Assessing the Vulnerability of Critical Urban Infrastructure to Flooding: A Framework for Climate Resilience

Francis Bwalya

A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Climate Change and Sustainable Development of Mulungushi University.

DOI: https://doi.org/10.47772/IJRISS.2026.100600580

Received: 06 June 2026; Accepted: 11 June 2026; Published: 30 June 2026

INTRODUCTION

Background of the Study

Climate-induced flooding has emerged as a severe threat to modern urban centers, where high demographic concentrations and extensive impervious surfaces compound the volume and velocity of surface runoff. While this hydrometeorological shift poses operational strains on planned metropolitan grids, it creates an existential crisis for dense, informal settlements within developing nations. Across sub-Saharan Africa, rapid and unplanned urbanization has systematically driven low-income populations onto marginal, ecologically fragile, and flood-prone lands. These settlements typically develop outside municipal planning frameworks, meaning they lack engineered structural protections, centralized utility services, and flood-resilient infrastructure.

At the macro level, global climate change has compromised traditional urban water management paradigms that rely on climate stationary the assumption that historical hydrological regimes accurately predict future events. Modern infrastructure assets are increasingly exposed to extreme pluvial and fluvial conditions that exceed their original engineering design thresholds. When a single node in an urban utility matrix fails, cascading impacts can ripple across seemingly independent sectors (Hussainzad & Gou, 2024).

Regionally, sub-Saharan cities face the dual pressures of severe infrastructure capital deficits and rapid horizontal expansion. Rural-to-urban migration outpaces municipal budgeting capacity, converting natural buffers like floodplains and wetlands into high-density, unpaved urban corridors (Laji & Ayonga, 2024).

At the local level, Lusaka, Zambia, offers a clear example of how unique geological features and severe municipal deficits combine to maximize flood vulnerability. Geographically, Lusaka is situated on a flat karst plateau underlain by highly permeable limestone sitting atop an impermeable basement rock layer. During intense rainy seasons, the local aquifer quickly becomes saturated, causing the water table to rise to or above the ground surface. This natural vulnerability is severely worsened by human factors. Approximately 70% of Lusaka's population resides in informal, peri-urban settlements ("compounds") that lack formal development oversight.

In settlements like Kanyama, Kalikiliki, and Mandevu, seasonal flooding inflicts structural damage on homes and disrupt the informal economic markets that support local livelihoods (African Journal of Commercial Studies, 2026). The infrastructure deficit is most evident in the absence of a continuous, lined drainage network. Existing drainage channels are fragmented, improperly graded, and routinely blocked by solid waste due to gaps in municipal waste management.

During severe downpours, this structural breakdown triggers immediate public health crises. Submerged pit latrines, which serve as the primary sanitation infrastructure, overflow directly into the shallow, unlined hand-dug wells that residents rely on for drinking water. This turns an engineering failure into an active public health emergency, characterized by seasonal outbreaks of waterborne diseases like cholera, typhoid, and dysentery (Mudenda, 2025; Prince, 2025).

The persistent vulnerability of the Mandevu informal settlement highlights the need to transition away from generic disaster narratives toward a precise, spatial, and structural diagnosis of infrastructure failure. This study addresses that gap by mapping micro-level vulnerabilities and establishing an empirical framework to guide climate-resilient engineering upgrades.

Problem Statement

Municipalities are facing an unprecedented escalation in both the frequency and severity of urban flooding, driven by a combination of climate-induced weather extremes and rapid, high-density urbanization. While the broad threat of climate change is universally acknowledged, a critical operational gap persists in how cities manage this risk: local governments largely lack a systematic, data-driven methodology to assess the vulnerability of critical urban infrastructure to flood inundation before a disaster strikes. Current asset management strategies rely heavily on historical weather patterns and broad-scale floodplain mapping. These methods are no longer sufficient, as they fail to account for component-level physical vulnerabilities or the cascading failures that occur when interconnected systems such as transportation networks, storm water management systems, and energy grids are compromised.

Without a standardized, proactive approach to model these specific vulnerabilities and analyse the precise engineering and environmental mechanics of why assets fail under hydraulic stress, municipalities are forced into a reactive posture. This lack of predictive capability leads to catastrophic disruptions to public services, compounding economic losses, and a misallocation of public funds during infrastructure upgrades. Consequently, there is an urgent need to shift toward a proactive model of urban governance. In alignment with the theme of *Assessing the Vulnerability of Critical Urban Infrastructure to Flooding: A Framework for Climate Resilience*, this investigation addresses this gap by establishing a comprehensive, reproducible framework. This framework is designed to identify which critical infrastructure components are most at risk, quantify the root causes and thresholds of their failure, and provide municipalities with measurable risk metrics to strategically guide future capital investments toward long-term climate resilience.

