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Enhancing Urban Drainage in Coastal Cities: A Simulation-Based Assessment of Nature-Based Solutions for Climate Resilience

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Abstract
Climate change is increasingly manifested through extreme rainfall events and sea-level rise, posing significant challenges to coastal cities worldwide. Rapid urbanization further exacerbates these pressures by intensifying runoff generation and overwhelming conventional drainage infrastructure. In this context, Nature-Based Solutions (NBS) have emerged as a promising approach to enhancing urban drainage performance by partially restoring natural hydrological processes. The main objective of this study is to assess the potential of integrated NBS to improve the hydraulic performance of urban drainage systems in tropical coastal settings. To this end, a systematic literature review is combined with scenario-based simulations using the Storm Water Management Model (SWMM) within simulated coastal urban scenarios constructed with synthetic yet literature-informed parameters. The simulation results indicate that a distributed network of bioswales, rain gardens, and permeable pavements may reduce peak discharge and total runoff volume by approximately 28.8% and 29.0%, respectively, primarily through enhanced infiltration capacity and delayed time to peak. These findings reflect outcomes derived from controlled simulation scenarios rather than direct predictions of field performance. Overall, this study provides a conceptual and quantitative simulation-based framework that can support urban planners and engineers in exploring the potential role of integrated NBS as part of adaptive drainage strategies for climate-vulnerable tropical coastal cities.

I. INTRODUCTION

The reality for coastal cities is that urban flooding has evolved from an occasional inconvenience into a serious threat to sustainable development. Climate change is driving progressive sea-level rise, while high-intensity precipitation events are becoming more frequent (Laino & Iglesias, 2023). At the same time, rapid urbanization transforms natural landscapes into impervious surfaces, accelerating runoff that overwhelms outdated drainage systems (Wannewitz et al., 2024). The resulting risk profile reflects the interaction of global and local stresses, indicating the need for a comprehensive revision of urban water management strategies (Chu et al., 2022; Wu, 2021). This spatial exposure is illustrated in the global coastal flood risk map in Figure 1 .

The situation is particularly acute in tropical coastal cities. Local vulnerabilities, including short-duration, high-intensity storms, land subsidence, and saltwater intrusion, compound global trends and reduce surface and subsurface stability (Gupta, 2020). Consequently, aging drainage

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networks are frequently overwhelmed, making urban flooding a recurring problem. As noted by La Loggia et al. (2020), addressing this challenge requires more than enlarging pipes; it necessitates flexible, sustainable methods to manage stormwater at the source.

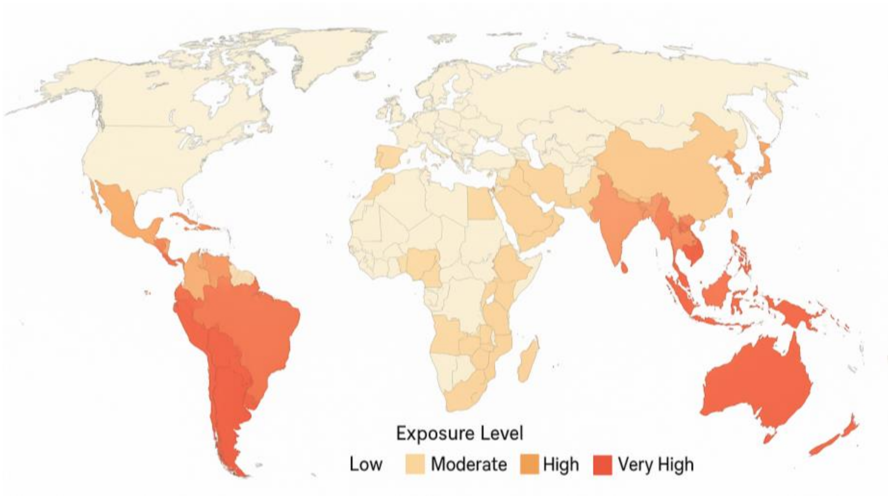

Figure 1. Global Exposure to Coastal Flooding (Adapted from relevant global risk datasets)

Nature-Based Solutions (NBS) and Sustainable Drainage Systems (SuDS) have emerged as innovative approaches that leverage natural processes for stormwater management. Extensive literature demonstrates their ecological, social, and economic co-benefits (Kabisch et al., 2022; Sowińska-Świerkosz & García, 2022). Global analyses further indicate that NBS can reduce the impacts of natural hazards under various scenarios (Debele et al., 2023; D'Ambrosio et al., 2023). However, a research gap remains: many studies focus on individual NBS components in isolation or are conducted in temperate climates, leaving limited quantitative evidence on integrated NBS portfolios in tropical coastal cities. This gap particularly affects the understanding of system-level impacts on peak-flow reduction and hydraulic resilience, limiting confidence in large-scale engineering applications.

