainage infrastructure.

b) Root Cause Analysis: The identified physical and structural deteriorations was meticulously analyzed to identify their primary causes, specifically covering environmental factors (weather, soil type, erosion), design deficiencies (inadequate sizing, material selection, lack of proper joints), construction issues (poor workmanship, improper compaction, inadequate curing), and operation and maintenance factors (lack of desilting, unauthorized dumping, vehicular overloading). A Root-Cause Analysis Report that includes: Observed defect, evidence collected, likely root cause category, reasoning/diagnosis and recommended action was carried out.

3.5.2 Hydraulic Data Interpretation

a) Channels and pipes where $QP > Q$ was flagged as hydraulically insufficient, indicating their inability to convey peak storm flows.

b) Observed physical blockages and constrictions was correlated with theoretical capacity loss, identifying critical bottlenecks that significantly reduce hydraulic efficiency.

c) Observed instances of overtopping and flooding was linked to specific sections of the drainage infrastructure to confirm hydraulic deficiencies.

The findings from the structural integrity assessment and hydraulic performance analysis was synthesized and correlated to understand the interdependencies between structural failures and hydraulic inefficiency. This integrated analysis formed the basis for comprehensive recommendations.

3.6 Ethical Considerations

The research adhered to ethical guidelines, ensuring that:

a) All data collection was conducted in a responsible and non-intrusive manner.
b) The privacy of individuals was respected during observations.
c) All findings was presented objectively and accurately.
d) Any potential biases was acknowledged and mitigated.
e) No destructive methods was used on the existing infrastructure, ensuring its preservation throughout the study.
f) Safety protocols was strictly observed during all site visits.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 FIELD INVESTIGATION RESULTS

A visual inspection was conducted along the drainage sections, with defects documented using photos and GPS. Common issues included surface cracks, concrete wear, exposed reinforcement, structural shifts, biological growth, sediment buildup, and erosion. Biological growth, sedimentation, and erosion were the most prevalent problems, notably reducing drainage performance. Figure 4.1 to 4.5 shows the defects documented during field investigation.

Figure 4.1: Severe sedimentation and debris (Hydraulic failure).

Figure 4.2: Structural failure characterized by a displaced concrete cover, indicating differential settlement and a critical safety hazard along the drainage alignment.

Figure 4.3: Biological growth within the drainage channel, facilitated by heavy sediment deposition, accelerating wall deterioration and increasing flow resistance.

Figure 4.4: Material degradation/ Spalling.

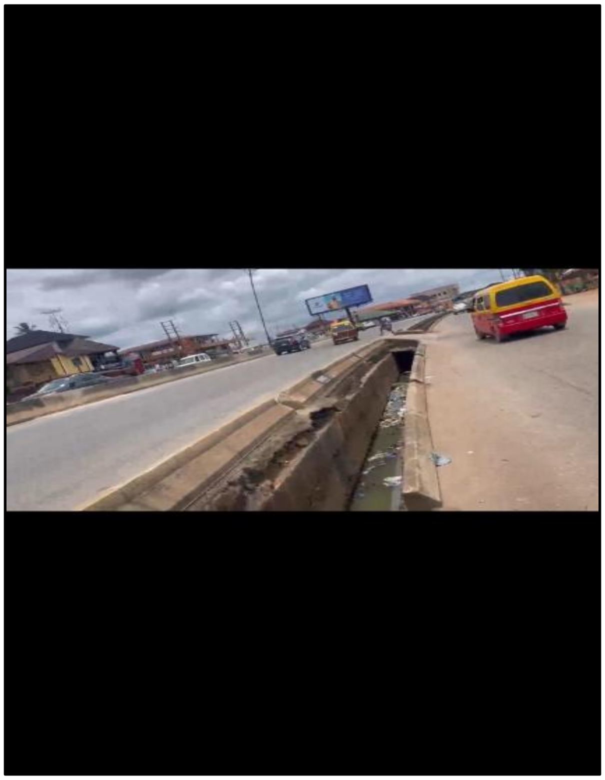

Figure 4.5: Major Structural Failure of the Drainage Channel Wall, demonstrating section collapse likely caused by foundation failure or extreme external lateral loading.

Table 4.1 Shows that all sampled drainage sections lie within the central and western axis of Ugbowo Road, covering about 2.5 km.

