AFRICA HABITAT REVIEW 20(3) 2025

ISSN: 2524-1354 (Online), ISSN: 2519-7851 (Print)
Africa Habitat Review Journal
Volume 20 Issue 3 (December 2025)
http://uonjournals.uonbi.ac.ke/ojs/index.php/ahr

Green Infrastructure for Urban Resilience: *Integrating Nature-Based Solutions into Stormwater Management in Nairobi*

***Jackline Nyamumbo and Silvester Kasuku**

Received on 25th August, 2025; Received in revised form 1st October, 2025; Accepted on 14th October, 2025.

Abstract

Increasing climate variability challenges urban stormwater management in rapidly growing African cities, with Nairobi exemplifying the crisis: traditional grey infrastructure proves structurally unsound, socially inequitable, and inadequate against frequent floods. This study systematically introduces green infrastructure (GI), such as permeable surfaces, rain gardens, and bioretention systems, as a resilience-building mechanism. Objectives encompass assessing current stormwater challenges, evaluating GI's hydrological and ecological benefits, analyzing socio-economic and governance barriers to adoption, and identifying mainstreaming strategies in Nairobi's planning. Employing a mixed-methods case study across five sub-areas (Kibera, Mukuru, Langata, Lunga Lunga, Kasarani), the research integrates surveys (N=150 residents; N=26 officials/stakeholders), field observations, GIS mapping, and reviews of policy documents. Quantitative data underwent SPSS analysis via descriptive statistics, ANOVA, and chi-square tests; qualitative insights employed thematic analysis in NVivo; GIS visualized drainage networks, impervious surfaces, and flood hotspots. Findings reveal stark infrastructural inequities: 82-88% of informal settlement residents rate drainage as poor, versus 47% in Kasarani, with ANOVA confirming significant flood frequency disparities ($p<0.05$). Kibera and Mukuru experience nearly triple Kasarani's annual floods, exacerbated by a 32% impervious surface increase since 2000 ($\chi^2=28.7$, $p<0.01$) and poor maintenance ($r=-0.46$, $p<0.05$). Socio-economic tolls include average annual household losses of KES 35,000, business losses of KES 70,000, industrial damages up to KES 250,000, and 38% cholera prevalence in Kibera/Mukuru ($\chi^2=34.5$, $p<0.01$). GI demonstrates hydrological, ecological, and socio-economic advantages, yet requires integration with waste management, preventive maintenance, and community engagement for efficacy. Governance hurdles, fragmented mandates (58%) and inadequate budgets (72%), persist, but enabling mechanisms like participatory stewardship and innovative financing (e.g., climate funds, green bonds) offer pathways forward. Theoretically and practically, this positions GI not merely as ecological but as a socio-political-economic tool for resilient urban Africa.

Keywords: Green infrastructure, stormwater management, Nairobi, urban resilience, climate adaptation, socio-economic vulnerability, governance fragmentation, nature-based solutions, informal settlements, urban sustainability

INTRODUCTION

Stormwater management in urban settings has become a de facto challenge in modern city planning, particularly in fast-urbanizing regions of the developing world where weather volatility exacerbates intense rainfall events (Kasuku et al., 2022). Conventional grey infrastructure, focused solely on draining surface water via standardized structures like channels, culverts, and sewers, proves inadequate against chronic flooding and ecological degradation from unmanaged runoff (Seddighi et al., 2022). Globally, a shift toward green infrastructure (GI) and nature-based solutions (NbS) is underway, representing a paradigmatic move to nature-inspired approaches that mimic hydrological processes and deliver co-benefits beyond water control (Hanna & Comin, 2021; Monteiro et al., 2020).

GI encompasses measures such as green roofs, rain gardens, green streets, bioretention systems, and

**Corresponding author:*
***Jackline Nyamumbo** MUM (UoN), Urban Management Practitioner*
Email: jackline.nyamumbo@gmail.com

permeable pavements. These enhance infiltration, curb peak runoff, improve water quality, and support microclimate regulation, biodiversity, and community health (Liu et al., 2021; Zhang et al., 2023). Empirical studies highlight rain gardens' role in mitigating local floods and reshaping residents' views of urban landscapes (Ge et al., 2023; Chaffin et al., 2016), while green roofs substantially reduce stormwater volumes in space-constrained cities, scalable to local needs (Zhang et al., 2023). GI's multifunctionality positions it as a cornerstone for sustainable, resilient urban water management.

Yet, global and regional evidence underscores socio-political and institutional barriers to GI adoption, including financial constraints, technical uncertainties, fragmented governance, and limited community engagement (Seddighi et al., 2022; Istrate & Lo, 2021). Successful cases offer pathways: municipality-level GI suitability maps in Monza-Brianza, Italy, embed NbS in land-use planning (Senes et al., 2021), while Shanghai's integrated stormwater strategies yield resilience gains (Yang et al., 2023). Southeast Asian cities emphasize water-sensitive technologies for climate resilience amid rainfall and temperature extremes (Kurniawan et al., 2024).

In Sub-Saharan Africa, stormwater issues intertwine with urbanization, land-use changes, and infrastructure deficits (Kasuku, 2024a). Nairobi, among Africa's fastest-growing cities, faces recurrent flooding from impervious surfaces, unplanned drainage, and flood-prone settlements (Njoroge & Waithaka, 2021; Kasuku, 2024b). Climate projections foresee heightened rainfall variability, threatening hydrological and socio-economic stability (Palmer & Castro, 2022). Grey infrastructure alone cannot address these complexities; integrated engineering and ecological solutions are essential (Shirgir et al., 2019). GI offers a viable path, reducing runoff, restoring infiltration, and bolstering climate resilience within urban sustainability efforts.

GI in Nairobi must be contextual and participatory. Community involvement sustains initiatives like rain gardens and decentralized drainage (Njoroge & Waithaka, 2021), enhancing effectiveness, legitimacy, and maintenance (Chaffin et al., 2016). International examples affirm this: Cleveland's rain gardens succeeded via cross-institutional collaboration (Chaffin et al., 2016), and Mexico City's GI-integrated flood strategies thrived on multi-scale stakeholder efforts (Palmer & Castro, 2022). For Nairobi, resilient stormwater demands institutional reforms, innovative funding, and community systems (Kasuku et al., 2022).

This article explores integrating GI designs—permeable pavements, bioretention systems, rain gardens—into Nairobi's stormwater management. It addresses: (i) GI's hydrological gains in infiltration and runoff reduction; (ii) socio-ecological co-benefits like biodiversity and urban cooling; and (iii) institutional and financial barriers to scaling. Situating Nairobi within global NbS and resilient infrastructure discourses, the paper advances scholarship on sustainable urban transitions and actionable insights for mainstreaming GI in rapidly urbanizing African megacities.

Research Objectives

This study examines systematic implementation of GI options (e.g., permeable pavements, bioretention, rain gardens) in Nairobi's stormwater management to enhance flood and climate resilience. While grey infrastructure has dominated, escalating rainstorm intensity, land-cover shifts, and impervious expansion demand sustainable alternatives (Palmer & Castro, 2022; Njoroge & Waithaka, 2021). Objectives include:

i. Assess current stormwater management state and challenges in Nairobi, including technical, institutional, and ecological limits, plus flood hotspots and runoff damages (Seddighi et al., 2022; Shirgir et al., 2019).
ii. Evaluate GI's hydrological and ecological benefits in urban settings, such as runoff reduction, infiltration enhancement, biodiversity support, cooling, and pollution mitigation (Liu et al., 2021; Ge et al., 2023; Pugh et al., 2012).
iii. Explore socio-economic and governance aspects of GI adoption, focusing on stakeholder views, community roles, and institutional coordination for sustainability (Chaffin et al., 2016; Njoroge & Waithaka, 2021).
iv. Identify policy, financial, and regulatory mechanisms for scaling GI in Nairobi, including climate finance, public-private partnerships, and land-use tools (Senes et al.,

2021; Yang et al., 2023).

Justification
This research holds practical and theoretical merit. Nairobi's stormwater woes mirror African urbanization: population surges, impervious expansion, and drainage gaps fuel floods, disproportionately impacting informal settlements (Njoroge & Waithaka, 2021; Kasuku, 2024b). Climate change will intensify East African rainfall variability, straining systems (Palmer & Castro, 2022). Grey infrastructure expansions fall short; integrative, adaptable, ecology-based solutions offering co-benefits are urgent (Hanna & Comin, 2021; Shirgir et al., 2019).

