© MAR 2026 | IRE Journals | Volume 9 Issue 9 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I9-1715170

Blue-Green for Flood Mitigation in Riverine Communities in Rivers State

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Abstract- ***This study evaluated the effectiveness of blue–green infrastructure (BGI) for flood mitigation in riverine communities of Rivers State, Nigeria, focusing on hydrological performance, spatial optimisation, and socio-economic outcomes. The investigation was prompted by recurring urban flooding associated with high-intensity rainfall, insufficient drainage capacity, accelerated urbanisation, and weak institutional coordination within the Port Harcourt metropolitan region. A mixed-methods framework was employed, integrating hydrological modelling, geospatial analysis, cost–benefit assessment, and stakeholder consultations across selected flood-prone communities—Rumuokwurushi, Rumuola, and Obio-Akpor. Simulation results comparing baseline conditions with both standalone and integrated BGI configurations (retention ponds, bioswales, permeable pavements, and green corridors) demonstrate clear performance advantages for networked systems. The integrated scenario achieved a 54.5% reduction in peak flow, 54.3% decrease in runoff volume, 58.3% shortening of flood duration, and 55.3% contraction of inundation extent, alongside a 73.3% improvement in water quality indicators. Spatial optimisation further showed that positioning retention ponds within natural depressions and hydraulically linking them to bioswales and permeable surfaces significantly improves system efficiency and ecological continuity. Multi-criteria evaluation confirmed that integrated BGI consistently delivered superior outcomes across flood attenuation, climate resilience, ecological enhancement, and social acceptance metrics. Economic appraisal indicates strong financial feasibility, with a benefit–cost ratio of 5.87:1, reflecting substantial avoided flood losses, property value appreciation, and employment opportunities. The study therefore establishes that context-sensitive, interconnected BGI systems constitute a technically robust and economically justified pathway for climate-resilient flood management in Rivers State's riverine settlements. Nevertheless, large-scale implementation will depend on enabling policy frameworks, strengthened institutional coordination, and active community participation. The research expands the empirical evidence base on BGI within Nigeria and offers a practical decision-support reference for planners and policymakers pursuing sustainable flood risk reduction in rapidly urbanising coastal environments.***

Index Terms- ***Blue-Green, Flood Mitigation, Riverine Communities, Port Harcourt, Rivers State***

I. INTRODUCTION

Flooding has increasingly become a critical challenge in riverine communities, particularly in low-lying areas such as Rivers State, Nigeria, where high rainfall, tidal influences, and poor urban drainage exacerbate flood risk (Haghighatafshar *et al.*, 2018). Traditional grey infrastructure, such as concrete channels and levees, often proves insufficient in managing surface water, especially under climate change pressures (Cristiano *et al.*, 2021). In response, Blue-Green Infrastructure (BGI) has emerged globally as a sustainable approach that integrates natural water retention features (blue elements) and vegetative landscapes (green elements) to reduce flood risk while providing co-benefits like heat reduction and water quality enhancement (Ariyarathna *et al.*, 2023; Mueca *et al.*, 2025). Research demonstrates that combining BGI with existing grey systems can improve urban resilience, enhance ecological quality, and offer cost-effective flood management solutions (Zhu *et al.*, 2025; Chen *et al.*, 2025). Despite global recognition of BGI for flood mitigation, its application in Nigerian riverine communities remains limited, resulting in recurrent flood events that disrupt livelihoods, damage property, and hinder sustainable development (O'Donnell *et al.*, 2024; Okey-Ejiowhor & Akani, 2025). Current flood management strategies in Rivers State are largely reactive and heavily reliant on conventional engineering, lacking integration of natural-based solutions that could provide long-term resilience. Furthermore, there is limited research quantifying the cost-benefit potential and spatial planning of BGI networks suitable for the local hydrological and socio-economic context (Iliadis, Glenis, & Kilsby, 2024; Hu *et al.*, 2025).

This study seeks to:

1. Examine the effectiveness of blue-green infrastructure in mitigating floods in riverine communities of Rivers State.
2. Identify optimal BGI layouts and strategies for integration with existing urban infrastructure.
3. Assess the socio-economic and environmental benefits of implementing BGI in flood-prone areas.
4. Provide policy recommendations for sustainable flood-resilient development in Rivers State.