This study addresses the gap by developing and applying a conceptual simulation framework to evaluate how integrated NBS could enhance hydraulic resilience in tropical coastal urban drainage. Our main contribution is a transferable methodology that enables planners to move from qualitative advocacy to quantitative appraisal, even in data-scarce contexts (Chairat & Gheewala, 2024). The paper is organized as follows: Section 2 presents a comprehensive literature review on urban resilience, NBS, and SuDS. Section 3 describes the mixed-methods approach combining literature review with scenario-based simulations. Section 4 presents hydraulic modeling outcomes, and Section 5 discusses the significance, limitations, and future research directions, concluding the study.

II. LITERATURE REVIEW

The paradigm shift in urban flood management is becoming evident, as rapid removal methods using grey infrastructure are increasingly complemented by holistic approaches that account for water retention, infiltration, and multifunctional use. Emerging practices such as NBS are central to this shift. However, there remains a wide gap between policy support and practical implementation, particularly in the Global South (Kumar et al., 2020; O'Donoghue et al., 2021). Urban resilience theory provides a lens for framing cities as complex systems capable of resisting shocks, adapting to changed conditions, and recovering rapidly (Goonesekera & Olazabal, 2022). In this study, resilience is operationalized primarily in terms of hydraulic performance indicators (e.g., peak discharge, runoff volume), rather than broader socio-ecological resilience dimensions (Mugume et al., 2024). This shifts the focus from solely preventing overflows to enhancing the system's ability to absorb shocks and recover efficiently.

NBS refers to interventions that leverage natural processes to manage human and environmental challenges while producing co-benefits for biodiversity and society (Sowińska-Świerkosz & García, 2022). A multidimensional performance evaluation framework has been proposed to appraise NBS projects more comprehensively (Sowińska-Świerkosz & García, 2021). In urban drainage, NBS interventions include retention ponds for storage, green roofs for evapotranspiration, and bioswales or permeable pavements for infiltration and conveyance. Their main advantage lies in decentralizing stormwater management and emulating pre-development hydrological regimes disrupted by urbanization. SuDS represent the engineered implementation of NBS principles, comprising structural and non-structural controls that manage runoff more sustainably than conventional piped systems (McClymont et al., 2020; O'Sullivan et al., 2020). By focusing on source control, slowing runoff, and improving water quality, SuDS act as the backbone of NBS strategies in built environments.

Table 1. Selected Previous Studies on NBS/SuDS for Urban Drainage.

Researcher(s)	Location	Focus	Method	Key Findings	Limitations
(D'Ambrosio et al., 2023)	Northern Italy	SuDS for climate adaptation	SWMM modeling	SuDS significantly reduce overflow volume and frequency.	Temperate climate focus; single catchment.
(García Sánchez & Govindarajulu, 2023)	Chennai & Kochi, India	Blue-Green Infrastructure	Case study analysis	Highlights planning integration challenges.	Qualitative; lacks quantitative hydraulic analysis.
(McClymont et al., 2020)	Brazil & UK	Multi-objective	Optimisation modelling	Effective balance of flood	High model complexity demands

		optimisation of SuDS		resilience, cost, and amenity.	extensive data.
(Mugume et al., 2024)	Generic Urban System	Blue-Green Infrastructure resilience	Scenario-based simulation	BGI maintains functionality during pipe failures.	Conceptual model, not site-specific.
(Wijaya et al., 2020)	Coastal Southeast Asia	Drivers of climate adaptation	Stakeholder surveys	Identifies key drivers for NBS adoption.	Does not measure technical performance.

A review of recent empirical work, summarized in Table 1, shows that while case studies abound, the field is fragmented. Many studies focus on single technologies or temperate climates, limiting evidence of integrated system-scale performance in tropical coastal zones (D'Ambrosio et al., 2023; García Sánchez & Govindarajulu, 2023; McClymont et al., 2020). This highlights the research gap that our study addresses: providing quantitative evidence of the systemic hydraulic impact of integrated NBS portfolios in tropical coastal cities (Gargiulo et al., 2020). Synthesizing the literature, we developed the conceptual framework shown in Figure 2. In this framework, an integrated NBS portfolio directly enhances intermediate hydraulic variables such as infiltration, storage, and conveyance which in turn promotes overall urban drainage resilience. The system becomes better equipped to absorb extreme rainfall shocks and recover efficiently, supporting the transformative potential of NBS in urban systems (Palomo et al., 2021).