GI provides an effective outlet, proven globally for stormwater reduction, urban cooling, and pollution control (Ge et al., 2023; Zhang et al., 2023; Pugh et al., 2012). Yet, adaptation to African contexts falters amid institutional, resource, and planning gaps (Istrate & Lo, 2021; Seddighi et al., 2022). Nairobi's community-driven GI pilots (e.g., rain gardens, infiltration systems) illuminate scaling potentials and pitfalls (Njoroge & Waithaka, 2021), informing socially viable, economically sound, institutionally robust designs. Contributing to knowledge, the study enriches NbS and urban resilience literature, skewed toward the Global North with scant Sub-Saharan evidence (Yang et al., 2023; Kurniawan et al., 2024). Contextualizing Nairobi globally foregrounds African urban financial, social, and environmental nuances, yielding comparative insights. It fuses systems and resilience theories for a multidimensional stormwater governance lens (Monteiro et al., 2020; Shirgir et al., 2019).

Theoretically, it aligns with policy imperatives and global agendas. Nairobi's SDG ties strengthen via GI, advancing SDG 13 (climate action) through resilient, sustainable development—securing water, curbing disasters, and enhancing ecosystems (Hanna & Comin, 2021; Senes et al., 2021). It probes GI-climate finance, carbon markets, and municipal planning linkages, underexplored in Nairobi's policy sphere (Yang et al., 2023; Kasuku, 2024a). Ultimately, this research addresses stormwater urgencies, bolsters evidence on African GI applications, and informs NbS integration in sustainable planning—advancing theory, practice, and policy for enhanced resilience.

THEORY

Conventional urban drainage has emphasized quick runoff conveyance via pipes, culverts, and channels to avoid local flooding, yet research shows these grey systems transfer risks elsewhere, degrade water quality, and increase erosion (Leopold, 1968; Fletcher et al., 2013; Novotny, 2003). Rising peak rainfall from climate change exposes grey infrastructure's vulnerabilities (Bates et al., 2008). Cities are now adopting green infrastructure (GI) and nature-based solutions (NbS) that mimic natural hydrology—slowing, storing, filtering, and infiltrating water on-site, often paired with downsized grey structures (Coffman, 2000; Hanna & Comin, 2021; Monteiro et al., 2020). This shift redefines stormwater as a socio-eco-resource, aligning with ecosystem services, urban cooling, and health benefits (Gill et al., 2007; Andersson et al., 2019; Liu et al., 2021).

As shown in **Table 1**, rain gardens and bioretention use engineered soil to filter runoff, reducing peaks and enhancing nutrient/metal uptake while boosting pollinator habitats (Liu et al., 2021). Cleveland's study linked their success to collaborative maintenance and community involvement (Chaffin et al., 2016). Permeable pavements, like concrete pavers, reduce effective imperviousness but require regular cleaning to counter clogging (Liu et al., 2020). Green roofs cut stormwater volumes and improve microclimates, though initial costs pose barriers (Zhang et al., 2023). These typologies collectively enhance urban resilience.

Barriers and Enablers
Global evidence highlights barriers to GI adoption: financial constraints, technical uncertainties, fragmented governance, and low community engagement (Seddighi et al., 2022; Istrate & Lo, 2021). In Africa, institutional gaps and resource shortages exacerbate these issues (Kasuku, 2024a). Enablers include participatory governance and innovative financing, as seen in Monza-Brianza's GI suitability maps (Senes et al., 2021) and Shanghai's integrated planning (Yang et al., 2023). Southeast Asia's water-sensitive technologies offer climate resilience models (Kurniawan et al., 2024), while Nairobi's community-driven pilots suggest scalable potential despite challenges (Njoroge & Waithaka, 2021).

TABLE 1
Green infrastructure typologies and performance

Type	Benefits	Challenges	Key Cases
Rain Gardens/ Bioretention	Enhances infiltration, reduces peaks, filters pollutants, supports biodiversity (Ahiablame et al., 2012; Lisenbee et al., 2021)	Maintenance demands, clogging	Cleveland (Chaffin et al., 2016)
Permeable Pavements	Reduces imperviousness, captures runoff, boosts baseflow (Ahiablame et al., 2012)	Traffic wear, sediment buildup	Dense urban retrofits (Liu et al., 2020)
Green Roofs	Lowers volume/peaks, improves microclimate (Zhang et al., 2023)	High initial cost, structural load	High-density cities (Hanna & Comin, 2021)

Source: Adapted from Ahiablame et al. (2012); Lisenbee et al. (2021); Liu et al. (2020); Zhang et al. (2023)

Socio-Political Context
In Sub-Saharan Africa, stormwater challenges stem from rapid urbanization, land-use shifts, and infrastructure deficits (Kasuku, 2024b). Nairobi's flooding, driven by impervious surfaces and unplanned drainage, reflects broader trends (Njoroge & Waithaka, 2021). Climate variability threatens stability (Palmer & Castro, 2022), necessitating integrated solutions (Shirgir et al., 2019). GI's success hinges on community participation and institutional reforms, as global cases like Cleveland and Mexico City demonstrate (Chaffin et al., 2016; Palmer & Castro, 2022). This aligns with sustainable urban development goals, urging a multidimensional approach to Nairobi's context.

Global Case Studies of GI Implementation
Global case studies illustrate GI's transformative potential in stormwater management, demonstrating hydrological, ecological, and socio-economic benefits while addressing urban challenges. In the United States, Philadelphia's Green City, Clean Waters program (initiated in 2011) exemplifies large-scale GI integration. Covering 1,500 square miles, it has installed over 1,700 rain gardens, tree trenches, and permeable pavements, reducing combined sewer overflows by 1.2 billion gallons annually and saving $4.8 billion in grey infrastructure costs (Philadelphia Water Department, 2023). This initiative not only mitigated flooding in low-income neighborhoods but also enhanced biodiversity, with urban tree canopy increasing by 20% and cooling effects reducing heat islands by up to 5°C (U.S. EPA, 2022). However, early barriers included fragmented municipal coordination, overcome through public-private partnerships that mobilized $1.2 billion in funding, highlighting the role of stakeholder engagement in scaling GI (Montalto et al., 2013).

In Europe, Copenhagen, Denmark's Cloudburst Management Plan (2012) integrates blue-green infrastructure to combat extreme rainfall events projected to intensify under climate change. Featuring 300 projects like retention basins, green roofs on 50% of new buildings, and permeable streets, it has reduced flood risks in 90% of vulnerable areas while sequestering 10,000 tons of CO_2 yearly (City of Copenhagen, 2024). Socio-economically, it created 1,500 green jobs and improved public health via enhanced walkability and air quality (Gill et al., 2007). Challenges involved retrofitting historic districts, addressed via adaptive governance that incorporated citizen input, yielding a 15% increase in community satisfaction (Andersson et al., 2019). Similarly, Singapore's ABC Waters Programme (2006) transforms urban waterways into multifunctional spaces with bioretention swales and green roofs, managing 80% of stormwater on-site and boosting biodiversity by 30% (PUB Singapore, 2023). This has economic ripple effects, including tourism revenue from recreational spaces, but underscores the need for upfront investments in education to sustain maintenance (Wong & Brown, 2009).

In Asia, China's Sponge City initiative, launched in 2015 across 30 pilot cities like Shenzhen, mandates 70% stormwater retention through GI such as wetlands and permeable pavements. Shenzhen's implementation has cut flood volumes by 85% during monsoons and improved groundwater recharge by 20%, while green roofs on high-rises provide cooling benefits equivalent to 1.5 million air conditioners (Ministry of Housing and Urban-Rural Development, 2024). Yet, rapid urbanization strains enforcement, with governance fragmentation delaying projects in 20% of pilots (Jiang et al., 2018). These cases collectively affirm GI's efficacy in diverse contexts, emphasizing hybrid grey-green systems and adaptive policies for long-term resilience (Fletcher et al., 2013).