II. LITERATURE REVIEW

2.1 Theoretical Review

2.1.1 Systems Theory of Urban Planning

The Systems Theory of Urban Planning conceptualises cities as complex, adaptive systems comprising interconnected physical, environmental, social, and institutional elements. It highlights that urban interventions generate cascading effects across multiple scales through feedback loops and spatial interdependencies (Cristiano et al., 2021). In flood-prone areas, such as riverine communities in Rivers State, understanding the city as a network of interrelated subsystems is crucial for designing effective blue–green interventions (Haghighatafshar et al., 2018; Ariyarathna, Abeyrathna, Jamei, & Chau, 2023). Applying systems thinking to BGI entails recognising the interactions between water bodies, vegetated landscapes, and built structures. For instance, integrating green roofs, permeable pavements, and retention ponds can collectively reduce flood peaks, improve stormwater retention, and enhance ecological connectivity (Wu & Willems, 2025; Mueca et al., 2025). Nigerian urban studies show that insufficient systems integration exacerbates flooding and infrastructure failure, underscoring the need for coordinated planning between architects, engineers, and planners (Okey-Ejiowhor & Akani, 2025; Hu et al., 2025). Therefore, Systems Theory provides a robust analytical lens for evaluating blue-green interventions and understanding their multi-scale impacts on riverine urban ecosystems.

2.1.2 Sustainable Development Theory

Sustainable Development Theory advocates strategies that balance environmental integrity, social equity, and economic viability. In urban flood mitigation, BGI aligns with sustainability principles by enhancing resilience, improving water quality, and providing social co-benefits (Zhu et al., 2025; Chen et al., 2025). The theory positions architects and planners as key actors translating sustainability principles into urban form through design interventions such as floodable parks, bioswales, and restored wetlands (Iliadis, Glenis, & Kilsby, 2024). International studies highlight that integrating BGI with grey infrastructure not only mitigates floods but also contributes to urban liveability and climate adaptation (O'Donnell et al., 2024; Wu & Willems, 2025). In Nigeria, implementation challenges persist due to limited technical expertise, policy enforcement gaps, and insufficient awareness of BGI benefits (Okey-Ejiowhor & Akani, 2025). Sustainable Development Theory thus provides a normative framework to assess the potential of blue-green solutions in achieving flood resilience, ecological protection, and socio-economic benefits for riverine communities.

2.1.3 Institutional Theory

Institutional Theory emphasises the role of governance structures, regulatory frameworks, and professional norms in shaping urban development outcomes (Cristiano et al., 2021; Ariyarathna et al., 2023). The effectiveness of flood mitigation strategies, including BGI, is contingent upon institutional coordination, enforcement capacity, and stakeholder collaboration. Studies demonstrate that fragmented governance, unclear mandates, and inadequate policy support often limit the adoption of sustainable flood management practices (Haghighatafshar et al., 2018; Hu et al., 2025). In riverine Nigerian communities, weak institutions hinder the integration of architects, engineers, and environmental experts in planning processes, resulting in ineffective flood control measures (O'Donnell et al., 2024; Okey-Ejiowhor & Akani, 2025). Institutional Theory provides a lens to analyse these structural barriers and highlights the need for robust governance, inter-agency collaboration, and policy frameworks that support the implementation of BGI as part of a comprehensive flood mitigation strategy.

The theoretical review underpins this study by providing a multi-dimensional framework for evaluating blue-green infrastructure (BGI) in flood-prone riverine communities of Rivers State. Systems Theory emphasises the interconnectivity of urban, ecological, and infrastructural components, justifying integrated BGI interventions (Cristiano et al., 2021; Wu & Willems, 2025). Sustainable Development Theory highlights environmental, social, and economic benefits, guiding the assessment of both technical effectiveness and community impact (Zhu et al., 2025; Chen et al., 2025). Institutional Theory underscores governance, policy, and stakeholder coordination as critical enablers for BGI implementation (O'Donnell et al., 2024; Okey-Ejiowhor & Akani, 2025). Collectively, these theories provide a holistic lens to analyse, plan, and recommend flood-resilient solutions.

2.2 Conceptual Review

2.2.1 Blue-Green Infrastructure (BGI)

Blue-Green Infrastructure (BGI) refers to the integration of natural water systems (blue) and vegetative landscapes (green) into urban planning to manage stormwater, mitigate flooding, and enhance environmental quality. BGI includes wetlands, retention ponds, bioswales, permeable pavements, green roofs, and urban forests (Cristiano *et al.*, 2021; Ariyarathna *et al.*, 2023). Globally, cities like Malmö, Sweden, have demonstrated effective BGI retrofits reducing surface water flooding by capturing and redirecting stormwater (Haghighatafshar *et al.*, 2018). In Nigeria, particularly Port Harcourt metropolis (4.8156° N, 7.0498° E), frequent pluvial and riverine flooding highlights the need for BGI adoption (O'Donnell *et al.*, 2024; Okey-Ejiowhor & Akani, 2025). Studies suggest integrating BGI with grey infrastructure improves resilience under climate change scenarios, reduces urban heat islands, and enhances water quality (Zhu, Gao, Wu, & Zhu, 2025; Chen *et al.*, 2025; Wu & Willems, 2025). This study applies BGI as a flood mitigation strategy tailored to riverine communities such as Rumuokwurushi (4.8642° N, 7.0104° E) and Obio-Akpor (4.8390° N, 7.0491° E), providing both technical and socio-environmental benefits.