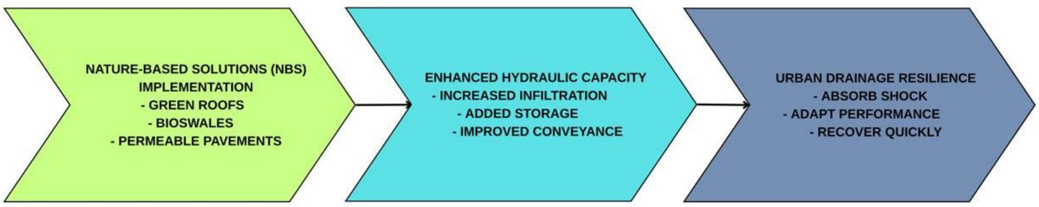

Figure 2. Conceptual Framework for NBS-Driven Drainage Resilience

III. RESEARCH METHOD

A. Research Design

The research goals are achieved through a hybrid research method that combines theoretical exploration with computational simulation. This approach allows numerical simulations to be grounded in established theoretical frameworks while generating quantitative insights into system dynamics. One of the core elements of the methodology is the development of a virtual representation of a tropical coastal watershed to enable controlled scenario analysis. This approach aligns with recent trends in infrastructure digitalization and simulation-based planning (Diana & Angga Mukti, 2025). The comparative framework is systematically designed to distinguish performance differences between baseline (existing) conditions and Nature-Based Solution (NBS) intervention scenarios.

B. Data and Simulation Parameters

The modeling framework incorporates synthetic parameters that represent typical tropical coastal urban conditions, ensuring both transparency and generalizability. Parameter values are derived from ranges reported in the literature, particularly for climate- and hydrology-sensitive variables (D'Ambrosio et al., 2023; Kumar et al., 2020). The key input parameters used in the SWMM simulations are summarized in Table 2. This parameterization ensures consistency with documented values while remaining suitable for conceptual, scenario-based analysis, which is the focus of this study.

Table 2. Input Parameters for Scenario Simulation

Parameter	Baseline Scenario	NBS Scenario	Unit	Source / Rationale
Rainfall Intensity	75 (design storm)	75 (design storm)	mm/hr	Synthetic event based on literature
Imperviousness	80%	60%	-	Assumed reduction from NBS
Curve Number (CN)	90	75	-	Standard SCS-CN method
Manning's n (surface)	0.015 (asphalt)	0.2 (grassed swale)	-	Engineering manuals
Infiltration Rate (Green Area)	Low	Medium-High	mm/hr	Derived from literature

C. Modeling Tool and Workflow

All hydrological simulations were conducted using the U.S. EPA Storm Water Management Model (SWMM), a widely validated platform for integrated hydrology–hydraulic modeling. SWMM can represent both conventional grey infrastructure and NBS elements in urban drainage systems. Scenario-based hydraulic modeling is particularly suitable for exploring complex urban water management challenges under controlled assumptions (Kwon et al., 2025; Omar et al., 2020). Figure 3 illustrates the overall research workflow, progressing from theoretical grounding to computational simulation and analytical interpretation. This structured workflow allows iterative refinement while maintaining methodological consistency.