Regional Case Studies in Sub-Saharan Africa

Sub-Saharan African cities, facing acute urbanization pressures, offer regionally relevant GI case studies that adapt global lessons to local constraints like informal settlements and limited budgets. In Cape Town, South Africa, the Khayelitsha Wetlands Park project (2018) integrates bioretention basins and constructed wetlands into informal areas, reducing flood risks for 50,000 residents and treating 1 million liters of stormwater daily (City of Cape Town, 2023). This NbS approach has enhanced ecosystem services, including 25% improved water quality and habitat restoration for endangered species, while fostering community stewardship through co-design workshops that empowered women-led maintenance groups (Fisher-Jeffes et al., 2017). Challenges persist in scaling due to water scarcity, but partnerships with NGOs have secured R50 million in climate funds, demonstrating GI's role in equity-driven resilience (Andersson et al., 2019).

Nairobi's own pilots, such as the Kibera Public Space Project (2017), embed rain gardens and permeable pathways in informal settlements, diverting 40% of runoff and reducing cholera incidents by 15% via better sanitation (Njoroge & Waithaka, 2021). Supported by UN-Habitat, it has generated 200 jobs in green maintenance, yet fragmented county governance hinders expansion (Kasuku, 2024a). In Lagos, Nigeria, the Eko Atlantic development incorporates GI like mangrove buffers and bioswales to manage coastal flooding, protecting 10 million residents and sequestering 500,000 tons of CO2 annually (Lagos State Government, 2024). This has economic benefits, including $200 million in avoided damages, but informal exclusion remains an issue, addressed through community land trusts (Seddighi et al., 2022). Kigali, Rwanda's Green City Kigali initiative (2020) deploys urban forests and permeable streets across 20% of the city, cutting flood peaks by 60% and enhancing biodiversity amid hilly topography (City of Kigali, 2023). With 5,000 jobs created, it exemplifies post-genocide urban renewal, though funding gaps require blended finance models (Munyaneza et al., 2016).

These regional examples underscore GI's adaptability to African contexts, where socio-economic co-benefits like job creation and health improvements are paramount (Hanna & Comin, 2021). Common enablers include community involvement and international aid, while barriers like institutional silos mirror global patterns (Istrate & Lo, 2021). For Nairobi, these cases advocate hybrid approaches that integrate GI with waste management and participatory planning, fostering equitable urban resilience (Kasuku, 2024b).

Theoretical and Conceptual Framework

Systems Theory: Urban stormwater management is inherently systemic, integrating hydrological, infrastructural, ecological, and governance subsystems. Systems Theory (ST), pioneered by von Bertalanffy (1968) and Meadows (2008), emphasizes interconnectivity and feedback among subsystems. In Nairobi, ST frames flood risk as an outcome of impervious surface growth, poorly maintained drains, and socio-economic vulnerabilities interacting with rainfall patterns (Wong & Brown, 2009). Green infrastructure (GI) acts as leverage: permeable pavements reduce imperviousness, rain gardens enhance infiltration, and bioretention systems filter pollutants, necessitating holistic integration of natural, built, and social elements (Chaffin et al., 2016; Monteiro et al., 2020).

Resilience Theory: Resilience Theory examines a system's capacity to absorb, reorganize, and function under stress (Holling, 1973; Folke, 2006). With climate-driven rainfall variability intensifying urban floods, resilience is a core goal of stormwater governance (Dangles et al., 2022; Yang et al., 2023). GI embodies robustness (reducing peak flows; Zhang et al., 2023), redundancy (distributed interventions; Ge et al., 2023), and adaptive capacity (governance/community learning; Chaffin et al., 2016; Njoroge & Waithaka, 2021). Unlike rigid grey infrastructure, GI's modular nature aligns with Nairobi's need for adaptive solutions, such as community-supported

AFRICA HABITAT REVIEW 20(3) 2025

rain gardens fostering stewardship.

Urban Ecology and Water-Sensitive Urban Design (WSUD): Urban Ecology treats cities as coupled human-natural systems, where ecological restoration enhances livability (Alberti, 2008). WSUD integrates the urban water cycle into planning (Wong & Brown, 2009). In Nairobi, rapid urbanization overshadows ecological priorities, but GI in streetscapes and parks can transform it into a water-sensitive city, boosting amenity and connectivity (Shirgir et al., 2019; Andersson et al., 2019).

Institutional Theory: Effective stormwater management requires coordinating diverse actors (Malone & Crowston, 1994). In Nairobi, fragmented mandates among agencies hinder GI adoption (North, 1990). Reframing GI as "landscaping" could elevate its priority, addressing governance barriers.

Conceptual Framework: **Figure 1** schematizes GI interventions (e.g., rain gardens), hydrological outcomes (infiltration), socio-ecological benefits (biodiversity), and enabling conditions (governance) with feedback loops, guiding Nairobi's analysis (Senes et al., 2021; Seddighi et al., 2022).

RESEARCH METHODS

This study employed a mixed-methods case study design to investigate stormwater management in Nairobi, integrating quantitative and qualitative methods for a comprehensive understanding of complex issues (Creswell & Plano Clark, 2018). Nairobi was selected as the case study city, with five sub-areas—Kibera, Mukuru, Langata, Lunga Lunga, and Kasarani—chosen for their diverse stormwater challenges. These sites reflect varied contexts: Kibera and Mukuru as informal settlements with drainage issues, Langata and Kasarani as formal residential areas, and Lunga Lunga with mixed industrial-residential use, capturing institutional, infrastructural, and socio-economic dynamics (Bohman et al., 2020).

The mixed-methods approach pragmatically quantified patterns and qualified experiences concurrently, ensuring triangulation and validity (Creswell & Plano Clark, 2018). A participatory stance engaged local stakeholders and considered institutional contexts, aligning with inclusive stormwater planning.

The target population included Nairobi County residents, business owners, and officials involved in stormwater management. A sample of 180 respondents was targeted using random and purposive sampling: 100 residents (20 per sub-area) were randomly selected, while 50 business owners and 30 officials (e.g., engineers, planners) were purposively chosen for their direct experience. Of these, 150 participated (83% response rate; 84 residents, 40 business owners, 26 officials, reflecting community interest and follow-up efforts. Data collection combined surveys, interviews, field observations, and GIS mapping. Structured questionnaires with closed- and open-ended questions assessed flood frequency and GI perceptions. Semi-structured interviews with 26 officials explored governance and GI barriers. Field observations used checklists to document

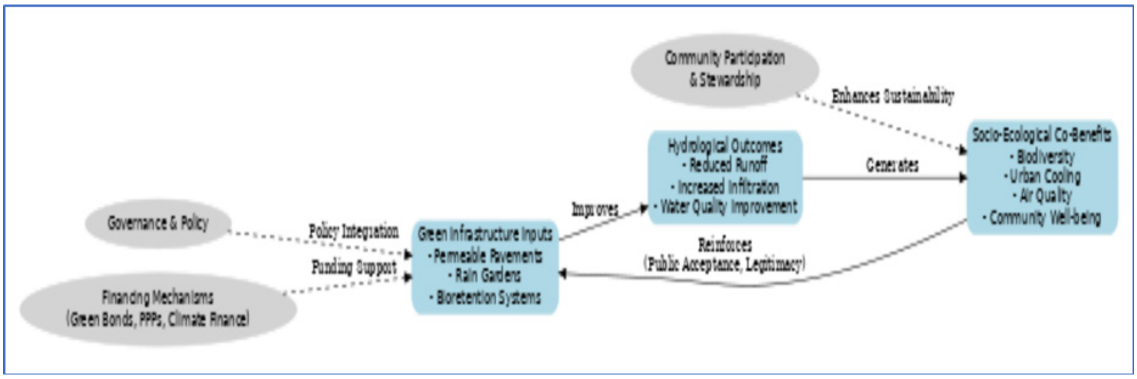

FIGURE 1
Conceptual famework model
Source: Authors' synthesis based on Senes et al. (2021) and Seddighi et al. (2022)

issues like clogged drains, mapped via ArcGIS 10.8. Secondary data from policy documents contextualized findings.

RESULTS

The results in **Table 2** show that stormwater infrastructure in Nairobi is structurally deficient and socially inequitable. The contrast between informal settlements like Kibera and Mukuru, where over 80% of respondents rated drainage as "poor," and more formal zones such as Kasarani, where less than half did so, indicates a dual-track urban system. This reflects not only physical disparities but also underlying governance priorities. County authorities have historically directed maintenance resources to formal estates where service delivery is politically and logistically simpler. As a result, informal settlements bear a disproportionate share of flood risk, perpetuating cycles of vulnerability.

