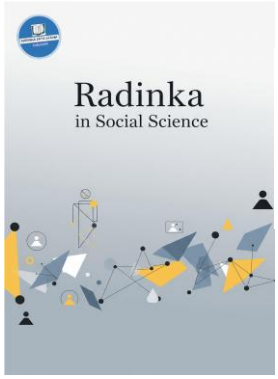

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A Comparative Cost-Benefit Analysis of Nature-Based Solutions (NBS) Versus Hard Engineering for Urban Flood Resilience in the Lagos Coastal Region

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Abstract

Lagos, Nigeria, faces systemic urban flooding exacerbated by rapid urbanization and climate change. This study conducts a systematic literature review (SLR) to comparatively analyze conventional Grey Infrastructure (GI) against Nature-Based Solutions (NBS) for flood resilience. Following a structured search of academic and grey literature from 2020–2024, data were synthesized across three lenses: policy context, functional effectiveness, and economic valuation. Results indicate that while GI provides immediate flood conveyance, it often lacks long-term adaptability and requires high maintenance. Conversely, NBS such as wetland restoration and urban green spaces exhibit superior lifecycle cost-efficiency and adaptive capacity. Findings reveal that the perceived economic superiority of GI is a methodological artifact of conventional Benefit-Cost Analysis (BCA), which undervalues environmental co-benefits. The study concludes that institutional fragmentation and infrastructure biases currently hinder NBS adoption in Lagos. To enhance resilience, targeted policy reforms are recommended, including the integration of comprehensive valuation frameworks that quantify ecosystem services and mandatory coordination between environmental and planning agencies.

Keywords: nature-based solutions, urban flood resilience, cost–benefit analysis, coastal region, climate adaptation planning

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Introduction

Lagos, Nigeria is one of the fastest-growing megacities globally and a critical hub for national and regional economic activities. Its low-lying coastal geography, extensive lagoon systems, and proximity to the Atlantic Ocean make it inherently susceptible to flooding. This vulnerability has been significantly intensified by rapid urbanization, population pressure, and climate change. Increasingly intense and erratic rainfall, rising sea levels, and frequent storm surges have transformed flooding in Lagos from an occasional environmental hazard into a recurrent and systemic urban challenge. These climatic pressures are compounded by human-induced factors such as uncontrolled land reclamation, encroachment on wetlands and floodplains, inadequate waste management, and the obstruction of natural drainage channels. As a result, flood events now cause widespread infrastructure damage, economic disruption, public health risks, and displacement of vulnerable populations, posing a serious threat to sustainable urban development in Lagos.

Flood risk management in Lagos has traditionally relied on Grey Infrastructure (GI), including concrete drainage systems, canals, embankments, and floodwalls. These engineered solutions are typically designed to provide rapid and visible control of floodwaters. While they have delivered short-term benefits in certain locations, growing evidence suggests that such interventions are increasingly insufficient in the face of climate uncertainty and extreme weather events. Grey infrastructure often alters natural hydrological processes, shifts flood risk spatially rather than reducing it, and requires substantial capital investment and continuous maintenance. In resource-constrained urban governance contexts, these financial and technical demands raise concerns about long-term effectiveness and sustainability. Moreover, rigid, single-purpose infrastructure offers limited adaptability to future climate scenarios, increasing the risk of infrastructure failure over time.

In contrast, Nature-Based Solutions (NBS) represent an alternative and increasingly prominent paradigm for flood risk management. By working with natural systems rather than against them, NBS seek to enhance flood resilience through ecosystem-based interventions such as wetland restoration, urban green spaces, bioswales, permeable surfaces, and green roofs. These approaches manage stormwater at its source, improve infiltration and water retention, and restore ecological functions that naturally regulate hydrological flows. Beyond flood mitigation, NBS deliver multiple co-benefits, including biodiversity conservation, urban cooling, improved air and water quality, and enhanced social well-being. Such multifunctionality positions NBS as adaptive and resilient solutions that align more closely with long-term sustainability and climate adaptation goals.

Despite the growing global evidence supporting the effectiveness of Nature-Based Solutions, their adoption in Nigeria remains limited. A key barrier lies in how flood management options are evaluated and prioritized. Existing studies and policy practices in Nigeria largely emphasize engineering performance and short-term cost considerations, with insufficient attention to lifecycle costs, ecosystem services, and broader socio-economic benefits. Conventional cost–benefit analysis frameworks tend to undervalue or exclude non-market benefits, thereby systematically favoring grey infrastructure over nature-based alternatives. This methodological limitation contributes to persistent investment biases, even where NBS may offer superior long-term value and resilience outcomes.