Table 4.1: GPS Coordinates Of Drainage Inspection Points

Location	Latitude (°N)	Longitude (°E)	Description
UBTH	6.389799	5.609258	Trapezoidal drain near UBTH; debris accumulation
Adolor Junction	6.390552	5.609289	Rectangular channel; filled with sand and debris
Uselu Shell (Sec. 1)	6.389188	5.609378	Trapezoidal section; standing water present
Uselu Shell (Sec. 2)	6.386650	5.609403	Trapezoidal extension; water-filled, signs of erosion

The proximity of UBTH and Adolor Junction points reflects drainage challenges concentrated around institutional and commercial zones, while the Uselu Shell sections represent the shift toward residential areas.

4.2 STRUCTURAL CONDITION ASSESSMENT (NON DESTRUCTIVE TESTING)

Table 4.2 presents rebound hammer test results from four key locations: UBTH, Adolor Junction, Uselu Shell (Section 1), and Uselu Shell (Section 2). At each site, four to five points that were tested, with three readings per point to ensure accuracy.

Table 4.2: Rebound Hammer Test Readings for Selected Locations

Location	Point	Readings (R_1, R_2, R_3)	Average R	Estimated Strength (MPa)
UBTH	1	38, 36, 40	38.0	17.5
	2	42, 36, 28	35.3	16.2
	3	30, 28, 27	28.3	12.7
	4	36, 37, 38	37.0	17.0
Adolor Junction	1	34, 36, 30	33.3	15.2
	2	30, 35, 36	33.7	15.3
	3	38, 35, 34	35.7	16.3
	4	32, 28, 32	30.7	13.8
Uselu Shell (Section 1)	1	28, 40, 30	32.7	15.0
	2	44, 40, 38	40.7	18.9
	3	50, 38, 40	42.7	19.8
	4	32, 32, 32	32.0	14.5
	5	32, 38, 38	36.0	16.5

Uselu Shell (Section 2)	1	35, 36, 36	35.7	16.3
	2	36, 32, 36	34.7	15.9
	3	38, 35, 38	37.0	17.0
	4	40, 38, 44	40.7	18.9

The empirical constants were based on standard field calibration correlations for medium-grade concrete in tropical environments (ASTM C805; Akinwumi et al., 2017; Oladipo & Adekoya, 2020), constants a = 0.5 and b = −1.5 were adopted, giving the working equation: Fc = 0.5R−1.5.

The compressive strength was estimated using the general empirical relationship:

$$f_c = aR + b \tag{4.1}$$

Where:

- Fc = Estimated compressive strength of concrete (MPa)
- R = Average rebound number
- a, b = Empirical constants derived from calibration data

Average rebound numbers and corresponding compressive strengths were then computed for all test points.

4.3 HYDRAULIC PERFORMANCE EVALUATION

4.3.1 Hydraulic Data from Field Investigation

Table 4.3 shows the field hydraulic data gotten at four locations along the Ugbowo drainage corridor to assess flow capacity and the effect of sediment deposition on effective depth.

Table 4.3: Summary of Hydraulic Data from All Locations

Location	Point	Height Before Clearing (cm)	Height After Clearing (cm)	Difference (cm)	Difference (m)	Converted Height (m)*
UBTH	1	165	168	3	0.03	—
	2	122	125	3	0.03	—
	3	120	122	2	0.02	—
	4	118	120	2	0.02	—
Avg Increase				**2.5**	**0.025**	—
Adolor Junction	1	54	60	6	0.06	—
	2	52	60	8	0.08	—
	3	50	58	8	0.08	—
	4	50	56	6	0.06	—
Avg Increase				**7.0**	**0.07**	—

Uselu Shell (Sec. 1)	1	—	—	—	—	1.62
	2	—	—	—	—	1.62
	3	—	—	—	—	1.60
	4	—	—	—	—	1.60
	5	—	—	—	—	1.58
Uselu Shell (Sec. 2)	1	—	—	—	—	1.58
	2	—	—	—	—	1.56
	3	—	—	—	—	1.55

Measurements were taken before and after debris/sediment removal, with results as shown above. The channel dimensions (width = **10.5 m**) were recorded on site. These measurements, in conjunction with slope and roughness data, were used to compute flow capacity. Converted Height applies to water-filled sections only.