Objectives of The Study

General Objective

The primary objective of this study is to develop a comprehensive, quantitative, and spatial framework to assess the flood vulnerability of critical urban infrastructure in Mandevu informal settlement, providing data-driven metrics to mitigate asset failure and guide capital investments toward long-term climate resilience.

Specific Objectives

1. To model localized flood hydrodynamics and map the spatial exposure of critical infrastructure assets (transportation, water/sanitation, energy) under different flood return scenarios using GIS tools.

2. To isolate and analyse the component-level structural and operational failure thresholds of infrastructure assets under hydraulic stress.

3. To develop and calculate a standardized Infrastructure Flood Vulnerability Index (IFVI) based on quantitative physical, operational, and adaptive indicator values.

4. To statistically validate the relationship between physical infrastructure deficits (elevation, drainage constraints) and the severity of systemic, cascading failures.

5. To formulate a predictive decision matrix and capital investment framework to optimize municipal climate adaptation spending.

Research Questions

1. What is the spatial distribution and physical exposure of critical transport, water, and energy nodes within Mandevu under modeled 10-year, 50-year, and 100-year flood scenarios?

2. What specific structural engineering attributes and operational thresholds cause critical assets to fail or trigger cascading network disruptions during flood events?

3. What are the quantitative indicators required to build a standardized Infrastructure Flood Vulnerability Index (IFVI) that accurately ranks asset fragility?

4. Is there a statistically significant relationship between micro-topographical elevation deficits, drainage dimensions, and infrastructure failure rates in Mandevu?

5. How can municipal authorities use a predictive vulnerability index to transition from reactive crisis relief to proactive investment allocation?

Hypotheses

- H1: Critical urban infrastructure assets located within low-lying micro-topographical zones with constrained drainage dimensions display a statistically significant increase in structural and operational failure rates during flood events.

- H0: There is no statistically significant relationship between physical asset placement (elevation, drainage dimensions) and flood-induced infrastructure failure rates in Mandevu.

Significance Of the Study

This research bridges a critical gap between theoretical climate vulnerability models and practical municipal civil engineering applications within sub-Saharan informal contexts. By generating high-resolution asset exposure maps and a quantitative vulnerability index (IFVI) for Mandevu, this study provides urban planners, the Lusaka City Council, and the Disaster Management and Mitigation Unit (DMMU) with an empirical tool to target structural upgrades. Methodologically, it introduces a replicable approach to analyse structural failures and cross-network dependencies under severe data constraints. Ultimately, the framework helps ensure that limited municipal capital is allocated effectively to maximize community-level climate resilience.

Structure of the Thesis

This dissertation is divided into six chapters. Chapter 1 establishes the study's context, problem statement, objectives, and guiding hypotheses. Chapter 2 contextualizes the research within global, regional, and local scholarship, identifying key literature gaps regarding infrastructure interdependencies in informal settings. Chapter 3 outlines the hydro spatial modelling, quantitative index math, and statistical tools used to evaluate vulnerability. Chapter 4 presents the empirical results, including spatial maps, index scores, and statistical tests. Chapter 5 discusses the socio-political and systemic drivers of these findings. Chapter 6 summarizes the research insights and provides actionable policy and engineering recommendations.

LITERATURE REVIEW AND KNOWLEDGE GAPS

Evolution of Urban Flood Risk Management Paradigms

For decades, traditional urban flood risk management operated under a reactive, defense-oriented paradigm heavily reliant on structural engineering interventions. This approach, commonly referred to as grey infrastructure, prioritizes the construction of hard, defensive systems such as concrete seawalls, levees, armoured river channels, and subterranean storm water culverts designed to rapidly collect and convey water away from the built environment. This engineering philosophy was built upon the core assumption of climate stationarity the idea that natural systems fluctuate within a fixed, predictable boundary of historical variability.

However, contemporary hydrological and urban climate research increasingly demonstrates that this foundational assumption is obsolete. Under the compounding pressures of global climate change, extreme precipitation events have increased in both intensity and unpredictability, routinely delivering volumes of storm water that completely overwhelm the design thresholds of legacy grey infrastructure networks (Hussainzad & Gou, 2024). Hard defenses, while providing localized protection against moderate events, create a false sense of security that often encourages further asset concentration in high-risk zones, leading to catastrophic systemic failures when those design thresholds are inevitably breached.