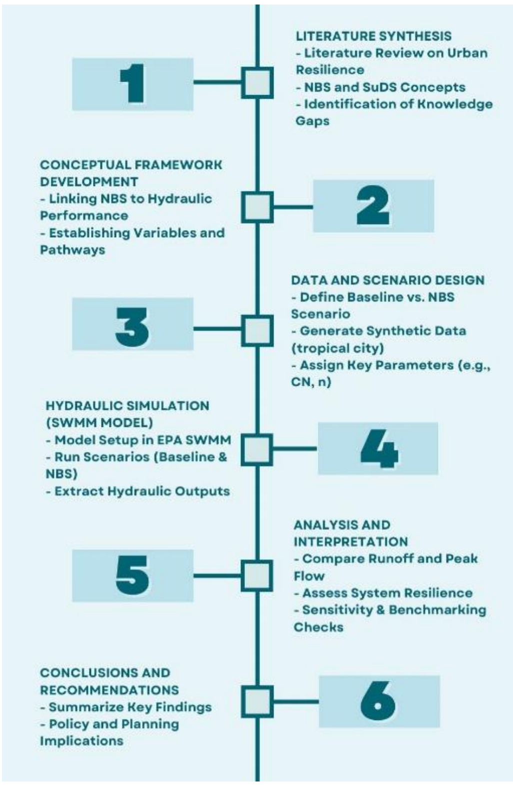

Figure 3. Research Methodology Flowchart

D. Defining Simulation Scenarios

To evaluate the hydraulic impacts of NBS implementation, two simulation scenarios were defined. Scenario 1 (Baseline) represents conventional urban drainage conditions characterized by high imperviousness (80%) and minimal green infrastructure. Scenario 2 (NBS Intervention) incorporates a distributed set of NBS measures, including bioswales, rain gardens, and permeable pavements across the catchment. This configuration reduces effective imperviousness to 60% while introducing multiple decentralized stormwater controls. By comparing these scenarios under identical rainfall conditions, performance differences can be attributed directly to the presence of NBS.

E. Model Confidence

Although field validation is beyond the scope of this conceptual study, model plausibility was established through benchmarking against comparable studies with similar objectives (D’Ambrosio et al., 2023; Mugume et al., 2024). Model configuration and output ranges are consistent with reported NBS performance characteristics in the literature. The robustness of the analysis was further supported by systematic sensitivity analyses focusing on key parameters, particularly infiltration rates and surface roughness coefficients (Sharan et al., 2023). Sensitivity analysis indicates that infiltration-related parameters exert the strongest influence on peak discharge reduction. In contrast, surface storage depth and roughness parameters have a moderate effect on runoff volume attenuation and time-to-peak delay. These findings suggest that the relative performance differences between scenarios are driven primarily by NBS-related hydrological processes rather than parameter uncertainty, increasing confidence in the comparative results.

IV. RESULT/FINDINGS AND DISCUSSION

A. Results and Findings

The results of the simulations show that the general drainage performance under the NBS intervention scenario has improved over the baseline in very significant and consistent ways. It appears that the integrated NBS system reduces runoff speed and volume by increasing retention and infiltration capacity, resulting in a lower peak discharge at the catchment outlet and a noticeable delay in time to peak, both of which are critical indicators of flood resilience. Figure 2 shows the comparative hydrographs between the baseline and NBS scenarios, clearly illustrating the attenuation of peak flow and temporal redistribution of runoff. Similar resilience improvements have been reported in studies analyzing drainage network bottlenecks (Mohammadiun et al., 2020).

For clarity and to provide an overall consolidated view of performance differentials, the key quantitative outputs from the hydraulic simulation are summarized in Table 3. The data illustrate favorable changes in major hydrological metrics, confirming the positive impact of the proposed NBS portfolio on system hydraulic behavior under simulated conditions. As summarized in Table 3, peak discharge and total runoff volume were reduced by approximately 28–29%, while infiltration capacity increased substantially. These results collectively indicate improved drainage system responsiveness during extreme rainfall events within the modeled scenarios.

Table 3. Summary of Simulation Outputs

Parameter	Baseline Scenario	NBS Scenario	Change (%)
Peak Discharge (m^3/s)	5.2	3.7	-28.8%
Time to Peak (min)	45	65	+44.4%
Total Runoff Volume (m^3)	15,800	11,220	-29.0%
Average Infiltration (mm/hr)	12	35	+191.7%

In addition, a brief sensitivity analysis was conducted to assess the robustness of the simulation outcomes. The results indicate that parameters related to infiltration capacity exert the strongest influence on peak discharge reduction, while surface roughness and storage depth show moderate effects on runoff attenuation and time-to-peak delay. Despite variations in parameter values, the overall direction and magnitude of performance improvement remained consistent across tested scenarios. This suggests that the reported results are relatively stable within the defined modeling assumptions. Accordingly, the quantitative results present a coherent picture of improved hydraulic performance under the NBS scenario. The observed 28.8% reduction in peak discharge and 29.0% reduction in total runoff volume indicate enhanced system capacity to manage extreme rainfall events in a simulated tropical coastal urban catchment. These findings should be interpreted as indicative potential rather than site-specific predictions, as actual effectiveness may vary depending on local geotechnical conditions, maintenance regimes, and urban spatial constraints (Bianciardi et al., 2023; Nelson et al., 2020).