Fig 4.6 to 4.9 shows the simple sketches of the different types of drainage systems that we looked at during our investigation in the Ugbowo area of Benin City. These diagrams show the main parts of the system, from small roadside gutters to large canals and ponds, that we looked at during our investigation.

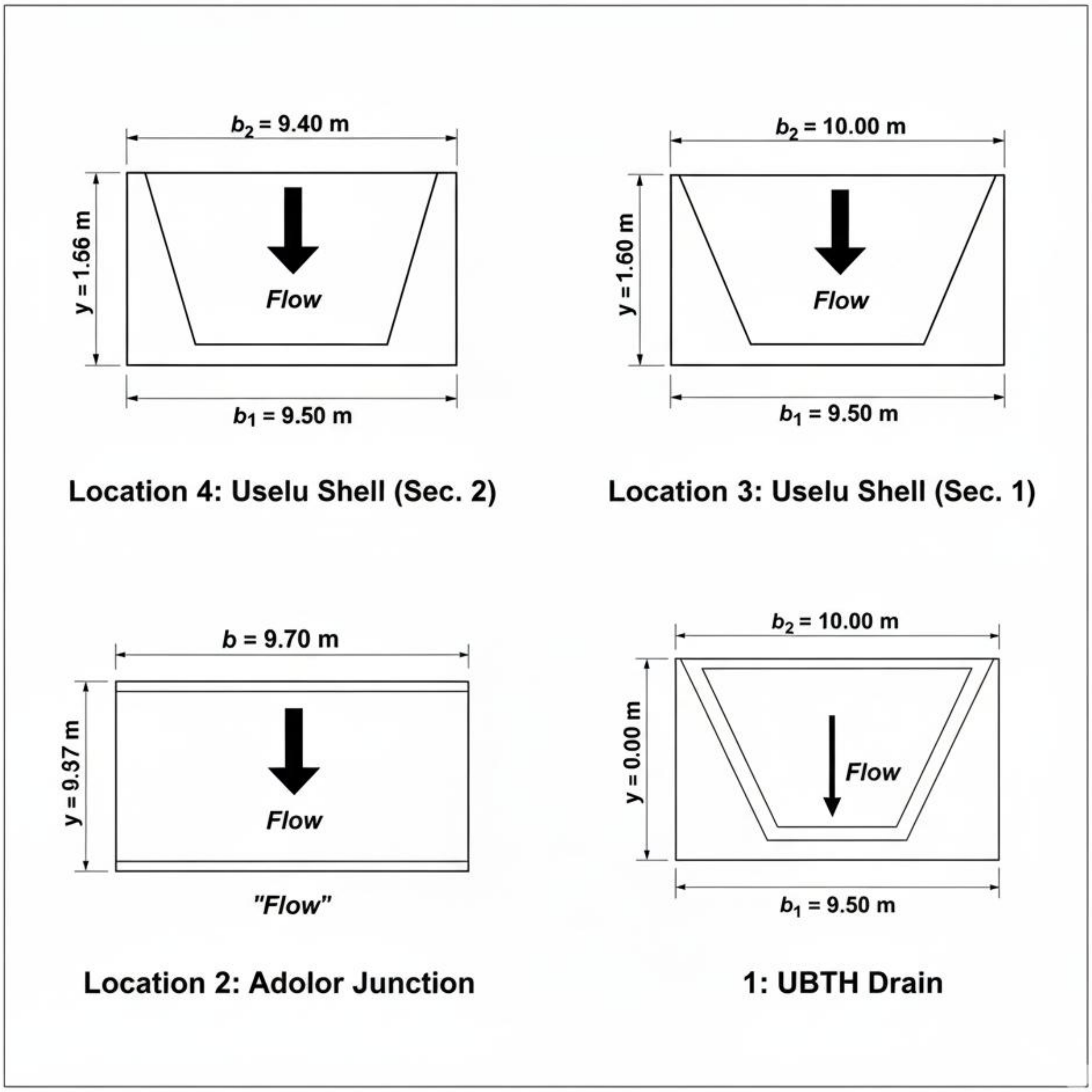

Figure 4.6–4.9: Cross sectional view showing layout and dimensions of trapezoidal and rectangular drains.