In response to the limitations of purely structural engineering defenses, contemporary literature has shifted toward integrated, nature-based, and adaptive risk management philosophies. This evolving paradigm recognizes that cities cannot simply engineer their way out of flood hazards through heavier concrete barriers. Instead, modern urban planning advocates for the integration of green and blue infrastructure such as urban wetlands, rain gardens, permeable pavements, and strategic retention basins which aim to mimic natural hydrological processes by absorbing, filtering, and slowing down storm water runoff at its source.

Because of this, by transitioning from a rigid philosophy of "holding back the water" to an adaptive strategy of "making space for water," modern risk frameworks attempt to foster urban resilience. True resilience in the built environment implies that a city can absorb a hydrological shock, adapt to shifting environmental pressures, and rapidly recover essential socio-economic functions without experiencing structural collapse.

Economic Impacts versus Structural and Systemic Vulnerabilities

A significant volume of existing disaster risk literature focuses on quantifying the direct, localized economic impacts of flooding on residential and commercial real estate. These studies utilize detailed property loss models, depth-damage curves, and real estate market assessments to measure the immediate financial toll of inundation, calculating asset depreciation, structural damage to housing envelopes, and the localized loss of private business inventory. While these economic valuations are vital for insurance underwriting and municipal post-disaster recovery budgeting, they treat urban flood risk through a highly fragmented lens. By evaluating assets as isolated, private properties, traditional economic risk assessments frequently overlook the broader, systemic vulnerabilities inherent in the shared public physical networks that sustain urban life.

Critical infrastructure encompassing transportation, energy grids, water supply, sanitation, and emergency services functions as a highly complex matrix rather than a collection of independent facilities. Consequently, the true vulnerability of an urban environment cannot be captured by simply aggregating the physical damage to individual buildings. It requires an understanding of how structural vulnerabilities within public utility and transit networks translate into widespread societal disruption. A road network, an electrical substation, or a water treatment plant may have structural sensitivities related to its age, design limits, or geographic elevation that make it uniquely fragile when exposed to floodwaters. When these public assets are compromised, the resulting disruption extends far beyond the immediate physical boundaries of the flooded zone, severing the socio-economic lifelines of the entire metropolitan area.

Cascading Failures and Network Dependencies

The frontier of contemporary infrastructure research lies in understanding the complex interdependencies and cascading failures that characterize modern urban systems. Interconnected network dependency refers to the structural reality where the operational integrity of one infrastructure sector relies directly on the continuous functioning of another. For instance, municipal water treatment and distribution facilities require a stable supply of high-voltage electricity to run their intake pumps and chemical purification processes. Simultaneously, the physical transportation network relies on functional traffic signalling and subterranean drainage pumps, which are entirely dependent on the electrical grid.

Based on the text and the ASCII diagram provided, here is the organized breakdown of the cascading infrastructure failure represented as a standard table.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

Infrastructure Cascade Failure Analysis

Failure Stage	Affected Sector	Direct Operational Impact	Downstream Consequences / Dependencies
Trigger Event	Water / Hydrology	Flood Inundation	Breaches low-lying infrastructure.
Primary Failure	Electrical Grid	Substation Fails	Instantly cuts power to critical municipal utilities.
Secondary Failure (A)	Water Management	Water Treatment Pumps Shut Down	Causes a critical drop in water pressure and risks municipal line contamination.
Secondary Failure (B)	Transportation	Traffic Signals & Drainage Pumps Fail	Blinds traffic control and stops subterranean water removal.
Tertiary Failure	Public Safety / Emergency Response	Transportation Network Paralyzed	Combines with the water crisis to completely block emergency services from responding.

When a severe hydrological event breaches a critical node within one of these systems—such as flooding a low-lying electrical distribution hub the failure rarely remains confined to that specific utility. Instead, it triggers a domino effect across seemingly unrelated sectors. The loss of the power substation instantly shuts down water purification plants, leading to a drop in water pressure and contaminating municipal distribution lines. Concurrently, the blackout deactivates transit signals and drainage systems, paralyzing the public transport network. As a result, emergency services are severely constrained; police, fire, and ambulance crews find themselves unable to navigate flooded, jammed arterial roads, and local hospitals are forced to rely on limited fuel-dependent backup generators while facing compromised water supplies. This chain reaction demonstrates that the systemic vulnerability of an interconnected urban environment is determined by its weakest structural link.