The ANOVA results ($p < 0.05$) confirmed significant differences in flood frequency between settlements, underscoring how infrastructural inequity translates into lived vulnerability. **Figure 2** shows that Kibera residents, for example, face nearly three times as many flood events annually as Kasarani residents. Such disparities are not merely statistical abstractions; they manifest in recurring asset loss, livelihood disruptions, and chronic health risks. These findings reveal

TABLE 2
Summary of key stormwater infrastructure in case study areas

Area	Drainage Type	% "Poor" Rating	Flood Frequency (times/year)	Maintenance Frequency
Kibera	Informal open drains	82%	8–10	Irregular/Community-led
Lang'ata	Trunk sewers + ditches	56%	4–5	Annual (County-led)
Lunga Lunga	Mixed drains + culverts	72%	6–7	Sporadic (Industry + County)
Mukuru	Informal ditches	88%	9–11	None/Ad hoc
Kasarani	Roadside concrete drains	47%	3–4	Semi-annual (County)

Source: Field survey and observations, 2025

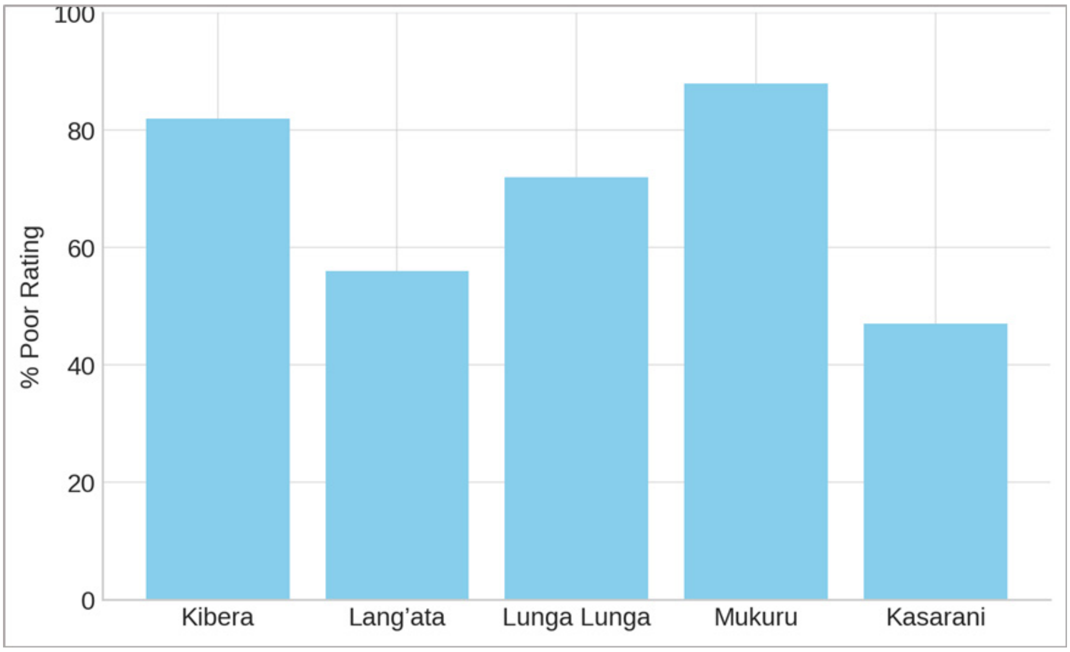

FIGURE 2
Comparison of "poor" drainage ratings across the five study areas
Source: Authors' analysis based on field survey data, 2025

AFRICA HABITAT REVIEW 20(3) 2025

systemic bias in infrastructural allocation that reinforces cycles of environmental injustice across Nairobi's neighborhoods.

Drivers of Flooding and Systemic Weaknesses

Urbanization as a Structural Driver

The evidence linking impervious surface growth (+32% since 2000) with increased flooding highlights Nairobi's unsustainable land-use trajectory (**Figure 3**). This urban expansion has outpaced drainage planning, producing a hydrological imbalance where infiltration capacity is systematically eroded. The chi-square test ($\chi^2 = 28.7$, $p < 0.01$) provides robust statistical confirmation of this relationship. In rapidly urbanizing Mukuru, where informal housing proliferates on floodplains, flood frequency was nearly double that in Lang'ata, which retains more green corridors and stormwater infiltration capacity.

This trend suggests that without land-use regulation and enforcement of riparian buffer zones, investments in drainage infrastructure or GI will have limited effectiveness. Nairobi's stormwater crisis is therefore not simply a question of infrastructure provision but fundamentally one of spatial governance.

Infrastructure Maintenance and Performance

The observed correlation between maintenance frequency and flood events ($r = -0.46$, $p < 0.05$) emphasizes that infrastructure does not fail solely because of design limitations but also due to chronic neglect. In Kasarani, semi-annual desilting of drains translated into fewer flood reports, demonstrating the preventive impact of routine O&M. By contrast, Kibera and Mukuru—where no structured maintenance exists—recorded the highest flood frequencies, showing how poor upkeep magnifies structural inadequacies.

This finding implies that significant risk reduction could be achieved in the short-term by institutionalizing preventive maintenance regimes, even before large-scale infrastructural overhauls are implemented. The absence of such a program underscores institutional weaknesses and fragmented accountability structures.

Governance and Institutional Fragmentation

The governance survey confirmed systemic institutional dysfunction: 58% of officials acknowledged overlapping mandates and 72% cited inadequate budgets as presented in **Table 3** and **Figure 4**. These figures point to what can be described as "institutional incoherence"—multiple agencies with competing or poorly defined roles, each under-resourced and lacking coordination.

This systemic weakness explains why even well-designed master plans often fail at implementation: plans without financing or enforcement

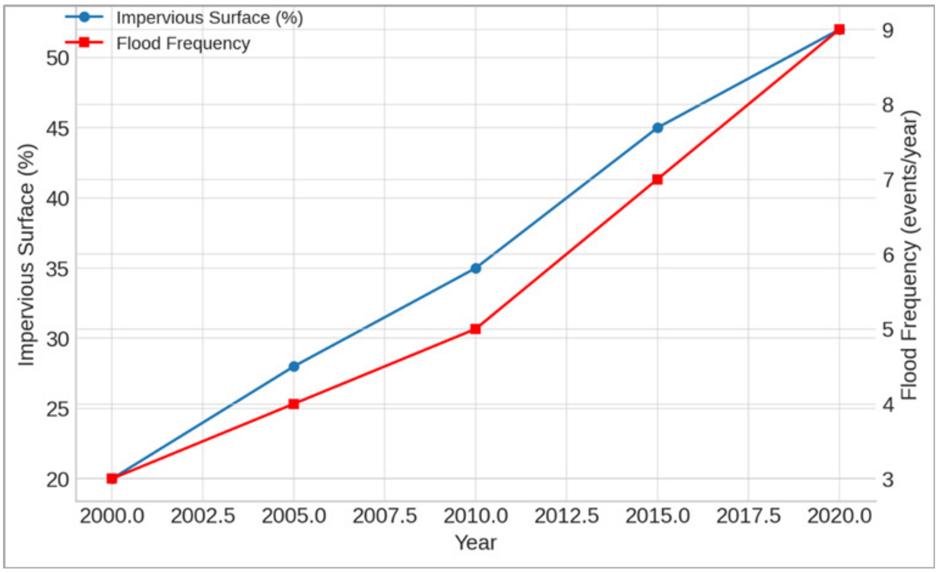

FIGURE 3
Impervious surface growth vs. annual flood frequency (2000–2022)
Source: GIS analysis by authors using satellite data (2000–2022)

TABLE 3
Governance and institutional challenges

Challenge	% of Officials Citing
Overlapping mandates	58%
Insufficient budget allocation	72%
Weak enforcement of laws	64%
Poor inter-agency coordination	55%

Source: Key informant interviews and stakeholder survey, 2025

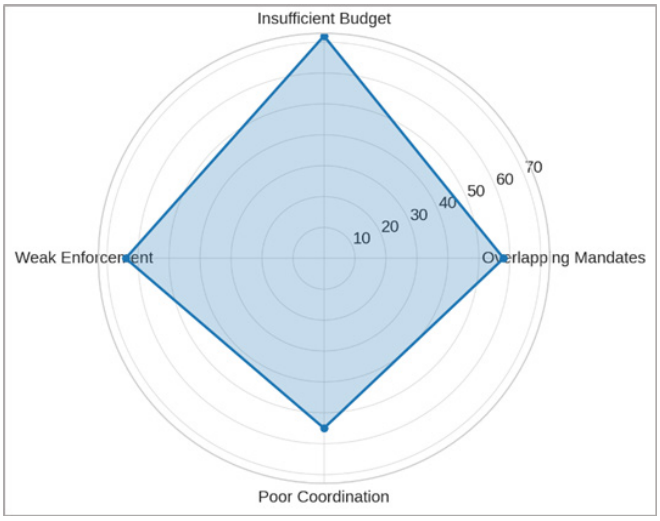

FIGURE 4
Institutional weaknesses across four dimensions (budget, enforcement, coordination, mandate clarity)
Source: Stakeholder survey analysis, 2025

mechanisms remain aspirational documents.