Table 4.4: Measured Geometric Parameters and Hydraulic Slopes

This table provides the fundamental measured dimensions and design properties for the four major drainage sections identified in the Ugbowo axis. These values are crucial because they form the basis for all subsequent hydraulic calculations.

Location	Section Type	Depth (y, m)	Bottom Width (m)	Top Width (m)	Side Slope (Z) (H:V)	Normal Slope (S)
Location 1: UBTH Drain	Trapezoidal	1.34	10.50	11.00	0.19:1	0.013
Location 2: Adolor Junction	Rectangular	0.97	9.70	9.70	N/A (Vertical Walls)	0.0127
Location 3: Uselu Shell (Sec. 1)	Trapezoidal	1.60	9.50	10.00	0.16:1	0.014
Location 4: Uselu Shell (Sec. 2)	Trapezoidal	1.56	9.00	9.40	0.13:1	0.015

This table effectively translates the visual information from the field sketches into the numerical data required to perform a comprehensive hydraulic analysis of the drainage network.

4.3.2 Hydraulic Capacity Calculation

The hydraulic performance was evaluated using Manning's Equation:

$$Q = \left(\frac{1}{n}\right) \times A \times R^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

(4.2)

Where:

- Q = Discharge (m^3/s)
- n = Manning's roughness coefficient Discharge computed using n = 0.013
- A = Flow area (m^2)
- R = Hydraulic radius (A/P) (m)
- S = Channel slope

Slope Determination:

Slope was calculated from measured invert levels along each section:

$$S = \left(\frac{\Delta h}{l}\right) \qquad 4.3$$

Where:

Δh = difference in invert levels (m)

L = horizontal distance between measured points (m).

Table 4.5 shows the computed slopes across all drainage sections ranged between 0.011 and 0.014**,** indicating gentle gradients suitable for urban surface runoff conveyance.

Table 4.5: Slope Measurements of the drainages

Location	**Points Considered**	**Chainage (m)**	**Height Difference (Δh, m)**	**Computed Slope (S)**
UBTH Drain	A–C	20	0.26	**0.013**
Adolor Junction	A–B	15	0.19	**0.0127**

Uselu Shell (Sec. 1)	A–B	25	0.35	**0.014**
Uselu Shell (Sec. 2)	A–B	22	0.24	**0.011**

Uselu Shell (Section 1) exhibited the steepest slope (0.014), while Uselu Shell (Section 2) had the lowest (0.011), reflecting slight variations in topography and construction alignment along the Ugbowo corridor.

Table 4.6: Flow Area and Hydraulic Radius Calculation

Location	**Section Type**	**Avg. Depth (m)**	**Width (b1) (m)**	**Width (b2) (m)**	**A (m^2)**	**P (m)**	**R (m)**	**S**	**Q (m^3/s)**
UBTH	Trapezoidal	1.34	10.50	11.0	14.57	13.26	1.10	0.013	20.44
Adolor Junction	Rectangular	0.59	9.70	_	5.72	10.88	0.53	0.0127	3.21
Uselu Shell (Sec. 1)	Trapezoidal	1.60	9.50	10.0	15.20	13.25	1.15	0.014	14.88
Uselu Shell (Sec. 2)	Trapezoidal	1.56	9.00	9.4	14.63	12.18	1.20	0.011	13.29

Table 4.6 summarizes the hydraulic parameters of the four drainage sections, showing flow area (A), wetted perimeter (P), hydraulic radius (R), slope (S), and discharge (Q) computed using

Manning's equation. The trapezoidal sections (UBTH and Uselu Shell) have larger flow capacities, while the rectangular section (Adolor Junction) has lower discharge.

4.3.3 Peak Discharge (Rational Method) and Capacity Comparison

The peak discharge (QP) from rainfall-runoff using the **Rational Method**:

$$Qp = CIA \qquad 4.4$$

For the study area, the following assumptions were applied based on field observations and literature for Benin City:

- C = 0.80 (highly impervious urban surface)
- I = 50 mm/hr
- A=1.2360 ha

QP = 0.8 × 50 × 1.2360 × 10^{-3}= 0.133 m3/s

Result: Q > QP ; The channel has sufficient hydraulic capacity.

The computed discharges for all locations exceed their peak design flows, indicating adequate hydraulic capacity. UBTH and Uselu Shell sections, being trapezoidal with higher slopes and larger wetted perimeters, show superior flow performance. Adolor Junction, with the smallest depth and rectangular shape, has the lowest capacity and requires regular desilting to maintain efficiency.