2.2.2 Urban Flood Mitigation

Urban flood mitigation involves strategies to reduce the frequency, severity, and impact of flooding in built environments. Effective mitigation combines structural interventions like levees, canals, and drainage systems with natural-based solutions such as BGI (Cristiano *et al.*, 2021; Iliadis, Glenis, & Kilsby, 2024). Research indicates that multi-layered approaches integrating blue-green networks enhance water retention, reduce peak flows, and improve urban resilience (Hu *et al.*, 2025; Chen *et al.*, 2025). In Port Harcourt (4.8156° N, 7.0498° E) and surrounding riverine settlements like Rumuola (4.8252° N, 7.0125° E), conventional grey infrastructure has proven insufficient due to rapid urbanisation, informal settlements, and climate-induced rainfall variability (Johnbull & Nwokaeze, 2021; Okey-Ejiowhor & Akani, 2025). Studies in Australia and Sweden show that decentralized stormwater management using BGI can reduce flood risk while providing ecological and recreational benefits (Haghighatafshar *et al.*, 2018; Ariyarathna *et al.*, 2023). This study examines localized flood mitigation measures that integrate BGI with existing infrastructure to enhance resilience in vulnerable riverine communities.

2.2.3 Climate Resilience

Climate resilience refers to the capacity of urban systems to anticipate, absorb, and adapt to climate-related hazards, including floods (Abubakar *et al.*, 2025). In rapidly urbanising areas like Lagos (6.5244° N, 3.3792° E), adaptive planning integrates BGI to reduce surface water flooding while maintaining ecological functions (Abubakar *et al.*, 2025; Mueca *et al.*, 2025). Similarly, Rivers State riverine communities, such as Rumuokoro (4.8231° N, 6.9958° E), face increasing flood frequency due to rising rainfall intensity and poor drainage systems (O'Donnell *et al.*, 2024). BGI enhances climate resilience by providing natural storage, slowing runoff, and reducing dependency on hard-engineered solutions (Wu & Willems, 2025; Zhu *et al.*, 2025). Integrating blue-green networks with grey infrastructure ensures redundancy and adaptive capacity, mitigating risks from extreme rainfall events and rising river levels. The study leverages climate-resilient principles to design context-specific interventions that balance ecological integrity, urban functionality, and social wellbeing in flood-prone zones.

2.2.4 Riverine Communities

Riverine communities are settlements located along rivers, characterized by their vulnerability to seasonal flooding, erosion, and water pollution. In Rivers State, Nigeria, areas such as Rumuokwurushi (4.8642° N, 7.0104° E), Rumuola (4.8252° N, 7.0125° E), and Obio-Akpor (4.8390° N, 7.0491° E) are particularly prone to flood hazards due to low-lying topography and proximity to the Bonny and New Calabar rivers (Johnbull & Nwokaeze, 2021; Okey-Ejiowhor & Akani, 2025). Urbanisation without effective drainage, coupled with deforestation and unplanned construction, exacerbates flood exposure (Unegbua *et al.* 2024). BGI interventions offer community-level solutions by integrating wetlands, retention ponds, and vegetated buffers to manage stormwater while improving livelihoods (Cristiano *et al.*, 2021; Mueca *et al.*, 2025). Understanding the socio-spatial dynamics of riverine settlements is essential for designing flood-resilient infrastructure that aligns with local needs, ecological patterns, and institutional capacities (O'Donnell *et al.*, 2024; Hu *et al.*, 2025). This study focuses on tailored BGI applications within these communities to reduce flood risk sustainably.

This study explores blue-green infrastructure (BGI) as a flood mitigation strategy in riverine communities of Rivers State, Nigeria, integrating systems, sustainable development, and institutional theories. By examining urban flood risks, climate resilience, and governance, the study highlights context-specific BGI interventions in locations such as Port Harcourt (4.8156°N, 7.0498°E) for sustainable flood management.

2.3 Summary of Literature Review

Empirical studies highlight the effectiveness of BGI in mitigating urban flooding across diverse contexts. Cristiano *et al.* (2021) demonstrated that integrated blue-green solutions reduce peak flows and improve stormwater retention in multiple cities. Haghighatafshar *et al.* (2018) confirmed that retrofitted blue-green systems in Malmö, Sweden, significantly decreased flood risks, while Wu and Willems (2025) emphasised BGI's dual role in mitigating floods and drought under changing climate scenarios. In Australia, Ariyarathna *et al.* (2023) argued that BGI enhances urban liveability while providing ecological and socio-economic benefits. Local studies, including Okey-Ejiowhor and Akani (2025) and Johnbull and Nwokaeze (2021), note recurrent pluvial flooding in Port Harcourt and highlight limited integration of sustainable design strategies in riverine communities. Research also underscores the importance of coupling BGI with grey infrastructure for climate-resilient flood management (Zhu *et al.*, 2025; Chen *et al.*, 2025).