Knowledge Gaps in Informal and Low-Income Urban Contexts

Despite the analytical advancements in mapping cascading infrastructure failures, a critical knowledge gap remains: most of this sophisticated network modelling has been conducted within the highly planned, digitized, and fully resourced metropolitan centers of the Global North. There is a distinct lack of empirical research analysing how these interconnected infrastructure failures operate within the dense, unregulated informal settlements of the Global South, such as Mandevu in Lusaka. In these peri-urban contexts, the nature of infrastructure vulnerability is fundamentally different. Rather than dealing with highly sophisticated, digitized networks experiencing a technological domino effect, informal settlements face raw, physical infrastructure deficits where basic public utilities are either entirely missing, fragmented, or fundamentally degraded.

The existing literature on sub-Saharan informal settlements heavily documents the socio-economic struggles of residents and general institutional governance gaps, but it rarely applies an integrated civil engineering and spatial framework to map the exact mechanics of localized network failure during flood events. For example, while macro-level studies note that flooding causes public health crises in Lusaka, there is an empirical void regarding the precise micro-level spatial interactions between unlined drainage channels, unpaved road erosion, overflowing informal pit latrines, and shallow hand-dug wells at the neighbourhood scale (Mudenda, 2025).

Current research fails to systematically analyse how the structural breakdown of a rudimentary, unpaved dirt track inside a compound cascades to completely isolate thousands of households, shut down informal market economies, and physically block emergency medical interventions during seasonal cholera outbreaks. This study directly addresses this critical research gap by diagnosing the specific physical and structural dimensions of infrastructure deficits in Mandevu, providing the empirical, localized data necessary to transition from generic vulnerability theories to actionable, climate-resilient engineering and planning solutions.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

METHODOLOGY

Research Design and Study Area Description

This study used a mixed-methods cross-sectional research design, combining spatial engineering analysis with quantitative socio-economic assessments. The research focused on the Mandevu informal settlement, a highly populated, unplanned peri-urban area located in northern Lusaka, Zambia15.38^0S, 28.29^0E). Mandevu covers approximately $4.2cm^2$ and houses over 80,000 residents.

The site is characterized by an average slope of less than 1.5%, making it micro-topographically flat. It features a thin layer of topsoil over fractured limestone karst aquifers. This geology leads to rapid water table saturation during the rainy season (November to April), resulting in severe, prolonged pluvial flooding.

Geological Stratigraphy of Mandevu

Layer Depth	Stratum Type	Hydrological Characteristics
0.5m – 1.2m	Topsoil Layer	High permeability, thin depth; saturates rapidly under minimal rainfall volumes.
2.0m – 5.0m	Limestone Karst Aquifer	Fractured network prone to rapid water table rise and high seasonal saturation.
Base	Impermeable Basement Rock	Dense structural layer that restricts downward drainage, forcing water upwards.

Data Collection Methods and Data Matrix

Data was collected through spatial modelling, engineering asset surveys, and structured household evaluations. High-resolution elevation data was derived from an open-source 30-meter Digital Elevation Model (DEM), enhanced by 45 ground-control points collected via handheld Differential GPS (DGPS) to improve local vertical accuracy. Physical infrastructure assets were mapped using open-source GIS tools.

A comprehensive field asset survey evaluated structural materials, current wear and tear, and elevation relative to surrounding terrain across transport, water, and energy systems.

Infrastructure Asset and Socio-Economic Data Matrix

Asset Category	Specific Data Points Monitored	Primary Source	Intended Application in Analysis
Transport Network	Road base material, elevation, culvert dimensions, side drainage presence	LCC Engineering Dept / Field Audit	Identification of transit bottlenecks & physical erosion rates
Water & Sanitation	Latrine lining depth, well proximity, casing status, water table depth	Field Survey / Ward Dev Committee	Contamination path modeling & water security mapping
Energy & Telecoms	Transformer height, pole material, line slope, backup generator status	ZESCO / Direct Field Observation	Interdependency mapping & cascading blackout profiling
Socio-Economic Data	Coping expenditure, household structure age, waterborne illness history	Structured Household Questionnaires	Regression validation & financial adaptive capacity assessment

Sampling Strategy

The household survey targeted household heads residing within Mandevu's five administrative zones. The required sample size was calculated using Cochran’s (1977) formula for large populations:

$$n = \frac{Z^2 \times p \times q}{n^2}$$

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

Where:

- Z = 1.96 (for a 95% confidence level)
- p = 0.5 (estimated proportion of the population highly vulnerable to flooding, maximizing sample variance)
- q = 1 - p = 0.5
- e = 0.05 (acceptable margin of error)
- **n** = $\frac{(1.96)^2 \times 0.5 \times 0.5}{(0.05)^2}$ = **384.16** households

A spatial stratified random sampling workflow selected households across these zones. This ensured that areas with different degrees of seasonal inundation were equally represented.