B. *Discussion*

The results presented in Table 3 directly address the primary research objective by demonstrating that a strategically integrated NBS portfolio may contribute to measurable improvements in the hydraulic resilience of urban drainage systems under simulated conditions. The observed reductions in peak discharge and runoff volume support the hypothesis that partial restoration of natural hydrological processes can alleviate pressure on conventional drainage infrastructure. Rather than positioning NBS as a standalone solution, the findings suggest it can serve as a complementary component that augments existing grey infrastructure. These results align with and extend previous modeling-based studies in comparable contexts.

The magnitude of peak discharge reduction observed in this study (28.8%) is consistent with the efficiency ranges reported by (D'Ambrosio et al., 2023) in their SuDS modeling research conducted in Italy. Similarly, (Mugume et al., 2024) emphasize the role of distributed blue-green infrastructure in enhancing system-wide resilience, particularly under network stress or partial failure conditions. By applying this conceptual framework to a tropical coastal urban context, this study contributes new evidence to a geographical and climatic setting that remains underrepresented in current literature. However, these agreements should be understood within the shared limitation that all cited studies rely primarily on simulation-based approaches.

From a hydraulic perspective, the observed efficiency gains can be explained by mechanisms of flow attenuation, increased surface storage, and delayed runoff conveyance, rather than by metaphorical comparisons. Distributed NBS elements introduce multiple retention and infiltration points, collectively reducing peak flow intensity and redistributing runoff temporally across the drainage network. This redistribution enhances redundancy and flexibility within the system, improving its ability to absorb hydrological shocks during extreme rainfall. Such characteristics are central to resilience-oriented infrastructure design and align with contemporary resilience theory.

Despite the positive simulated outcomes, several practical trade-offs and uncertainties must be critically considered. Long-term performance of NBS may be affected by maintenance challenges, including sediment accumulation and clogging of infiltration media, which can reduce hydraulic efficiency over time (Kumar et al., 2020). In densely populated coastal cities, spatial limitations may constrain the scale and placement of NBS elements, potentially limiting their cumulative impact. Furthermore, uncertainty remains regarding system performance under compound events such as consecutive storms or fluctuating groundwater levels, which were not explicitly modeled in this study. These factors highlight the need for cautious interpretation and reinforce the importance of field-based validation.

Table 4. Policy and Engineering Implications of NBS Adoption

Aspect	Benefits	Challenges	Recommendations
Technical Design	Augments hydraulic capacity, improves water quality, and mitigates urban heat.	Requires interdisciplinary design; long-term performance data is limited.	Develop context-specific design guidelines for tropical coasts.
Urban Planning	Increases green space, enhances public amenity, and well-being.	High competition for urban land; high upfront costs.	Mandate NBS in zoning laws and development control regulations.
Policy & Governance	Fulfills climate adaptation mandates; promotes sustainable, livable cities.	Fragmented institutional responsibilities; lack of dedicated funding streams.	Establish inter-departmental task forces; pioneer public-private partnership models.
Maintenance & Operations	Creates green jobs; fosters community ownership and stewardship.	Demands new skill sets beyond traditional pipe maintenance.	Develop and fund long-term management plans; promote community engagement programs.

C. Policy & Governance Implications

The simulated hydraulic performance improvements provide a technical basis for the policy and governance implications summarized in Table 4. The observed reduction in peak discharge suggests that zoning regulations could prioritize integrating NBS into flood-prone sub-catchments to mitigate localized hydraulic overloads. Similarly, the documented delay in runoff response supports phased implementation strategies in which NBS deployment is aligned with drainage network upgrade schedules. The increased infiltration capacity observed in the simulations further underscores the importance of land-use regulations that protect permeable surfaces in rapidly urbanizing coastal areas.

As summarized in Table 4, the successful translation of these simulated benefits into practice requires coordinated planning across technical, institutional, and regulatory domains. While the benefits of NBS adoption are multifaceted, their realization depends on addressing challenges related to land availability, funding mechanisms, and institutional fragmentation (Barker et al., 2024). By explicitly linking modeled hydraulic outcomes to planning and governance instruments, this study aims to reduce the normative gap between technical results and policy recommendations. Such alignment is essential to ensure that policy guidance remains grounded in empirical system behavior rather than aspirational objectives.