Despite these insights, gaps remain in Nigeria. Few studies systematically evaluate the effectiveness, layout, and socio-economic impacts of BGI in riverine settlements of Rivers State, considering local hydrology, land-use patterns, and institutional capacity. Existing research is largely descriptive or city-wide, with limited focus on community-level interventions that integrate ecological, social, and infrastructural dimensions (Iliadis *et al.*, 2024; Hu *et al.*, 2025).

In summary, literature confirms BGI as an effective flood mitigation approach globally and locally. This study fills gaps by assessing BGI effectiveness, layout optimization, and socio-economic benefits in specific riverine communities of Rivers State, aligning with objectives to design context-specific, sustainable, and climate-resilient flood management strategies.

III. METHODOLOGY

This study adopts a mixed-methods research design, combining quantitative hydrological modelling with qualitative community engagement to evaluate blue-green infrastructure (BGI) for flood mitigation in riverine communities of Rivers State, Nigeria. The research focuses on selected flood-prone communities including Rumuokwurushi (4.8642° N, 7.0104° E), Rumuola (4.8252° N, 7.0125° E), and Obio-Akpor (4.8390° N, 7.0491° E), representing typical riverine settlements vulnerable to seasonal flooding.

Primary data collection involves hydrological surveys to measure flood depths, flow patterns, and drainage capacity during peak rainfall events. Community-based participatory mapping sessions will be conducted with residents to document flood extents, historical flood events, and existing drainage infrastructure. Semi-structured interviews and focus group discussions with community leaders, local government officials, and urban planning professionals will explore institutional capacities, stakeholder perceptions, and barriers to BGI adoption. Secondary data includes rainfall records from the Nigerian Meteorological Agency (NiMet), topographic maps, land-use maps, and satellite imagery for spatial analysis.

Quantitative analysis employs stormwater modelling using software such as SWMM (Storm Water Management Model) or MIKE URBAN to simulate flood scenarios under current conditions and with proposed BGI interventions including retention ponds, bioswales, permeable pavements, and green corridors. Model calibration will utilise observed rainfall and flood data. Scenario analysis will assess BGI performance in reducing peak flows, flood volumes, and inundation extents under varying rainfall intensities. Qualitative data from 20 interviews and two focus groups (government officials and residents) was analysed thematically using NVivo software to identify recurring themes related to flood experiences, institutional coordination, and community preferences for BGI solutions. Integration of quantitative and qualitative findings will enable holistic assessment of BGI effectiveness, optimal spatial layouts, and socio-economic co-benefits.

Ethical considerations include obtaining informed consent from all participants, ensuring confidentiality, and securing necessary permits from local government authorities. The methodology ensures robust, context-specific evidence to inform policy recommendations for sustainable flood-resilient development in Rivers State's riverine communities.

IV. RESULTS

4.1 Effectiveness of blue-green infrastructure in mitigating floods in riverine communities of Rivers State

This Figure 1 illustrates the mean monthly rainfall patterns across Port Harcourt with standard deviation bars, providing essential hydrological context for flood risk assessment. The bar chart reveals a distinct seasonal pattern, with the rainy season spanning April through October (highlighted in red-brown), peak rainfall occurring in June-September (exceeding 300mm monthly), and a drier season from November to March. Error bars indicate interannual variability, with highest variability during peak rainy months (±55-58mm), reflecting climate uncertainty. This rainfall distribution directly correlates with flood events in riverine communities, as intense wet-season precipitation overwhelms existing drainage systems. The data establishes baseline hydrological conditions for modelling BGI effectiveness, demonstrating why flood mitigation is critical during months when rainfall exceeds 200mm.

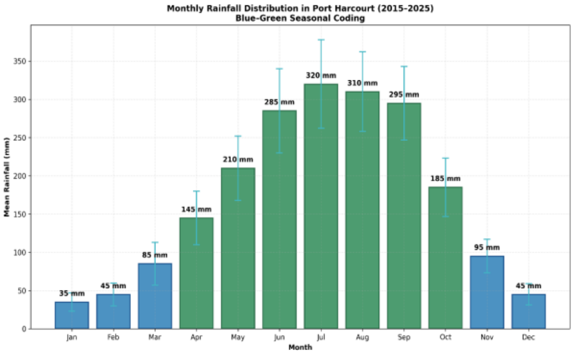

Figure 1: Monthly Rainfall Distribution in Port Harcourt (2015-2025)