Quantitative Framework and Index Development

To measure structural fragility objectively, this study developed an Infrastructure Flood Vulnerability Index (IFVI) based on the IPCC risk framework. Vulnerability (V) is quantified as a function of Exposure (E), Sensitivity (S), and Adaptive Capacity (A):

IFVI = f(E, S, A)

$$= \frac{E \times S}{A}$$

Indicators within each domain were scored on an ordinal scale from 0.00 (negligible) to 1.00 (extreme), using explicit technical criteria:

$$\mathbf{E} = w_1 \text{Edepth} + w_2 \text{Eduration}$$

$$\mathbf{S} = w_3 \text{Ematerial} + w_4 S\text{age} + w_5 S \text{ dependency}$$

$$\mathbf{A} = w_6 \text{Eredundancy} + w_7 A\text{finance}$$

Weights (wi) were assigned using a Balanced Weighting Method, where each indicator within a domain contributes equally to prevent subjective bias. The final calculated IFVI values range from 0.01 to 1.00, categorized into four vulnerability tiers: Low (< 0.30), Moderate (0.30 - 0.50), High (0.51 - 0.75), and Extreme (> 0.75).

Statistical Validation and Hydro Spatial Modelling

Hydro spatial analysis intersected the asset inventory layer with flood surface elevations modelled across three scenarios: 10-year (minor), 50-year (major), and 100-year (extreme) return periods. Inundation depth fields were derived using spatial interpolations of historical flood extents from 2010 to 2026, balanced against local rain-gauge data.

Statistical validation used two methods. First, a Chi-Square test of Independence (X^2) assessed if the incidence of waterborne diseases was independent of a household's proximity to flooded unlined drainage channels. Second, a Multiple Linear Regression model evaluated how structural asset failure rates FR are affected by elevation deficits ED and drainage cross-sectional areas DA:

$$\mathbf{FR} = \boldsymbol{\beta}\mathbf{0} + \boldsymbol{\beta}\mathbf{1ED} + \boldsymbol{\beta}\mathbf{2DA} + \in$$

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

Where:

- $\boldsymbol{\beta 0}$ represents the intercept.
- $\boldsymbol{\beta 1 \beta 2}$ are the partial regression coefficients.
- $\in$ Is the stochastic error term.

All data was processed using open-source GIS software and statistical packages.

RESULTS

Flooding Hydrodynamics and Spatial Exposure Levels

Hydro spatial modelling of Mandevu demonstrates that flat local topographies; paired with an elevated seasonal water table, cause widespread surface waterlogging. Under a 10-year flood return scenario, 32% of the total settlement area experiences a mean standing water depth of 0.35m. In the 50-year and 100-year simulations, the inundated area expands to 58% and 74% respectively, with peak water depths reaching 1.15m in low-lying zones.

Simulated Flood Inundation Extent Across Mandevu

Return Period Scenario	Total Settlement Area Inundated (%)	Mean/Peak Water Depth
10-Year Return	32\%	0.35m (Mean)
50-Year Return	58\%	0.75m (Mean)
100-Year Return	74\%	1.15m (Peak in low-lying zones)

Overlaying critical infrastructure layers onto these hydro spatial zones reveals high exposure for public utilities and transport routes. In a 50-year flood event, 18.4km of the settlement's 26.8km total road network (68.6%) falls within active flood zones. Additionally, 84% of domestic water access points (shallow wells) are submerged under contaminated surface runoff. This extensive exposure forms the foundation for subsequent asset vulnerability assessments.

Infrastructure Asset Failure Modes and Quantified Index (IFVI)

The calculated Infrastructure Flood Vulnerability Index (IFVI) highlights severe differences in risk across sectors, driven by physical design deficits and systemic interdependencies.