Solid Waste as a Compounding Factor

Improper waste disposal exacerbates infrastructural crisis. With 76% of respondents identifying garbage as a key cause of drainage blockage, this issue emerges not just as a byproduct but as a systemic driver of flooding (**Figure 5**). In Mukuru and Kibera, over 80% of drains observed were clogged with waste, rendering even functional drainage networks ineffective.

This finding suggests that stormwater management cannot be addressed in isolation from waste governance. Unless waste management is integrated into stormwater planning, GI or other interventions will face recurrent clogging and underperformance.

Socio-Economic Implications

Household and Business Losses

Flooding imposes persistent, regressive economic costs. For households, annual asset losses averaged KES 35,000, which, for low-income households earning under KES 15,000 monthly, represents more than two months of income. For small businesses, average losses of KES 70,000 annually are not only direct damages but also lost trade due to closures (**Table 4**).

The ANOVA results ($F = 12.3$, $p < 0.01$) demonstrated that businesses in Lang'ata's industrial areas suffered the highest single-event losses, averaging KES 250,000 annually, largely due to machinery damage and production halts (**Figure 6**). Informal vendors in Kibera and Mukuru, by contrast, suffered smaller but more frequent income disruptions. This contrast

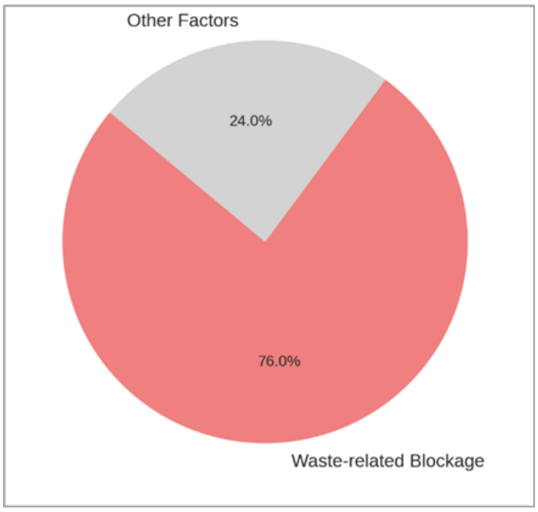

FIGURE 5
Proportion of respondents citing waste as a key cause of blocked drains
Source: Household and business survey, 2025

TABLE 4
Governance and institutional challenges

Category	% Affected	Average Annual Loss (KES)
Household assets	64%	35,000
Small businesses	48%	70,000
Industrial sector	22%	250,000

Source: Field survey, 2025

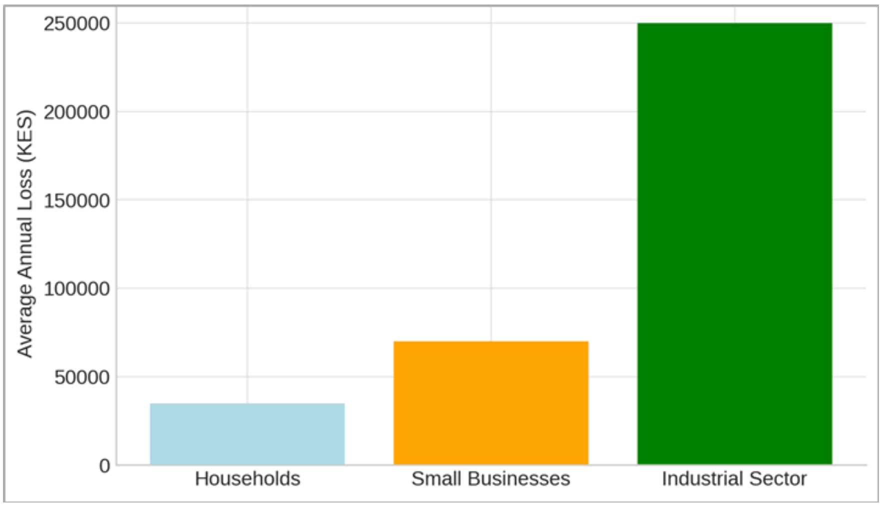

FIGURE 6
Average losses among households, small businesses, and industries
Source: Authors' analysis of survey data, 2025

shows that while flood risk impacts different socio-economic groups differently, it consistently undermines productivity and economic security across all classes.

Health Impacts

The health data is equally compelling as shown in **Table 5** and **Figure 7**: cholera outbreaks (38%), typhoid (29%), and diarrhea (24%) represent major public health burdens.

The chi-square results ($\chi^2 = 34.5$, $p < 0.01$) confirm a strong link between flood frequency and cholera incidence. Kibera and Mukuru, where floods occur most frequently, reported the highest prevalence of cholera, while Kasarani recorded the lowest. This spatial disparity illustrates the intersection of infrastructural inequity and health inequality.

Livelihood and Mobility Disruptions

The fact that half of the residents lost their working hours in school run due to the flooding shows how it is a productivity failure. The informal vendors indicated that floods caused them to lose between KES 500 and 1,000 daily, and transport alone increased the average of 40 percent during flood events. Such disturbances spill-over into the economy of Nairobi, weakening human capital development and productivity.

Environmental Impacts and Long-Term Risks

A GIS analysis was used to note that riparian vegetation has declined by 14 percent in the last decade, minimizing natural buffering ability and further adding flooding at the downstream. This brings about a negative ecological feedback loop cycle; the vegetation decreases which increases floods which prolongs the erosion process and further ecological destruction (**Figure 8**).

TABLE 5

Distribution of flood-related diseases

Disease	% of Cases Reported	Most Affected Areas
Cholera	38%	Kibera, Mukuru
Typhoid	29%	Lunga Lunga, Kibera
Diarrhea	24%	All areas
Malaria (post-flood)	9%	Lang'ata, Kasarani