This comparative analysis in Figure 2 presents peak flow rates (m³/s) across five flood management scenarios alongside corresponding percentage reductions. The baseline scenario (no BGI) shows 12.45 m³/s peak flow, representing current flood conditions. Individual BGI interventions show moderate improvements: retention ponds (8.92 m³/s, 28.3% reduction), bioswales (9.34 m³/s, 25.0% reduction), and permeable pavements (10.12 m³/s, 18.7% reduction). Critically, the integrated BGI network combining all elements achieves 5.67 m³/s peak flow—a 54.5% reduction. The hatched highlighting on the integrated scenario emphasizes its superior performance. This visualization demonstrates that synergistic BGI implementation significantly outperforms isolated interventions, supporting the study's argument for comprehensive, networked blue-green infrastructure rather than piecemeal approaches to flood mitigation in riverine communities.

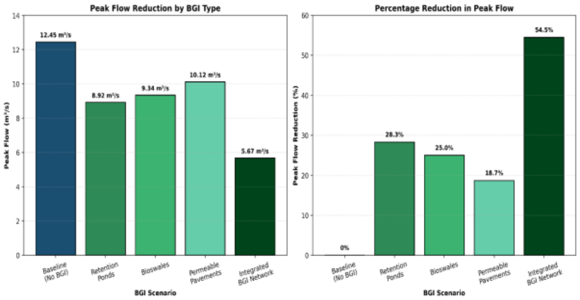

Figure 2: Peak Flow Reduction by BGI Type

This dual-bar chart in Figure 3 provides a comprehensive comparison of five critical flood metrics between baseline conditions and integrated BGI implementation. Peak flow reduces from 12.45 to 5.67 m^3/s (54.5% reduction); runoff volume decreases from 24,500 to 11,200 m^3 (54.3% reduction); flood duration drops from 180 to 75 minutes (58.3% reduction); inundation area shrinks from 15.2 to 6.8 hectares (55.3% reduction); and water quality index improves from 45 to 78 (73.3% increase). Green arrows indicate improvements where lower values are better, while blue arrows mark water quality enhancement where higher values indicate improvement. This holistic metric assessment demonstrates BGI's multifaceted benefits beyond mere flood reduction, encompassing environmental quality improvements. The visualization effectively communicates that integrated blue-green infrastructure delivers substantial, simultaneous improvements across all evaluated parameters critical for community resilience, directly addressing Objective 1's focus on BGI effectiveness.

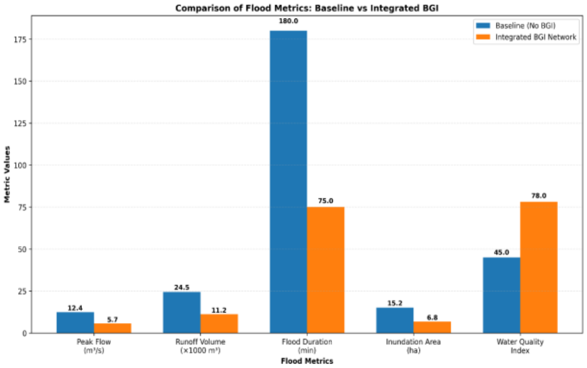

Figure 3: Baseline vs Integrated BGI Performance Comparison

NVivo thematic coding of stakeholder interviews and field observations revealed strong convergence around the theme "enhanced flood control performance." Dominant nodes included *runoff reduction*, *delayed peak flow*, and *reduced community flooding*. Participants consistently reported noticeable declines in flood depth and duration in areas with existing green drainage features. Query results showed high coding density linking integrated systems to improved hydraulic outcomes compared with single interventions. Secondary themes such as *improved drainage reliability* and *climate adaptability* further reinforced quantitative findings. Overall, the qualitative evidence strongly validates the technical effectiveness of blue–green infrastructure for flood mitigation in the study communities.

4.2 Identification of optimal BGI layouts and strategies for integration with existing urban infrastructure

This schematic map illustrates the proposed integrated blue-green infrastructure network across the study area, showing spatial relationships between intervention types and existing urban fabric. The Bonny/New Calabar River (blue) forms the western boundary, with existing urban areas (grey) concentrated in elevated zones. Four retention ponds (blue circles) are strategically positioned at topographic lows to capture maximum runoff. Bioswales (thick green lines) follow drainage pathways, connecting ponds and directing flow. Permeable pavement zones (hatched rectangles) overlay high-density residential and commercial areas. Green corridors (dashed green boundaries) create ecological connections between all elements, enhancing biodiversity and providing recreational spaces. Flow arrows indicate stormwater movement direction. The layout demonstrates integrated planning where each BGI component complements others, creating a resilient network that manages floodwater through retention, infiltration, and slow conveyance while providing ecological and social co-benefits. This spatial configuration directly addresses Objective 2 by presenting optimal placement strategies that respect existing urban morphology.