4.4: SECONDARY DATA COLLECTION

Unavailable Documentation and Study Limitation: A key limitation was the inability to source essential localized documents, including As-Built Drawings and official Drainage Master Plans for Benin City. The absence of these documents necessitated a reliance on field measurements (Section 3.3.1.3) to characterize the existing channels.

Literature Review Context: The literature review focused on two critical areas to contextualize the field results:

1. **Structural Integrity:** Studies consistently show that the in-situ concrete strengths in tropical drainage systems often fall below the required standard of (20-25 MPa). This degradation is primarily linked to poor construction quality control (e.g., curing) and aggressive environmental factors, which validates the low compressive strengths measured via the Rebound Hammer (Section 3.3.1.2).
2. **Hydraulic Functionality:** Research indicates that the main cause of urban flooding is typically operational failure, not hydraulic undersizing (Q often exceeds Q-P). Functional failure occurs because the effective flow area is severely reduced by indiscriminate solid waste dumping, lack of routine desilting, leading to overtopping and localized bottlenecks (Section 3.4.1).

4.5 DATA ANALYSIS AND INTERPRETATION

4.5.1 Structural Data Interpretation

The estimated compressive strengths ranged from 12.7 to 19.8 MPa, below the 20–25 MPa standard (ACI 318, 2019). UBTH (12.7 MPa) and Adolor Junction (13.8 MPa) were weakest, likely due to poor mix and moisture damage, while Uselu Shell sections (up to 19.8 MPa) were stronger. Lower strengths corresponded with cracks and erosion. Overall, most sections require rehabilitation to restore structural reliability.

Table 4.7 shows the root cause analysis matrix gotten for the ugbowo drainage channels.

Table 4.7: Root-Cause Analysis Matrix for Ugbowo Drainage Infrastructure

Observed Defect	Evidence	Root Cause	Recommended Action
Longitudinal cracks	Rebound ≤15 MPa	Weak mix / poor curing	Replace sections; ensure proper curing
Honeycombed concrete	Porous, low rebound	Inadequate vibration	Patch; ensure proper compaction
Blocked channels	Debris at Adolor, Uselu	Waste dumping	Provide gratings; enforce cleanup
Biological growth	Vegetation, stagnant water	Low flow / poor slope	Regular clearing; maintain slope
Sediment buildup	2–7 cm depth loss	Silt accumulation	Routine desilting; add traps
Road flooding	Blocked inlets	Misaligned / clogged entries	Regrade, add inlets, ensure maintenance

Table 4.7 links observed defects in the Ugbowo drainage to their root causes and recommended actions. Construction issues (cracks, honeycombing, misaligned joints) stem from poor material or workmanship, while operational, hydraulic, and environmental problems require maintenance, slope correction, and debris control.

4.5.2 Hydraulic Data Interpretation

a) **Identification of insufficient channel:** All drainage sections have computed capacities (Q) above their peak discharges (Q_p) for a 50 mm/hr storm, showing adequate conveyance: UBTH (20.44 m³/s), Adolor Junction (3.21 m³/s), Uselu Shell 1 (14.88 m³/s), and Uselu Shell 2 (13.29 m³/s). Efficiency may be reduced by sediment, debris, or low slopes. Adolor Junction, with its shallow rectangular section, is most prone to flooding. Figure 4.10 compares Q and Q_p at each location.