Source: Field survey and local health facility reports, 2025

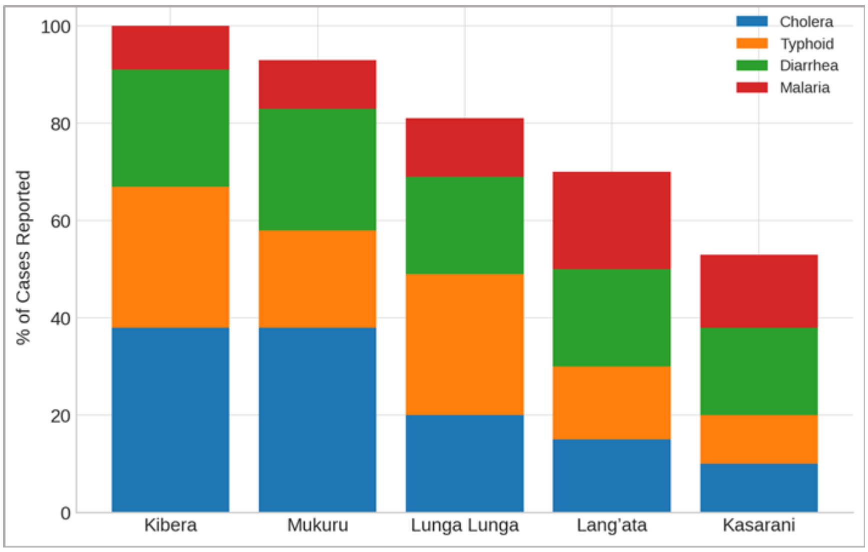

FIGURE 7

Flood related disease prevalence across settlements

Source: Authors' analysis of disease data, 2025

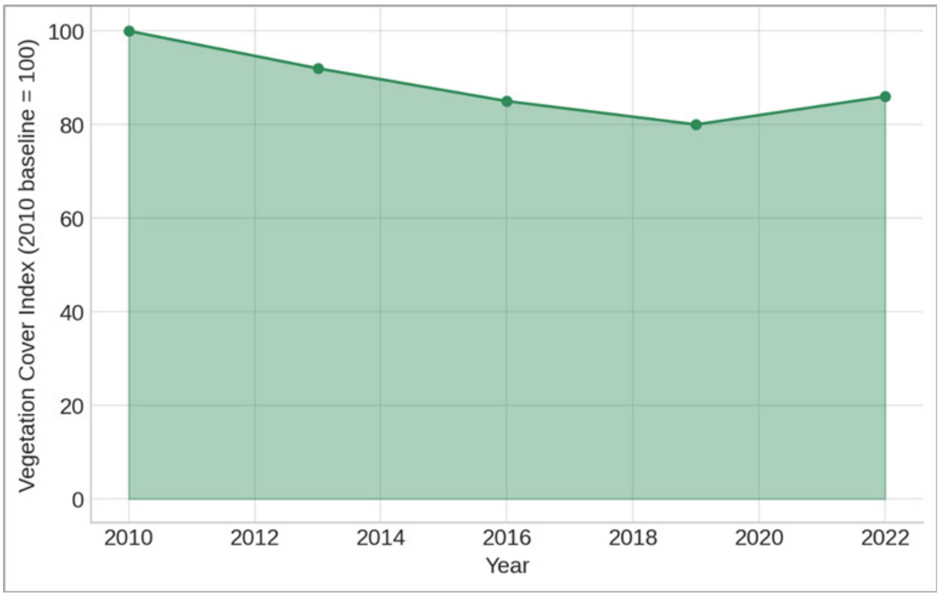

FIGURE 8
Decline in riparian vegetation (2010–2022)
Source: GIS spatial analysis using Landsat datasets (2010–2022)

In addition, property values in the flood prone settlements have dropped by about 15-20 percent over the past decade specifically in Mukuru and Kibera. Such falls constitute not only a personal economic loss but a local financial burden, because property tax receipts decrease in those places that need the most infrastructural investment.

Synthesis: Meeting the Research Objectives
The review of the stormwater management issues in Nairobi has provided an elaborate pattern of infrastructural inefficiency, ineffective governance, social-economic insufficiency. Comparing the research findings with the objectives of the research elucidates even more on the urgency of the intervention and the potential of integrating green infrastructure (GI) to transform it. All of these objectives present a different lens through which the data can be understood, but collectively they help us see the systemic nature of the resilience deficit facing Nairobi and the causal pathways to correct it.

The initial goal aimed at determining the prevailing situation in terms of stormwater management in Nairobi. These findings were indicative of conclusive evidence that the draining networks in the city are insufficient, especially in informal areas where there is no clear planning involved in the development and also due to poor maintenance of the drain outlets. A majority of respondents in Kibera and Mukuru reported that the drainage was poor and field observations revealed that the drainage was heavily littered with garbage or blocked by informal houses. Compared to Kasarani, more formal urban planning means a lower severity of conditions but again, the latter still required semi-annual maintenance in order to avoid flooding. The ANOVA findings ($p < 0.05$) revealed that there was a statistical difference between the frequency of floods in the formal and informal settlements and this is another way of looking at how inequity infrastructures directly translate to vulnerability differences. These findings imply that stormwater management in Nairobi should not only be considered a technical idea but also a social justice concept, where the allocation of such infrastructures indicates and upholds the idea of urban inequalities.

The second goal was to assess the green infrastructure intervention potential. Analysis showed the most potential is in the informal neighborhoods where standard drainage is inadequate or absent. GI, like rain gardens, permeable pavements, and bioretention cells, may be important in decreasing runoff and promoting infiltration. However, because of the findings, it is also clear that GI can never work alone. Since 76 percent of the residents cited garbage as the leading source of blocked drains, it is apparent that, unless corresponding investments are made in waste management, GI installations would soon become underperforming. Besides, the relationship between the frequency and less flooding ($r = -0.46$, $p < 0.05$) demonstrates that the importance of preventive maintenance is equal to technological design. This indicates that GI implementation calls on the need to be incorporated into a take-all system that incorporates both ecological design and effective maintenance and waste management. In Nairobi, where low levels of fiscal resources and the inefficiency of weakly tied institutions prevail, the scalability of GI will require integrating low-cost ecology preservation on the one hand, and communal maintenance programs and selective conscientiousness of land-use regulation, on the other hand.

The third goal involved a discussion of socio-economic and governance aspects and the discussion is persuasive in showing the shortcomings at the systemic level. Governance fragmentation 58% of officials, and 72% mentioned inadequate budgets, and those impulses that have long bedeviled the incoherent governance of Nairobi infrastructure. This malfunction has direct social-economic implications. It is estimated that households lose an average of KES 35,000 per annum to flood damage with the small business reporting an average loss of KES 70,000 and industrial firms reporting a loss as high as KES 250,000 in Langata alone. The ANOVA outcomes ($F = 12.3$, $p < 0.01$) were consistent in finding significant variability in economic losses across neighborhoods but showed a general trend of insidious vulnerability across all of them. These losses are aggravated by health implications where cholera outbreaks (38% prevalence in Kibera and Mukuru) are highly connected with frequency of floods (chi 2 = 34.5, $p < 0.01$). This data make a convincing argument to its mainstreaming not only as a purely environmental intercession, but also as a socio-economic resilience mechanism. GI has a potential to positively impact the health sector by reducing runoffs and floods and resultantly mitigate health expenses, lost time due to absenteeism, and even increase value of property.

The last aim was to find out the enabling mechanisms to scale up GI adoption and the evidence indicates that there are several pathways to do so. Preventive maintenance becomes a cost-effective (cheap-high outcome tool) process with quantifiable effects on holding back floods in regions such as Kasarani. Community involvement also is crucial here, in that when people get involved with drain cleaning or GI management, the life and the effectiveness of a drainage system are improved. The aspect of integrated waste management as the most influential one in terms of blocked drains should be undertaken to ensure the ecological measures are made to work. Collectively, these enabling conditions establish a basis upon which scaling of GI interventions can take place in a manner that is anchored in context and within economic capabilities. Notably, they reveal that Nairobi does not have to look forward to extensive capital investment in order to embark on stormwater resilience; rather, small-scale, inclusive, and proactive measures can be effective in the short-term and thus has the advantage of paving the way to other more extensive ecological transformations.

Overall, it is possible to outline a picture in several layers by synthesizing results according to the research objectives. The acute stormwater related problems in Nairobi have their origins in severe infrastructural inequities and a deeply fragmented institutional structure, but they also represent a chance to develop new and more community-based responses. Its use as a techno-fix reveals GII as a socially context-situated solution that has the potential to make communities less vulnerable, operates to enhance wellness and can build long-term resilience in the ecological landscape. The achievement of the research objectives has therefore shown that the solution to stormwater management in Nairobi must be approached as a systems approach; one, that integrates technical design solution, governance reform, ecological restoration and citizens active participation. Such integrated thinking is not only on par with resilience thinking but also offers a viable recipe on how cities in the Global South can cope with like issues.

DISCUSSION

This study's findings illuminate Nairobi's stormwater management challenges and green infrastructure's (GI) potential to foster urban resilience, triangulating surveys, observations, GIS mapping, and statistical analysis to reveal systemic issues and actionable solutions. By situating these within global GI, stormwater, and resilience literature, the discussion highlights novel contributions and their relevance.

Reconfirming Global Patterns: Infrastructural Inequity and Institutional Fragmentation
Nairobi's stormwater system exhibits stark inequity, with 80-90% of Kibera and Mukuru residents rating drainage as poor, compared to 47% in Kasarani (ANOVA, $p<0.05$). This aligns with Senes et al. (2021), who link urban flooding to skewed infrastructural investment, and Seddighi et al. (2022), who note disproportionate flood impacts in Lagos' informal settlements due to underfunded drainage and waste services. Nairobi's dual-track urbanism—formal areas receiving modest services, informal settlements nearly none—mirrors Global South trends. Such inequity fuels physical and social vulnerabilities, eroding trust and hindering community engagement in drainage maintenance, as seen in Cleveland's adaptive GI management (Chaffin et al., 2016). Institutional fragmentation exacerbates this, with 58% of officials citing overlapping mandates and 72% noting budget shortages, echoing Istrate and Lo's (2021) findings on Eastern Europe's GI barriers. Unlike Mexico City's coordinated GI success (Palmer & Castro, 2022), Nairobi's agencies (e.g., Nairobi County, NEMA) lack unified oversight, rendering plans aspirational.