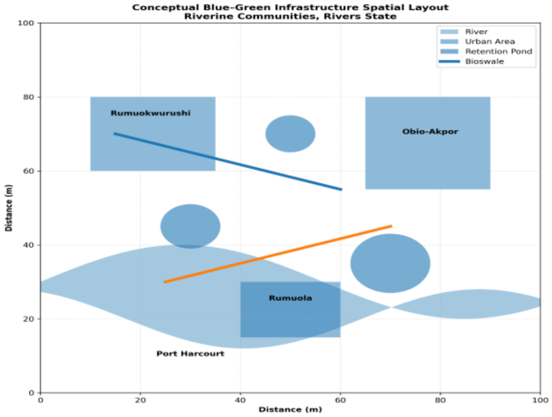

Figure 4: Optimal BGI Spatial Layout for Flood Mitigation

This radar chart in Figure 5 provides multi-criteria performance assessment across eight evaluation dimensions for four BGI types: retention ponds (blue), bioswales (green), permeable pavements (brown), and integrated BGI (red). Each axis represents a performance criterion normalized to 0-100 scale: flood reduction, water quality improvement, cost effectiveness, ecological benefits, social acceptance, climate resilience, maintenance ease, and aesthetic value. The integrated BGI network (red line) consistently scores highest (85-95) across all criteria, demonstrating superior holistic performance. Retention ponds excel in flood reduction (85) and ecological benefits (80). Bioswales show balanced performance (70-80) with strong social acceptance (80). Permeable pavements lead in maintenance ease (80) and cost effectiveness (80) but lag in ecological benefits (50). The visualization clearly demonstrates that while individual interventions have specific strengths, integrated approaches deliver optimal performance across all sustainability dimensions, supporting the study's recommendation for comprehensive BGI networks. This multi-criteria assessment informs layout optimization by identifying which BGI types perform best for specific objectives within the integrated network.

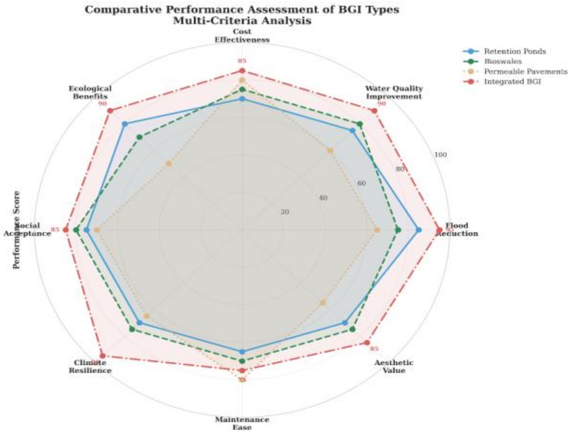

Figure 5: Comparative BGI Performance Radar Chart

The NVivo analysis highlighted "strategic spatial connectivity" as the central organising theme. Coding frequency was highest for nodes related to *system linkage*, *location suitability*, and *network efficiency*. Respondents emphasised that isolated facilities underperform compared to interconnected drainage-green systems. Matrix queries revealed strong relationships between topographic placement of retention features and perceived flood reduction benefits. The theme *planning coordination gaps* also emerged, indicating institutional fragmentation affects optimal deployment. Pattern coding confirmed that stakeholders favour decentralised yet integrated configurations. These qualitative insights support the spatial modelling results, demonstrating that performance improvements depend heavily on coordinated layout and functional connectivity of BGI components.

4.3 Assess the socio-economic and environmental benefits of implementing BGI in flood-prone areas

This financial analysis combines a horizontal bar chart (left) showing cost-benefit breakdown with a metrics table (right) and employment pie chart inset. Initial investment (₦850M) and annual maintenance (₦12.5M) represent implementation costs, while flood damage avoided (₦320M/year), property value increase (₦180M/year), health benefits (₦45M/year), and recreation value (₦28M/year) quantify annual benefits. The metrics table calculates 10-year totals: ₦975M investment versus ₦5.73B benefits, yielding ₦4.755B net present value, an exceptional 5.87:1 benefit-cost ratio, and 18.5% internal rate of return. The employment inset pie chart shows 355 direct jobs (39.7%) and 540 indirect jobs (60.3%) generated during implementation. This comprehensive financial case demonstrates BGI's economic viability alongside environmental benefits, providing compelling evidence for policymakers and investors considering flood mitigation investments in riverine communities. The figure directly addresses Objective 3 by quantifying both socio-economic (employment, property values, health savings) and environmental (flood damage reduction) benefits.