This study addresses this gap by adopting an integrated comparative framework that evaluates Grey Infrastructure and Nature-Based Solutions through three interrelated lenses: policy and institutional context, functional effectiveness for flood mitigation, and comprehensive economic valuation. Focusing on Lagos State as a critical case study, the research examines how existing governance structures shape infrastructure choices, compares the performance of GI and NBS under flood risk conditions, and interrogates the adequacy of prevailing economic appraisal methods in capturing the full value of nature-based interventions. By synthesizing recent evidence on lifecycle costs, ecosystem services, and co-benefits, the study advances a more holistic understanding of flood resilience as a multidimensional public good.

The findings of this research are significant for urban planners, policymakers, and climate adaptation practitioners. Infrastructure decisions made in Lagos today will have long-term implications for exposure, vulnerability, and resilience in the face of escalating climate risks. Given limited public resources and growing development pressures, there is an urgent need for decision-support frameworks that prioritize solutions offering durable, cost-effective, and socially inclusive outcomes. This study provides a structured and context-sensitive comparison of grey infrastructure and nature-based solutions and contributes evidence-based insights to support more sustainable and resilient flood risk management strategies in Lagos and other rapidly urbanizing coastal cities in the Global South.

Literature Review

Review of Flood Management Frameworks in Nigeria

Effective flood resilience is predicated on a robust and coherent policy framework. Nigeria's approach to water management is guided by several documents that, while aiming for sustainability, often face implementation gaps. The concept of Integrated Water Resources Management (IWRM) is a guiding principle, yet a critical review of policy and practice suggests challenges in its application across the country (Adewuyi & Ologunorisa, 2022). These policies must also align with broader national development goals, such as those outlined in the Climate-resilient development blueprint for water management in Nigeria (UNDP Nigeria, 2023), which emphasizes a proactive stance toward climate adaptation. However, the policies often prioritize traditional, centralized water infrastructure, which may inadvertently slow the adoption of decentralized, ecosystem-based solutions. Addressing climate change adaptation at the policy level is vital, yet constraints and opportunities within the water sector's implementation mechanisms must be thoroughly examined to understand why innovative solutions are not yet mainstream (Oluwatuyi & Adebola, 2021).

The transition from policy commitment to on-the-ground implementation is complicated by Nigeria's fragmented institutional landscape. Flood disaster management in Nigeria is characterized by institutional complexity, where multiple agencies operate with overlapping mandates, often leading to coordination failures (Echendu, 2022). This fragmentation contributes to implementation challenges, particularly in a large, multi-level governance structure like Lagos State (Olukunga et al., 2024). The capacity of institutions to effectively lead climate-resilient urban development is a significant barrier across sub-Saharan African cities, requiring enhanced coordination and political will (Feleke et al., 2024). Governing climate change adaptation in urban coastal Nigeria, specifically Lagos State, requires a critical analysis of these institutional limitations to ensure that funding and strategies translate into tangible resilience gains rather than bureaucratic bottlenecks (Ajibade & McBean, 2021).

Comparative Effectiveness of Infrastructure Types (Grey Infrastructure (GI) Performance and Nature-Based Solutions (NBS) Efficacy

Grey Infrastructure (GI) has historically formed the bedrock of flood control in the Niger Delta region and coastal cities like Lagos. These hard solutions, including concrete river channelization and large drain construction, are designed for rapid conveyance and were initially seen as definitive solutions to mitigate large-scale flooding (Abam & Oki, 2020). However, their performance in dynamic coastal environments is increasingly being questioned. While they offer immediate protection, GI often fails to cope with the increased volume and intensity of modern rainfall events and can increase flood vulnerability downstream by speeding up runoff and reducing natural infiltration. Furthermore, a framework for flood risk assessment and management developed for the Lagos coastal region highlights that GI can be prone to blockages and requires significant, consistent maintenance that is often neglected (Adeloye et al., 2020). This suggests that the reliance on GI may create a false sense of security while locking the city into high-cost, high-maintenance infrastructure that lacks climate adaptability.