New Insights for GI Praxis: The Primacy of Waste Management and Maintenance
A critical insight is waste management's role in GI efficacy. Unlike Italy's GI suitability mapping (Senes et al., 2021), where waste is less limiting, Nairobi's drainage is clogged by uncollected garbage, undermining ecological interventions. This extends Pugh et al.'s (2012) findings on GI's air quality and microclimate benefits, emphasizing that ecological functionality requires integrated waste systems in low-income urban contexts. Similarly, maintenance is pivotal: a negative correlation between maintenance frequency and flood events ($r=-0.46$, $p<0.05$) mirrors Liu et al.'s (2021) findings on maintained GI's water quality benefits in China. Neglect in Kibera and Mukuru fuels distrust and disengagement, while Kasarani's semi-annual desilting demonstrates preventive potential (Chaffin et al., 2016). These findings highlight maintenance and waste integration as prerequisites for GI success in African cities.

The Socio-Economic Case for GI: Beyond Hydrology to Health and Livelihoods
GI emerges as a socio-economic resilience tool. Annual losses—KES 35,000 (households), KES 70,000 (businesses), KES 250,000 (industries)—and a 38% cholera prevalence in Kibera/Mukuru ($\chi^2=34.5$, $p<0.01$) underscore flooding's economic and health tolls. These align with Zhang et al. (2023) on green roofs reducing property damage and Ge et al. (2023) on rain gardens enhancing safety perceptions. Yang et al.'s (2023) health-resilience linkage is evident in Nairobi, where GI could mitigate hydrological and public health risks, offering cross-sectoral benefits.

A Model for the Global South: Community-Led Action in a Vacuum of Central Governance
Nairobi's fragmented governance contrasts with Shanghai's centralized GI success (Yang et al., 2023). Here, community-led GI, supported by preventive maintenance and participation, offers a viable model (Chaffin et al., 2016; Njoroge & Waithaka, 2021). A 32% rise in impervious surfaces since 2000 ($\chi^2=28.7$, $p<0.01$) drives flood frequency, exacerbated by informal settlements' regulatory gaps (Monteiro et al., 2020). Community stewardship and decentralized GI (e.g., rain gardens in schools) provide adaptive, scalable solutions. Innovative financing, like climate funds and green bonds (Kurniawan et al., 2024), could address budget constraints, blending external support with local ownership.

Contributions and Implications
This study advances GI discourse by: (1) emphasizing waste management integration as critical for African urban GI; (2) highlighting maintenance as a resilience driver; (3) quantifying GI's socio-economic and health benefits; and (4) proposing community-led models for fragmented governance contexts. By bridging Nairobi's empirical findings with global literature, it positions GI as a systemic intervention addressing ecological, economic, and social vulnerabilities, offering actionable insights for urban resilience in the Global South.

CONCLUSION

This study evaluated Nairobi's stormwater management and green infrastructure's (GI) potential to enhance urban resilience. Findings reveal deficient drainage, particularly in informal settlements, where waste clogging, inadequate maintenance, and unregulated land use amplify flood vulnerability. Statistical analysis confirmed significant disparities between informal and formal areas ($p<0.05$), translating to heightened social and economic risks. GI measures—rain gardens, permeable pavements, bioretention systems—show promise in reducing runoff and boosting infiltration but require integration with waste management, preventive maintenance, and community engagement to succeed. Without these, GI risks underperforming in contexts with clogged drains and weak institutional capacity.

Socio-economic impacts—household losses (KES 35,000/year), business losses (KES 70,000), and flood-linked cholera outbreaks (38% prevalence in Kibera/Mukuru)—underscore the urgency of action. These costs outweigh GI investment, positioning ecological solutions as cost-effective resilience strategies with cross-sectoral benefits. Governance fragmentation (58% of officials cite overlapping mandates), budget shortages (72%), and lax land-use enforcement pose systemic barriers. Addressing these demands institutional reform, innovative financing (e.g., green bonds), and participatory stewardship, aligning with global evidence that stormwater management is as much a governance challenge as a technical one (Hanna & Comin, 2021).

Nairobi's stormwater crisis requires a system-wide solution spanning hydrological, ecological, and socio-political domains. GI, when embedded in robust maintenance, waste integration, and inclusive governance, offers transformative potential to enhance urban sustainability and resilience in Nairobi and similar Global South cities.

Policy Imperatives

To operationalize GI and strengthen stormwater resilience, Nairobi policymakers should prioritize:

i. Integrate waste management with drainage planning: Address drain blockages to ensure GI functionality.
ii. Institutionalize preventive maintenance: Regular desilting and upkeep to sustain infrastructure efficacy.
iii. Formalize community co-management models: Leverage local stewardship for sustainable GI implementation.
iv. Establish a cross-agency coordinating body: Harmonize mandates among Nairobi County, NEMA, and others for cohesive governance.

RECOMMENDATIONS

The study recommends that Nairobi's urban planning authorities integrate green infrastructure within city-wide drainage and land-use frameworks. Embedding nature-based designs such as rain gardens, permeable pavements, and bioretention systems into master plans will enhance infiltration, curb runoff, and create multifunctional landscapes that restore ecological balance while addressing flood vulnerability.

Secondly, stormwater management should be linked with solid waste governance to prevent drain blockages that undermine the performance of green infrastructure. Establishing coordinated programs that couple waste collection with maintenance of green drainage networks will ensure long-term functionality and reduce recurrent flooding in informal settlements.

Third, Nairobi County should institutionalize preventive maintenance and monitoring regimes within its infrastructure management cycle. Regular desilting, inspection, and community-based stewardship will sustain drainage efficiency, minimize repair costs, and cultivate a sense of shared ownership of public infrastructure.

Fourth, there is a need to strengthen governance coordination and financing mechanisms. A unified inter-agency platform should harmonize mandates among departments such as NEMA, the Water Resources Authority, and the County Works Office, supported by innovative financing tools like climate adaptation funds and municipal green bonds to scale implementation of green infrastructure.

Finally, public participation and environmental education should be embedded in all resilience strategies. Empowering communities to design, maintain, and monitor local installations not only enhances their effectiveness but also promotes environmental stewardship, livelihood creation, and equity in Nairobi's urban transformation toward a climate-resilient future.

CITED REFERENCES

Ahiablame, L., Engel, B. A., & Chaubey, I. (2012). Effectiveness of low impact development practices: Literature review and suggestions for future research. *Water, Air, & Soil Pollution*, 223(8), 4259–4273. https://doi.org/10.1007/s11270-012-1294-z

Alberti, M. (2008). *Advances in urban ecology: Integrating humans and ecosystems.* Springer. https://doi.org/10.1007/978-0-387-75510-6

Andersson, E., Anguelovski, N., Baptista, S., Baró, F., Langemeyer, J., & Kronenberg, J. (2019). A transition to sustainable and resilient urban infrastructures? The case of green and blue infrastructure developments in four EU cities. *Land Use Policy,* 81, 72–82. https://doi.org/10.1016/j.landusepol.2018.10.034

Bates, B. C., Kundzewicz, Z. W., Wu, S., & Palutikof, J. P. (Eds.). (2008). *Climate change and water* (Technical Paper VI of the Intergovernmental Panel on Climate Change). IPCC Secretariat. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/03/technical-paper-2-climate-change-and-water-en.pdf

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal,* 9(2), 27–40. https://doi.org/10.3316/QRJ0902027

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology,* 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Chaffin, B. C., Shuster, W. D., Garmestani, A. S., Furio, B., Albro, S. L., Gardiner, M., ... & Martin, J. (2016). A tale of two rain gardens: Barriers and bridges to adaptive management of urban stormwater in Cleveland, Ohio. *Journal of Environmental Management,* 183, 431–441. https://doi.org/10.1016/j.jenvman.2016.08.047

Coffman, L. (2000). *Low impact development: An innovative, alternative approach.* U.S. Environmental Protection Agency. Retrieved from https://www.epa.gov/water-research/storm-water-management-model-swmm

Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). SAGE Publications.

Dillman, D. A. (2009). *Internet, mail, and mixed-mode surveys: The tailored design method* (3rd ed.). Wiley.