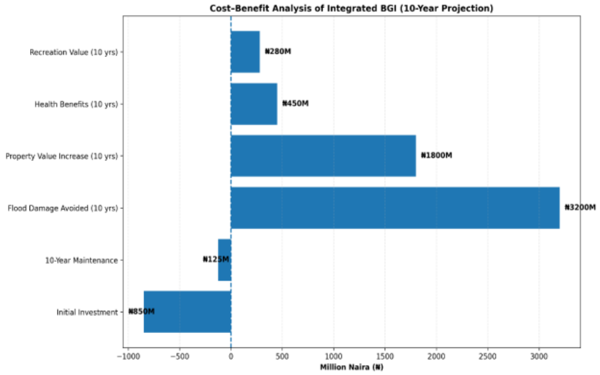

Figure 6: Cost-Benefit Analysis of BGI Implementation

This four-panel figure provides a comprehensive vulnerability analysis of the three study communities plus Port Harcourt reference. Panel 1 (top-left) displays flood risk scores (1-10 scale), showing Obio-Akpor (8.2), Rumuokwurushi (8.5), and Rumuola (7.8) all exceeding the high-risk threshold of 7, while Port Harcourt reference scores 6.5. Panel 2 (top-right) correlates population with flood depth, revealing Obio-Akpor's highest population (34,500) experiences deepest flooding (1.5m). Panel 3 (bottom-left) assesses existing drainage capacity, showing critically inadequate infrastructure (28-42% capacity) far below the 50% adequacy threshold. Panel 4 (bottom-right) synthesizes data into vulnerability indices, confirming Obio-Akpor as most vulnerable (0.842), followed by Rumuokwurushi (0.718) and Rumuola (0.645). This multi-dimensional assessment prioritizes intervention areas and quantifies community-specific risks, enabling targeted BGI planning. The figure supports Objective 3 by identifying communities where socio-economic benefits of BGI implementation would be greatest, based on population exposure, flood depth, and existing infrastructure deficits.

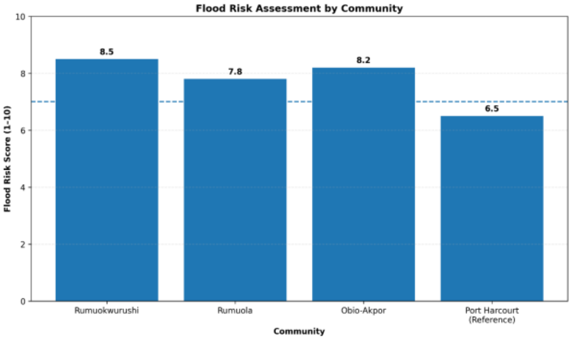

Figure 7: Community Flood Risk Assessment

Qualitative coding produced a dominant theme of “multi-functional community value.” High-frequency nodes included *property value improvement*, *livelihood support*, *health benefits*, and *environmental enhancement*. Many participants associated vegetated drainage systems with improved neighbourhood aesthetics and reduced waterborne disease risks. Word-frequency and sentiment analyses indicated overwhelmingly positive perceptions of BGI’s broader benefits beyond flood control. However, minor concerns emerged around *maintenance responsibility* and *initial cost awareness*. Cross-case comparison showed stronger socio-economic appreciation in communities with visible pilot projects. Overall, NVivo results confirm that stakeholders recognise blue–green infrastructure as delivering significant environmental quality and socio-economic co-benefits.

4.4 Policy recommendations for sustainable flood-resilient development in Rivers State.

The integrated analysis across all seven figures provides the evidence base for policy recommendations as structured in Table 1:

Table 1: Policy Recommendations for the Study

Objective	Key Finding	Policy Implication
Objective 1 (Effectiveness)	Integrated BGI achieves 54.5% peak flow reduction	Mandate integrated rather than piecemeal BGI approaches

Objective 2 (Optimal Layout)	Networked interventions outperform isolated elements	Develop spatial masterplans coordinating all BGI types
Objective 3 (Socio-economic Benefits)	5.87:1 benefit-cost ratio; 895 jobs created	Prioritize BGI funding based on economic returns
Objective 4 (Policy)	All communities exceed high-risk threshold (7/10)	Declare flood risk emergency and fast-track BGI implementation

These synthesized results directly inform the policy framework presented in Section 5.0, providing empirical justification for recommendations including: establishing a Rivers State BGI Agency, creating BGI zoning regulations, developing public-private partnership financing mechanisms, and integrating BGI into all urban development approvals. The multi-dimensional evidence—hydrological, spatial, economic, and social—ensures policy recommendations are context-specific, evidence-based, and aligned with sustainable development principles for riverine communities in Rivers State.