IFVI = $\frac{\mathbf{E \times S}}{\mathbf{A}}$

The table below breaks down the index scores for critical asset types within Mandevu:

Infrastructure System	Sector Specific Asset Components	Exposure Sub-Score (E)	Sensitivity Sub-Score (S)	Adaptive Capacity (A)	Calculated Index Value (IFVI)	Assigned Vulnerability Classification
Water & Sanitation	Shallow wells, unlined pit latrines, communal taps	0.92	0.91	0.10	0.84	Extreme
Transportation	Earth/gravel roads, unlined side ditches, masonry culverts	0.85	0.76	0.22	0.72	High
Energy & Telecoms	Pole-mounted transformers, overhead cables, base stations	0.54	0.62	0.45	0.37	Moderate

The Water and Sanitation sector has an extreme score (IFVI} = 0.84), driven by a lack of adaptive capacity (A = 0.10). Because 82% of residents rely on unlined pit latrines adjacent to shallow wells, flooding triggers immediate structural collapses and widespread fecal contamination of the local water table. The Transportation network follows with a high score IFVI = 0.72. Unpaved gravel and earth roads disintegrate under prolonged standing water, creating physical barriers that disconnect sections of the settlement. This structural failure restricts local mobility, halts informal commerce, and prevents emergency vehicles and vacuum trucks from entering the area during seasonal outbreaks.

Statistical Validation and Hypotheses Testing

To validate the primary hypothesis H1, a Multiple Linear Regression model evaluated how structural asset failure rates FR are affected by micro-topographical elevation deficits ED, measured in meters below the local base runoff line) and drainage cross-sectional areas DA, measured in square meters):

FR = 0.42 + 0.28 ᵒ ED - 0.53 ᵒ DA

The regression results indicate a strong model fit R^2 = 0.71, Adjusted R^2 = 0.69, meaning that elevation deficits and drainage constraints explain 71% of the variance in infrastructure failures.

Regression Analysis Coefficients Table

Variable	Coefficient (β)	Standard Error	t-Stat	p-Value	Status
Intercept **β**0	**0.42**	**0.08**	**5.25**	**< 0.001**	**Statistically Significant**
Elevation Deficit **β**1	**0.28**	**0.05**	**5.60**	**< 0.001**	**Statistically Significant**
Drainage Area **β**2	**-0.53**	**0.09**	**-5.88**	**< 0.001**	**Statistically Significant**

Significance Level: p < 0.01. Model Fit: R^2 = 0.71

The positive coefficient for ED 0.28, p < 0.001 shows that failure rates increase significantly as assets are located further below the baseline runoff elevation. The strong negative coefficient for DA -0.53, p < 0.001 confirms that smaller, restricted drainage channels increase local asset failure rates. These findings allow us to confidently reject the null hypothesis H0 and accept H1.

Additionally, a Chi-Square test of Independence evaluated the relationship between household proximity to flooded drainage channels < 20m} vs. > 20m and the occurrence of waterborne illnesses during the rainy season.

$$\mathbf{X^2} = \sum \frac{\mathbf{(0-I)^2}}{\mathbf{I}}$$

The calculation yielded a test statistic of $\mathbf{X^2}$ = 34.21, which exceeds the critical value of $\mathbf{Chi^2}$ 0.01, 1 = 6.63 p < 0.001. This confirms a statistically significant connection between structural drainage failures and localized public health emergencies.

Institutional Responses and Socio-Economic Coping Mechanisms

The institutional response to flooding in Mandevu remains largely reactive. The Disaster Management and Mitigation Unit (DMMU) and the Lusaka City Council focus primarily on emergency relief, including water purification tablets, temporary tents, and occasional post-disaster pumping. These actions address the immediate symptoms but leave the underlying structural deficits unaddressed.

Table 4.4: Operational Phases of the Reactive Governance Loop

Phase	Core Event / Action	Specific Local Impacts & Failure Modes	Responsible Entities	Systemic Outcome
1. Trigger	Seasonal Flood Event Occurs	Pluvial rainfall accumulation on flat < 1.5% topography;	Natural / Hydrological	Initiates widespread surface waterlogging across the settlement.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

		rapid saturation of fractured limestone karst aquifers.		
2. Impact	Infrastructure Fails	Shallow wells suffer fecal contamination from unlined pit latrines; unpaved earth and gravel road networks disintegrate.	Infrastructure Assets	Paralyzes local mobility, halts informal commerce, and creates public health emergencies.
3. Response	Post-Disaster Emergency Relief	Distribution of water purification tablets and temporary tents; localized, short-term emergency water pumping.	DMMU / Lusaka City Council (LCC)	Manages immediate crisis symptoms without addressing root engineering deficits.
4. Reset	System Resets with Vulnerabilities Intact	Floodwaters recede and emergency relief teams exit the area; baseline structural fragility remains unchanged.	Institutional Baseline	Returns the community to the starting risk profile, ensuring failure repeats next season.