Nature-Based Solutions (NBS) are emerging as a robust, multi-functional alternative, offering intrinsic ecological benefits alongside flood mitigation. Global evidence suggests that systems like restored wetlands, urban forests, and permeable paving significantly enhance flood resilience by increasing infiltration, storing water, and slowing down runoff (Kabisch et al., 2023). The application of NBS for flood risk reduction in Lagos is currently an area of increasing academic focus, though practical implementation remains limited. Adebayo and Olayinka (2022) examined the local perception of NBS in Lagos, noting that while there is awareness of the benefits, substantial implementation challenges exist, including land use conflicts and policy inertia. The UN Environment Programme (UNEP) has strongly advocated for the global adoption of NBS for climate change adaptation due to their cost-effectiveness and dual benefits (UNEP, 2021). Thus, while the technical effectiveness of NBS is high, the barrier in Lagos is less technical and more related to implementation strategy and overcoming established infrastructure biases.

The choice of flood management strategy directly impacts the vulnerability and resilience of coastal communities. The persistent urban sprawl in Lagos, particularly in peri-urban areas, continues to encroach on natural flood defenses, increasing flash flood vulnerability regardless of the engineered solution (Ibeabuchi & Nwankwo, 2023). A detailed examination of Lagos coastal communities reveals that the combination of natural and engineered hazards necessitates holistic adaptation strategies (Nkwunonwo et al., 2021). Recent systematic reviews of resilience strategies in the Lagos Metropolis underscore the potential pathways toward aligning flood control with sustainable development goals, emphasizing the need for comprehensive and adaptive solutions (Lawanson et al., 2024). Ultimately, while GI focuses primarily on protecting existing assets, NBS enhances the intrinsic resilience of the ecosystem and the community, offering a more complete long-term adaptation measure against chronic climate-induced hazards (Odekunle & Oyeniran, 2022).

Methodology

This study adopts a systematic literature review (SLR) to comparatively assess Grey Infrastructure (GI) and Nature-Based Solutions (NBS) for flood resilience, with specific attention to Nigeria and comparable urban contexts. The methodology follows a transparent, stepwise process to ensure rigor, reproducibility, and clarity.

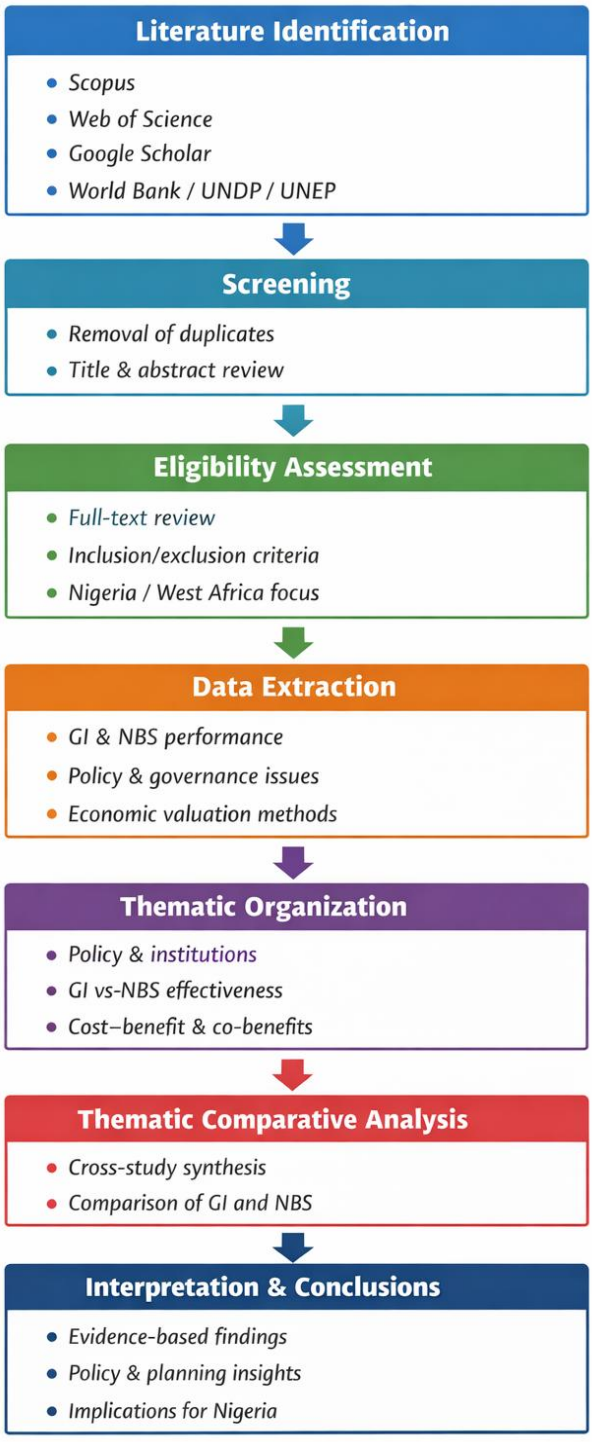

Figure 1. Methodological Flow (Textual Chart)