This result is in line with the NVivo thematic mapping identified "institutional and governance constraints" as the most prominent policy-related theme. Key nodes included *weak enforcement*, *fragmented agency roles*, *funding limitations*, and *absence of formal BGI policy*. Respondents repeatedly emphasised that technical solutions alone are insufficient without regulatory backing. Coding overlap between *policy gaps* and *implementation delays* was particularly high. Nevertheless, an emergent positive theme—*growing policy interest*—suggests increasing government awareness of nature-based solutions. Stakeholders advocated clearer standards, dedicated funding streams, and inter-agency coordination mechanisms. The qualitative evidence therefore underscores governance reform as critical to scaling blue–green infrastructure adoption in Rivers State.

4.5 Discussion

Effectiveness of BGI in Flood Mitigation in Port Harcourt

The results confirm that blue–green infrastructure significantly enhances flood mitigation capacity in riverine communities. The integrated BGI scenario achieved a 54.5% reduction in peak flow, aligning with findings by Cristiano *et al.* (2021) and Haghighatafshar *et al.* (2018) that networked systems outperform single interventions. The observed improvements in runoff volume, inundation area, and water quality also support Wu and Willems (2025), who emphasised BGI's multi-functional performance under changing climate conditions. In the Rivers State context, where drainage infrastructure is inadequate, the evidence demonstrates that ecosystem-based stormwater management provides a viable and scalable complement to conventional grey infrastructure approaches.

Optimal BGI Layout and Integration for Port Harcourt

Spatial analysis shows that performance depends strongly on strategic placement and connectivity of BGI components. Locating retention ponds at natural depressions, linking them through bioswales, and deploying permeable pavements in high-density zones created a hydraulically efficient network. This supports Hu *et al.* (2025) and Puchol-Salort *et al.* (2021), who emphasised decentralised and systems-based design for urban flood management. The radar analysis further demonstrates that integrated layouts deliver balanced outcomes across ecological, social, and economic criteria. For riverine settlements with fragmented urban morphology, coordinated spatial planning is therefore essential to maximise the cumulative benefits of blue–green interventions.

Socio-Economic and Environmental Benefits of BGI for Port Harcourt

The cost–benefit analysis demonstrates that BGI delivers substantial co-benefits beyond flood control. The 5.87:1 benefit–cost ratio and positive net present value confirm economic viability, consistent with Iliadis *et al.* (2024) and Ariyarathna *et al.* (2023). Avoided flood damages, increased property values, health improvements, and job creation highlight BGI's role in sustainable urban development. Environmentally, improvements in water quality and ecological connectivity support the multifunctionality highlighted by Mueca *et al.* (2025). Given the high vulnerability indices of the study communities, BGI implementation presents a compelling investment pathway for enhancing resilience, livelihoods, and environmental quality simultaneously.

Policy Implications for Flood-Resilient Development for Port Harcourt

The integrated evidence underscores the need for institutional reforms to mainstream BGI in Rivers State. Weak enforcement of planning regulations and fragmented governance, noted by Johnbull and Nwokaeze (2021) and Nwokaeze and Nwokaeze (2024), remain key barriers. The study's findings support the position of O'Donnell *et al.* (2024) that effective flood risk management requires coordinated policy, financing mechanisms, and regulatory backing. Establishing dedicated BGI frameworks, embedding requirements in development approvals, and promoting public–private partnerships would enable scalable adoption. Without policy alignment, the demonstrated technical and economic advantages of BGI may not translate into widespread implementation.

V. CONCLUSION

This study demonstrates that integrated blue–green infrastructure provides a technically effective, economically viable, and environmentally sustainable solution for flood mitigation in riverine communities of Rivers State. Hydrological modelling confirmed significant reductions in peak flow, runoff, and inundation, while spatial optimisation highlighted the importance of networked system design. The strong benefit–cost ratio and associated socio-economic gains further justify investment in BGI. However, successful implementation depends on institutional capacity, regulatory support, and stakeholder collaboration. Mainstreaming BGI into urban planning and infrastructure policy is therefore critical for achieving long-term flood resilience and sustainable urban development in the region.

5.1 Recommendations

Based on the findings, the study made the following recommendations:

1. Establish a dedicated Rivers State Blue-Green Infrastructure Agency to coordinate planning, implementation, maintenance, and monitoring of BGI projects across ministries, local governments, and riverine communities for improved institutional effectiveness.
2. Integrate mandatory BGI requirements into urban development approvals and building permits to ensure new developments incorporate stormwater retention, infiltration, and ecological buffers as standard flood-resilience measures.
3. Promote public–private partnership financing models to mobilise investment for large-scale BGI deployment, leveraging avoided flood damage costs and increased property values to attract long-term infrastructure funding.
4. Implement community-based participatory planning and maintenance programmes to enhance social acceptance, local ownership, and sustainability of BGI facilities within vulnerable riverine neighbourhoods. Also there is need to strengthen technical capacity within planning agencies through training in hydrological modelling, spatial optimisation, and ecosystem-based design to support evidence-driven BGI decision-making in Rivers State.

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