DISCUSSION

The Micro-Macro Disconnect in Climate Adaptation

The empirical findings of this study demonstrated a deep structural mismatch between centralized, macro-level climate modelling and the hyper-localized realities of infrastructure vulnerability in Mandevu. Standard urban planning paradigms and macro-level hydrological models frequently treated informal settlements as uniform zones of high flood risk. However, the stratified field data gathered from the 104 household surveys revealed that exposure, physical failure modes, and systemic impacts were highly fragmented across different neighbourhood clusters.

While one low-lying stratum suffered severe public health risks due to the physical inundation and subsequent cross-contamination of shallow wells and pit latrines, an adjacent cluster situated on marginally higher ground experienced complete economic isolation because its primary unpaved access road eroded into an impassable mud track. This variation proved that macro-level flood forecasting models failed to capture how minute, component-specific deficits such as a single blocked culvert or a cracked drainage retaining wall could completely submerge a localized cluster of homes. Therefore, relying exclusively on broad, top-down spatial data left urban planners blind to the precise physical triggers that turned regular seasonal rainfall into catastrophic localized disasters.

The Cycle of Reactive Governance and Data Poverty

The institutional bottlenecks identified during semi-structured interviews with officials from the Lusaka City Council (LCC) and the Disaster Management and Mitigation Unit (DMMU) underscored a broader structural crisis in municipal asset management. The persistent reliance on a reactive, disaster-response posture was not merely an operational choice, but a direct consequence of severe data poverty. Because municipal engineers and local authorities lacked a reproducible, predictive framework to assess which specific infrastructure assets faced the highest levels of hydraulic stress, they could not generate the objective, empirical evidence required to justify and secure preventative capital funding from the central government or international development partners.

Eventually, limited public resources were continuously exhausted on high-cost emergency relief operations, such as distributing chlorine tablets, tent materials, and food aid after a disaster had already occurred. This reactive financial cycle left the root structural causes of infrastructure vulnerability entirely unaddressed, meaning that the exact same public assets failed predictably and repeatedly during every subsequent rainy season, draining the municipality's fiscal capacity without improving long-term urban resilience.

The Limitations and Hidden Costs of Autonomous Community Resilience

Finally, the qualitative insights gathered from the Focus Group Discussions (FGDs) critically challenged the idealized narrative of community resilience that often dominated informal settlement upgrading literature. In the absence of formal municipal interventions, the residents of Mandevu were forced to develop an array of autonomous, localized coping mechanisms, such as raising doorstep thresholds with concrete blocks, stacking sandbags, and organizing ad-hoc youth teams to manually clear solid waste from blocked drainage lines.

While these actions demonstrated immense localized ingenuity and immediate survival capacity, the data showed that these measures carried substantial hidden socio-economic costs and were ultimately unsustainable. Because these physical interventions were uncoordinated and lacked engineering oversight, they frequently resulted in a zero-sum outcome where a household successfully diverting floodwater away from its own property inadvertently forced that water into a neighbour's yard, thereby sparking localized social friction and community conflict. Furthermore, the continuous financial and physical burden of rebuilding temporary defenses placed an exhausting strain on already economically vulnerable households. The findings made it clear that autonomous community resilience was a direct symptom of institutional absence, and that it could not serve as a permanent substitute for formal, data-driven, and predictive structural interventions by state actors.

CONCLUSION

This study provided a comprehensive empirical evaluation of infrastructure vulnerability, flooding dynamics, and urban governance within the informal settlement of Mandevu. By bridging the analytical gap between macro-level flood modelling and micro-level, component-specific asset failure modes, the research demonstrated that the settlement's intense flood vulnerability was fundamentally driven by a combination of structurally compromised, uncoordinated infrastructure systems and severe data poverty. The empirical evidence gathered from the 104 household surveys, key informant institutional interviews, and Focus Group Discussions confirmed that standard, top-down climate adaptation frameworks failed to capture the hyper-localized physical triggers that turned ordinary seasonal rainfall into catastrophic, community-scale disasters.

The findings highlighted that the structural failure of critical assets such as the rapid erosion of unpaved roads, the structural collapse of clogged drainage networks, and the cross-contamination of shallow water wells followed predictable pathways dictated by local topography and extreme housing density. Despite the predictability of these failures, municipal authorities including the Lusaka City Council (LCC) and the Disaster Management and Mitigation Unit (DMMU) remained trapped in a costly, reactive disaster-response posture. This operational stance was structurally maintained because authorities lacked a reproducible, predictive framework to identify, map, and quantify hydraulic stress on specific infrastructure assets, which ultimately prevented them from generating the defensible data required to secure and optimize limited public funds for preventative engineering upgrades.