Step 1: Literature Search Strategy

A comprehensive literature search was conducted across peer-reviewed academic databases (Scopus, Web of Science, and Google Scholar) and authoritative grey literature sources (including World Bank, UNDP, and UNEP reports). To capture interdisciplinary evidence, structured keyword combinations were applied using Boolean operators, including:

i. ("Nature-Based Solutions" OR "Green Infrastructure") AND ("Grey Infrastructure" OR "Conventional Flood Control")
ii. ("Flood Resilience" OR "Climate Adaptation") AND ("Lagos" OR "Nigeria")
iii. ("Cost–Benefit Analysis" OR "Economic Valuation") AND ("Ecosystem Services")

The review focused on publications from 2020 to 2024 to ensure that the analysis reflects current scientific evidence, policy discourse, and methodological advances.

Step 2: Screening and Selection of Studies

Retrieved records were screened in two stages. First, titles and abstracts were reviewed to remove duplicates and exclude studies not related to flood risk management or infrastructure-based adaptation. Second, full-text screening was conducted using predefined inclusion criteria:

1. Direct relevance to flood mitigation, resilience, or climate adaptation;
2. Explicit focus on GI, NBS, or their comparison;
3. Applicability to Nigeria, West Africa, or comparable developing-country urban contexts;
4. Inclusion of policy, governance, performance, or economic evaluation dimensions.

Only studies meeting all criteria were retained for synthesis (see References for the final corpus).

Step 3: Data Extraction and Analytical Framework

From each selected source, structured data were extracted, including:

i. Evidence on technical and functional performance of GI and NBS;
ii. Identified institutional, governance, and implementation barriers;
iii. Approaches to economic valuation, including cost–benefit analysis and treatment of co-benefits (e.g., ecosystem services, social and environmental gains).

The extracted data were organized under three core analytical themes:

i. Policy, governance, and institutional frameworks for flood management in Nigeria and West Africa;
ii. Comparative effectiveness of GI and NBS for flood mitigation and resilience;
iii. Economic valuation methods and the extent to which co-benefits are incorporated.

Step 4: Synthesis and Comparative Analysis

A thematic comparative analysis was employed to synthesize findings across the selected studies. Evidence was systematically compared to address the study's guiding research questions:

1. What is the current state of flood management policy and governance in Nigeria?
2. How do GI and NBS compare in terms of effectiveness, adaptability, and sustainability?
3. How can the full economic value of NBS, including co-benefits, be adequately captured in decision-making?

This structured synthesis ensures that conclusions are grounded in a coherent and systematically reviewed body of evidence.

Results and Discussion

Comparative Performance of Cost–Benefit Analysis Methodologies

The results of the review reveal that the apparent economic superiority of Grey Infrastructure (GI) in flood management is largely a methodological artifact rather than an intrinsic performance advantage. Conventional Benefit–Cost Analysis (BCA), which dominates infrastructure appraisal in Nigeria, systematically privileges GI by focusing on short-term, engineering-oriented indicators such as flood peak attenuation and construction costs, while excluding broader social and environmental externalities (Sajid & Qureshi, 2020). This methodological bias leads to an underestimation of the true value of Nature-Based Solutions (NBS), whose benefits are distributed across multiple sectors and time horizons. Consistent with Oppong et al. (2023), the findings demonstrate that when lifecycle costs, avoided damage, and indirect benefits are incorporated, the economic gap between GI and NBS narrows substantially and, in many cases, reverses. This highlights a critical institutional challenge in Lagos and similar Nigerian cities: prevailing appraisal frameworks are not aligned with the multifunctional nature of contemporary climate adaptation strategies. Without methodological reform, decision-making processes will continue to favor capital-intensive, single-purpose solutions that may be economically suboptimal in the long term.