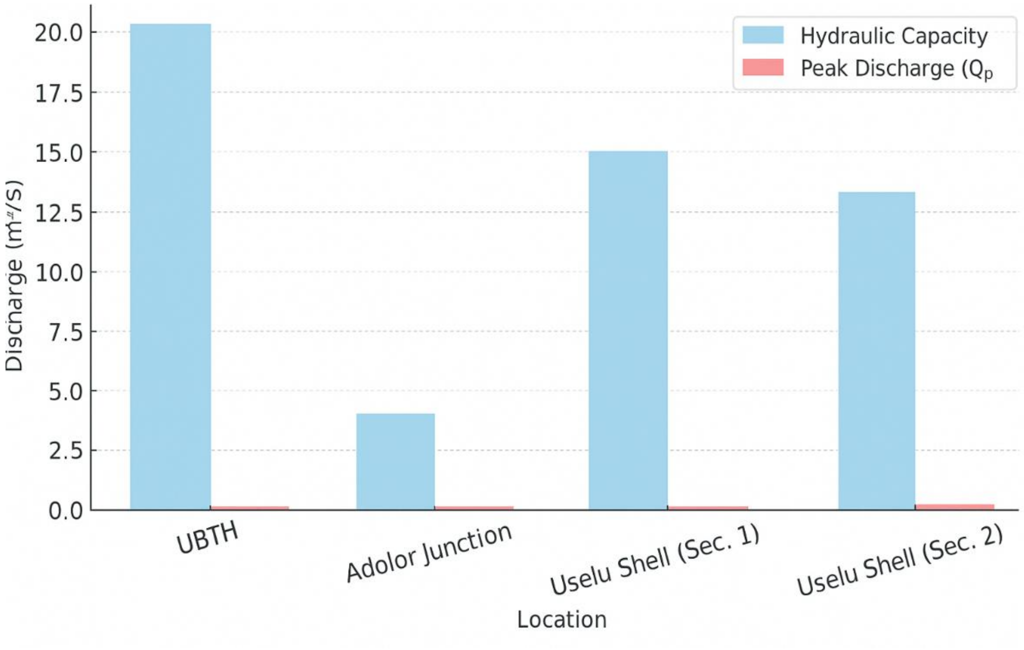

Figure 4.10: Comparison of Hydraulic Capacity and Peak Discharge across Locations.

b) **Correlation of Blockages and Capacity Loss:** While the theoretical capacity shows a surplus at all locations, the physical inspection of the channels revealed significant sedimentation and debris accumulation, which severely reduces the available flow area. To accurately reflect real-world performance, the actual Capacity (Q) was computed by estimating a typical 30% reduction in the flow area across all sections due to these blockages. The resulting correlation between peak storm flow and the Actual Capacity (Q) clearly identifies a critical bottleneck in the system. While the UBTH, Uselu Shell 1, and Uselu Shell 2 sections maintain a significant hydraulic surplus even with a 30% reduction in area, the Adolor Junction is flagged as hydraulically insufficient**.** With a Qactual of 2.09 m3/s against a peak discharge (Qp) requirement of 2.50 m3/s, it demonstrates a -0.41m3/s deficit. This finding confirms that the limited capacity at Adolor Junction is the primary structural cause of the observed overtopping and localized flooding.

c) **Confirmation of Hydraulic Deficiencies:** The calculated hydraulic deficiency at Adolor Junction (a deficit of -0.41 m3/s provides the technical justification for the observed instances of overtopping and flooding in this specific area. The shallow, rectangular cross-section of the junction makes it highly susceptible to this capacity loss, confirming the site observations.

This integrated analysis, combining the structural integrity findings with the calculated hydraulic inefficiency, forms the basis for the comprehensive recommendations for remediation.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This research investigated the structural integrity and hydraulic performance of existing drainage systems along Ugbowo Road, Benin City, using a combination of field investigation, non-destructive testing (rebound hammer), geometric measurements, and hydraulic computations. The study aimed to identify the factors responsible for the poor performance and frequent flooding incidents observed along the corridor. Results revealed that most drainage sections were adequately designed in terms of capacity but have deteriorated structurally due to material weakness, poor maintenance, and environmental exposure. The measured compressive strengths ranged between 12.7 MPa and 19.8 MPa, below the recommended 20–25 MPa standard for reinforced concrete drainage works. Structural defects such as cracking, surface wear, and honeycombing were most prevalent around UBTH and Adolor Junction, indicating inadequate compaction, poor curing, and exposure to aggressive conditions. From the hydraulic assessment, computed capacities from Manning's Equation were greater than their corresponding peak discharges derived from the Rational Method, suggesting that the channels were hydraulically sufficient under design conditions. However, field observations showed significant blockage, siltation, and debris accumulation, which have reduced the actual effective flow areas by up to 30%. The Adolor Junction section particularly showed reduced capacity and frequent surface flooding during heavy rainfall. In summary, the drainage network along Ugbowo Road can still function efficiently if properly maintained, as its design capacity is adequate. The major causes of failure are poor maintenance, structural deterioration, and human-induced blockage rather than undersized construction. Proper rehabilitation and consistent desilting are required to restore the system to full functionality.