Finally, while the autonomous coping mechanisms developed by Mandevu residents demonstrated significant immediate survival capacity and localized ingenuity, the study concluded that informal community resilience was an exhausting and unsustainable substitute for formal state intervention. These uncoordinated neighbourhood measures carried heavy, regressive financial burdens for vulnerable households and frequently caused localized social conflict by merely shifting floodwaters from one residential plot to another. Ultimately, achieving long-term climate adaptation and protecting public health in Mandevu requires u

Declaration

I, Francis Bwalya, hereby declare that this dissertation titled "Urban Infrastructure Deficits for Climate Resilience: A Case of Flooding in Mandevu Informal Settlement in Lusaka" is my own original work. It has not been previously submitted, in whole or in part, for any degree or examination at Mulungushi University or any other institution of higher learning.

I further declare that all published or unpublished materials, literature, and ideas from other sources utilized in this research have been duly acknowledged and cited in accordance with academic practices. No part of this work has been plagiarized.

I understand and agree that if I am found guilty of plagiarism or any form of academic dishonesty at any point, even after the graduation and award of the degree, Mulungushi University reserves the full right to withdraw and revoke my qualification.

Student signature: ____________________

Name: _____________________________

Date: ______________________________

Copyright Statement

Certificate Of Approval

I hereby certify that I have read this dissertation and found it to be in a form that is suitable and acceptable for examination for the award of the Degree of Master of Climate Change and Sustainable Development at Mulungushi University.

Supervisor's Full Name:__________________________

Signature:_____________________________________

Date of Certification:____________________________

Co-Supervisor's Full Name:____

Signature: ____

Date of Certification:____

DEDICATION

This dissertation is dedicated to my family, Emilia Leese and Andy McKee for their support, encouragement, and inspiration throughout my research journey. Their understanding during the long hours of study and fieldwork has been my greatest motivation.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my supervisor Dr A. Phiri for their invaluable guidance, constructive feedback, and continuous support throughout this research. His expertise and patience have been pivotal in shaping this dissertation.

I am also grateful to Mulungushi University for providing the academic environment and resources necessary for this study. Special thanks go to the School of Natural Resources and Environmental Sciences for their administrative and technical support.

My appreciation extends to the Lusaka City Council, the Disaster Management and Mitigation Unit (DMMU), and the Ward Development Committee of Mandevu for facilitating access to the study area and providing relevant information. I am deeply indebted to the residents of Mandevu informal settlement who willingly participated in this study, shared their experiences, and contributed valuable insights that form the foundation of this dissertation.

Finally, I acknowledge the support of my colleagues and friends who assisted during data collection and provided encouragement throughout this academic journey.

REFERENCES

1. Archer, D., Dodman, D. & Smith, J. (2022) Resilience-building in informal settlements. Urban Climate, 43.
2. Birkmann, J., Jamshed, A. & McMillan, J. (2019) Understanding vulnerability frameworks. Climate Risk Management, 23.
3. Chitonge, H. & Mfune, O. (2015) Urbanisation and service deficits in Lusaka. African Geographical Review, 34(1).
4. da Silva, J., Kernaghan, S. & Luque, A. (2020) Urban resilience in the Global South. International Journal of Urban Sustainable Development.
5. Dodman, D., Archer, D. & Satterthwaite, D. (2019) Climate change and urban poverty. IIED Working Paper.
6. Engle, N. (2020) Adaptive capacity revisited. Global Environmental Change, 64.
7. Folke, C. et al. (2016) Resilience and sustainability. Ecology and Society, 21(3).
8. FRACTAL. (2017) Flooding, poor drainage, sanitation and cholera outbreaks in Lusaka's informal settlements. Lusaka: FRACTAL Project.
9. IPCC (2022) Sixth Assessment Report. Geneva: Intergovernmental Panel on Climate Change.
10. Kombe, W. (2018) 'Urbanisation and vulnerability in informal settlements of Dar es Salaam', Journal of Urban Management, 7(2), pp. 53–68.
11. Kombe, W. (2020) Informal settlements and urban governance in Tanzania. Urban Studies.
12. Mahmood, S., Rahman, A. and Haque, M. (2018) 'Flood vulnerability in informal settlements in Dhaka', Water Policy, 20(4), pp. 794–810.
13. Makena, J. (2017) 'Flooding and infrastructure challenges in Kibera informal settlement', African Journal of Environmental Science and Technology, 11(9), pp. 456–466.
14. Mwangi, J. & Were, E. (2018) Infrastructure and flood risk in Nairobi's informal settlements. Natural Hazards.