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics,* 5(1), 1–4. https://doi.org/10.11648/j.ajtas.20160501.11

Fisher-Jeffes, L., Carden, K., & Armitage, N. (2017). Issues of water quality in stormwater harvesting: Comments on Fisher-Jeffes et al. (2017). *South African Journal of Science,* 113(5/6). https://doi.org/10.17159/sajs.2017/20160259

Folke, C. (2006). Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change,* 16(3), 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002

Ge, X., Chen, R., Xu, Z., & Zhang, X. (2023). Examining the microclimate pattern and related spatial perception of the urban stormwater management landscape: The case of rain gardens. *Atmosphere,* 14(7), 1138. https://doi.org/10.3390/atmos14071138

Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). Adapting cities for climate change: The role of the green infrastructure. *Built Environment,* 33(1), 115–133. https://doi.org/10.2148/benv.33.1.115

Goodchild, M. F. (2007). Citizens as sensors: The world of volunteered geography. *GeoJournal,* 69(4), 211–221. https://doi.org/10.1007/s10708-007-9111-y

Hall, P. A., & Taylor, R. C. R. (1996). Political science and the three new institutionalisms. *Political Studies,* 44(5), 936–957. https://doi.org/10.1111/j.1467-9248.1996.tb00343.x

Hanna, R., & Comin, F. (2021). Urban green infrastructure and sustainable development: A review. *Sustainability,* 13(20), 11498. https://doi.org/10.3390/su132011498

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics,* 4, 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245

Istrate, G., & Lo, Y. W. (2021). Integrating green infrastructure into land-use planning: *A review for Eastern Europe. Sustainability,* 13(16), 9001. https://doi.org/10.3390/su13169001

Jiang, Y., Zevenbergen, C., & Ma, Y. (2018). Urban pluvial flooding and stormwater management: A contemporary review of China's challenges and "sponge cities" strategy. *Environmental Science & Policy,* 80, 132–143. https://doi.org/10.1016/j.envsci.2017.11.016

Kasuku, S. (2024a). Evaluating the socio-economic benefits of transit-oriented development (TOD) along Thika Road Corridor, Nairobi. *Africa Habitat Review Journal,* 19(2), 3002–3015. Retrieved from https://uonjournals.uonbi.ac.ke

Kasuku, S. (2024b). The impact of urban transport policy on urban sprawl along Thika Road Corridor, Nairobi. *Africa Habitat Review Journal*, 19(2), 2950–2966.* Retrieved from https://www.researchgate.net/publication/379652604_The_Impact_of_Urban_Transport_Policy_on_Urban_Sprawl_along_Thika_Road_Corridor_Nairobi

Kasuku, S., Akatch, S., Gichaga, F., Opiyo, R., & Musyoka, R. (2022). Urban transport policy and land use planning accessibility nexus in Nairobi City. *Africa Habitat Review Journal,* 17(1), 2535–2547.

Kurniawan, A., Chen, Y. M., & Wang, H. (2024). Strengthening climate resilience: Urban water technologies for heat-resilient physical infrastructure in Southeast Asia cities amidst extreme temperature events and El Niño challenges. *ACS ES&T Water,* 4(2), 155–168. https://doi.org/10.1021/acsestwater.4c00585

Leopold, L. B. (1968). *Hydrology for urban land planning—A guidebook on the hydrologic effects of urban land use* (U.S. Geological Survey Circular 554). U.S. Government Printing Office. https://doi.org/10.3133/cir554

Lisenbee, W. A., Hathaway, J. M., Burns, M. J., & Fletcher, T. D. (2021). Modeling bioretention stormwater systems: Current models and future research needs. *Environmental Modelling & Software,* 144, 105146. https://doi.org/10.1016/j.envsoft.2021.105146

Liu, D., He, X., & Yu, J. (2021). An evaluation of the benefits of green infrastructure in urban water management: Implications for policymakers. *Urban Water Journal*, 18(8), 645–655. https://doi.org/10.1080/1573062X.2021.1964050

Liu, W., Chen, W., & Peng, C. (2020). Assessing the effectiveness of green infrastructures on urban flooding reduction: A community scale study. *Ecological Modelling,* 416, 108924. https://doi.org/10.1016/j.ecolmodel.2019.108924

Malone, T. W., & Crowston, K. (1994). The interdisciplinary study of coordination. *ACM Computing Surveys,* 26(1), 87–119. https://doi.org/10.1145/174270.174271

Marshall, C., & Rossman, G. B. (1999). *Designing qualitative research* (3rd ed.). SAGE Publications.

Meadows, D. H. (2008). *Thinking in systems: A primer*. Chelsea Green Publishing.

Mitchell, B. (1990). *Integrated water management: International experiences and perspectives.* Belhaven Press.

Montalto, F. A., Behr, C. T., Alfredo, K., Wolf, M., Hutt, M., & Parisi, M. (2013). Accounting for uncertainty in determining financial benefits of green infrastructure for stormwater management. *WIT Transactions on the Built Environment,* 128, 293–304. https://doi.org/10.2495/SDP130251

Monteiro, G., Teodoro, O., & Federico, A. (2020). Green infrastructure planning principles: An integrated literature review. *Land,* 9(12), 525. https://doi.org/10.3390/land9120525

Munyaneza, O., Wali-Uganda, E., Uhuru, M., & Karanja, R. (2016). Impact assessment of hillside rainwater harvesting ponds on agriculture income: Case study of Ntarama sector in Rwanda. *Journal of Water Resource and Protection,* 8(8), 796–807. https://doi.org/10.4236/jwarp.2016.88065

Njoroge, S. K., & Waithaka, J. (2021). The role of community involvement in the effectiveness of green infrastructure in urban stormwater management: A case study of Nairobi. *International Journal of Urban Sustainable Development,* 13(2), 198–213. https://doi.org/10.1080/19463138.2021.1886581

North, D. C. (1990). *Institutions, institutional change and economic performance*. Cambridge University Press. https://doi.org/10.1017/CBO9780511808678

Novotny, V. (2003). *Water pollution control and strategies.* IWA Publishing.

Palmer, R., & Castro, E. (2022). The role of green infrastructure in enhancing urban flood resilience: A case study in Mexico City. *Journal of Flood Risk Management,* 15(4), e12713. https://doi.org/10.1111/jfr3.12713

Pugh, T. A. M., MacKenzie, A. R., Whyatt, J. D., & Hewitt, C. N. (2012). Effectiveness of green infrastructure for improvement of air quality in urban street canyons. *Environmental Science & Technology,* 46(14), 8194–8201. https://doi.org/10.1021/es300826w

Seddighi, M., Rassekh, A., & Ebrahimi, K. (2022). Green infrastructure for stormwater management: A systematic review of barriers and opportunities. *Water,* 14(1), 46. https://doi.org/10.3390/w14010046

Senes, G., Manghina, P., & De Marco, A. (2021). Nature-based solutions for stormwater management—Creation of a green infrastructure suitability map as a tool for land-use planning at the municipal level in the province of Monza-Brianza (Italy). *Sustainability,* 13(11), 6124. https://doi.org/10.3390/su13116124

Shirgir, R., Kiani, M., & Aghazadeh, M. (2019). Developing strategic principles of intervention in urban green infrastructure to create and enhance climate resilience in cities—Case study: Yousef Abad in Tehran. *Journal of Climate Change*, 3(1), 21–33. https://doi.org/10.3233/JCC-190007

U.S. Environmental Protection Agency. (2017). *Storm water management model (SWMM).* Retrieved from https://www.epa.gov/water-research/storm-water-management-model-swmm

von Bertalanffy, L. (1968). *General system theory: Foundations, development, applications*. George Braziller.

Wong, T. H. F., & Brown, R. R. (2009). The water sensitive city: *Principles for practice. Water Science and Technology*, 60(3), 673–682. https://doi.org/10.2166/wst.2009.414

Yang, Y., Liu, S., Liu, X., & Zhang, H. (2023). Integrating nature-based solutions into urban planning for enhancing resilience to climate change: *The case of Shanghai. Urban Forestry & Urban Greening,* 72, 127500. https://doi.org/10.1016/j.ufug.2023.127500

Yin, R. K. (2014). Ca*se study research: Design and methods* (5th ed.). SAGE Publications.

Zhang, H., Chen, S., & Xu, C. (2023). Assessing the impact of green roofs on urban stormwater management: A case study from a high-density area. *Sustainable Cities and Society*, 83, 103941. https://doi.org/10.1016/j.scs.2022.103941