5.2 CONTRIBUTION TO KNOWLEDGE

This research has contributed to the understanding of urban drainage performance in several ways:

1. It provided empirical data on the current physical and hydraulic conditions of the Ugbowo drainage system.
2. It established that functional blockage, not design inadequacy, is the main cause of drainage inefficiency and localized flooding.
3. It demonstrated the usefulness of combining structural (NDT) and hydraulic analysis for a comprehensive evaluation of drainage infrastructure.
4. It provided a framework for low-cost assessment applicable to similar urban drainage systems across Nigerian cities.

5.3 RECOMMENDATIONS

Based on the findings, the following recommendations are proposed to improve the performance and longevity of the existing drainage infrastructure:

Structural Improvements:

1. Reconstruct weak sections with compressive strength below 15 MPa using high-quality concrete of at least 25 MPa strength.
2. Repair cracks and honeycombed areas using epoxy or polymer-modified mortar to restore surface protection.
3. Apply anti-corrosion coatings on exposed reinforcement to prevent further degradation.

4. Provide erosion protection at vulnerable channel banks using concrete lining or gabion structures.

Hydraulic and Maintenance Measures:

1. Regular desilting and clearing of the channels, especially before the rainy season, to maintain design flow area.
2. Install trash screens and silt traps at inlet points to prevent entry of solid waste.
3. Regrade low-slope sections to improve hydraulic efficiency and avoid water stagnation.
4. Introduce inspection chambers and access covers for easier cleaning and routine maintenance.
5. Implement routine inspection schedules managed by the Edo State Ministry of Works and Environment.

Environmental and Policy Measures

1. Public awareness campaigns to discourage indiscriminate dumping of waste into drains.
2. Strict enforcement of sanitation laws to prevent obstruction and damage to public drainage.
3. Develop a drainage asset management plan supported by GIS for record-keeping and periodic performance monitoring.
4. Ensure quality control during future drainage construction, including field concrete testing and supervision.

5.4 SUGGESTIONS FOR FURTHER STUDY

To enhance knowledge and improve drainage management, the following areas are recommended for further study:

1. Advanced hydrodynamic modelling using real-time rainfall and discharge data to simulate system response during storms.
2. Durability studies on concrete materials exposed to tropical weather and waste-induced chemical attack.
3. Socio-environmental assessments on how community behavior affects drainage efficiency.
4. Comparative analysis of drainage systems in other parts of Benin City to develop a citywide maintenance strategy.

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APPENDIX

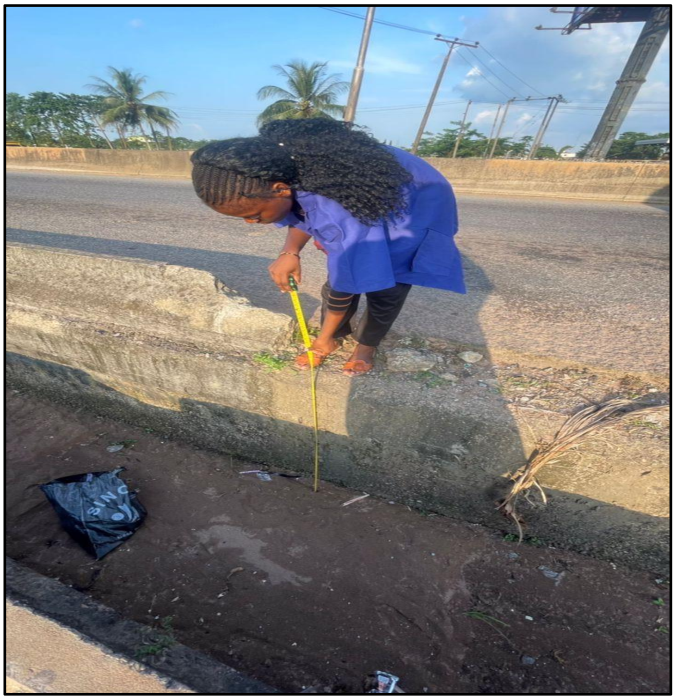

Plate A1: Field measurement of channel depth and siltation.

Plate A2: Non-destructive testing (visual documentation).

Plate A3- A5: General view of environmental and maintenance constraints.