Economic Significance of Ecosystem Services and Co-Benefits

A central result of this study is that the economic competitiveness of NBS becomes evident only when ecosystem services and co-benefits are explicitly valued. Unlike GI, which delivers narrowly defined flood protection outcomes, NBS provides a portfolio of regulating, provisioning, and cultural ecosystem services. The reviewed evidence shows that benefits such as improved water quality, enhanced public health, recreational opportunities, carbon sequestration, and biodiversity conservation generate substantial socio-economic returns that are typically excluded from standard BCAs (Wamsler et al., 2020). Empirical studies demonstrate that these co-benefits can equal or exceed the monetary value of direct flood mitigation alone, particularly in dense urban environments (Daigneault et al., 2021). Furthermore, the capacity of green infrastructure to moderate urban heat stress and improve thermal comfort strengthens its role as a cross-sectoral climate adaptation measure (Lafortezza et al., 2021). The results therefore underscore the necessity of adopting integrated valuation frameworks that internalize co-benefits, as advocated by Teng et al. (2024), to avoid systematic undervaluation of NBS in urban flood risk management.

Long-Term Economic Efficiency and Adaptive Capacity

The discussion further reveals that short-term cost comparisons obscure the decisive long-term economic advantages of Nature-Based Solutions. Grey Infrastructure is characterized by high operation and maintenance costs, technological rigidity, and increasing vulnerability to failure under intensified climate extremes, conditions that are particularly pronounced in the coastal and flood-prone context of Lagos. In contrast, NBS exhibits dynamic performance characteristics: as ecological systems mature, their flood attenuation capacity, resilience, and co-benefit delivery often increase over time, resulting in lower lifecycle costs and greater adaptive flexibility. The

reviewed studies consistently indicate that GI tends to lock cities into expensive and path-dependent infrastructure trajectories, whereas NBS supports incremental adaptation and system learning under uncertainty. From an economic perspective, the findings shift the evaluation focus from initial capital expenditure to long-term financial sustainability, risk reduction, and adaptive capacity. This repositioning strengthens the argument that NBS represents not only an environmentally preferable option but also a fiscally prudent investment for achieving durable flood resilience in rapidly urbanizing cities such as Lagos. The results demonstrate that the perceived economic inferiority of Nature-Based Solutions is largely a consequence of inadequate evaluation frameworks. When assessed using comprehensive, lifecycle-oriented, and ecosystem-inclusive methodologies, NBS emerges as a robust, cost-effective, and adaptive alternative to conventional grey infrastructure for urban flood resilience in Nigeria.

Conclusion

This comparative analysis confirms that while traditional Grey Infrastructure (GI) remains the prevailing operational strategy in Lagos, it offers diminishing returns on investment and creates a false sense of security while lacking the adaptability required for long-term climate resilience. The systematic literature review reveals that Nature-Based Solutions (NBS) are technically effective, providing superior flood management capabilities coupled with vital, quantifiable co-benefits that enhance overall urban sustainability. The primary obstacle to their widespread adoption is not technical or economic—particularly when co-benefits are included—but rather the pervasive institutional complexity and fragmented governance structures in Nigeria, which tend to favor familiar, centralized, and politically visible GI projects. Overcoming this institutional inertia and addressing established infrastructure biases is the critical next step for Lagos. To mainstream Nature-Based Solutions in Lagos, several targeted policy reforms are recommended. Lagos State agencies must transition away from simple Benefit-Cost Analysis (BCA) for flood projects in favor of comprehensive assessment tools that quantify ecosystem services and social co-benefits, such as carbon sequestration and public well-being. Furthermore, policy must enforce greater coordination between flood control, urban planning, and environmental protection agencies to overcome institutional fragmentation and protect remaining wetlands and mangroves from encroachment. There is also a vital need to train local professionals in the design and maintenance of NBS, supported by investments in advanced flood risk mapping and monitoring technologies. Finally, the default position for any new flood mitigation project should be a Nature-Based Solution, placing the burden of proof on proponents of GI to demonstrate why hard engineering is necessary or superior for a specific context.

Conflicts of interest

The author declares no conflict of interest.

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Author contribution

Bukola Sunday Odediran: Conceptualization, Methodology, Software, Data curation, Writing-original draft preparation, Visualization, Investigation, Supervision, Software, Validation, Writing-reviewing, and editing.

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