D. Limitations and Future Work

We openly acknowledge the limitations of this study, which is based entirely on simulation using synthetic and secondary data; therefore, the results should be interpreted as indicative rather than predictive for any specific site. The modeling framework represents a simplified abstraction of real-world conditions and does not account for factors such as sediment clogging, long-term degradation of infiltration capacity, fluctuating groundwater levels, or sequential storm events, all of which may moderate NBS performance over time (Kumar et al., 2020). Importantly, no field calibration or observational data were available to validate the simulated outputs. Future research should prioritize field-based calibration and long-term monitoring of implemented NBS in tropical coastal cities to assess real-world performance and maintenance requirements. Integrating hydraulic modeling with socio-economic analysis would also enhance understanding of cost-effectiveness and stakeholder trade-offs (Berman et al., 2020). Additionally, coupling NBS simulations with grey infrastructure optimization models may support the design of more robust hybrid systems that can address uncertainty and climate extremes.

V. CONCLUSION AND RECOMMENDATION

This study finds that, in simulated tropical coastal urban scenarios, integrating Nature-Based Solutions (NBS) is associated with notable improvements in key hydraulic performance indicators. Scenario-based SWMM simulations indicate reductions in peak discharge and total runoff volume of approximately 28–30%, along with increased infiltration rates and a delayed time to peak, collectively suggesting enhanced drainage system responsiveness under extreme rainfall conditions. Rather than asserting definitive effectiveness, these results should be interpreted as indicative of the potential hydraulic benefits of integrated NBS portfolios under controlled modeling assumptions. In conceptual terms, this study contributes by proposing a transferable assessment framework that links distributed NBS implementation to system-scale drainage resilience through measurable hydraulic indicators, thereby supporting early-stage evaluation when site-specific data remain limited (Lemes de Oliveira, 2025).

Several limitations must be acknowledged. The analysis relies entirely on synthetic input data and does not account for field calibration or long-term performance degradation processes, such as sediment clogging or maintenance variability, that may moderate real-world outcomes. Accordingly, future research should prioritize empirical validation through field-based calibration in tropical coastal cities and long-term monitoring of NBS performance during repeated storm events. Further work may also integrate emerging mapping technologies and advanced materials to improve design optimization and monitoring accuracy (Putra Jaya & Tommy Hendryarto, 2025; Setyadi Tommy, 2025), enabling a more comprehensive understanding of how hybrid grey–green systems can support adaptive urban flood management.

AI Use Statement

The authors declare that artificial intelligence tools, including ChatGPT, were used solely to improve the manuscript's linguistic quality, including grammar, clarity, and textual coherence. The entirety of the research process, including study conception, data collection, analytical procedures, interpretation of findings, and formulation of conclusions, was conducted independently by the authors. The authors bear full responsibility for the originality, accuracy, and integrity of the published work.

REFERENCES

Barker, A., Garcia-Blanco, G., Garcia, I., & Aguirre-Such, A. (2024). The role of strategic planning in Nature- based Solutions (NBS) transformation: An evaluation of the Green Cities Framework in mainstreaming NBS in 6 European countries. *Nature-Based Solutions*, *6*. https://doi.org/10.1016/j.nbsj.2024.100157

Berman, M., Baztan, J., Kofinas, G., Vanderlinden, J. P., Chouinard, O., Huctin, J. M., Kane, A., Mazé, C., Nikulkina, I., & Thomson, K. (2020). Adaptation to climate change in coastal communities: findings from seven sites on four continents. *Climatic Change*, *159*(1), 1–16. https://doi.org/10.1007/s10584-019-02571-x

Bianciardi, A., Becattini, N., & Cascini, G. (2023). How would nature design and implement nature-based solutions? *Nature-Based Solutions*, *3*. https://doi.org/10.1016/j.nbsj.2022.100047

Chairat, S., & Gheewala, S. H. (2024). The conceptual quantitative assessment framework for Nature-based Solutions (NbS). In *Nature-Based Solutions* (Vol. 6). Elsevier Inc. https://doi.org/10.1016/j.nbsj.2024.100152

Chu, E., Brown, A., Michael, K., Du, J., Lwasa, S., & Mahendra, A. (2022). "Unlocking the potential for transformative climate adaptation in cities": From the global commission on adaptation (2021). In *The Sustainable Urban Development Reader* (pp. 86–90). Taylor and Francis. https://doi.org/10.4324/9781003288718-20

D'Ambrosio, R., Longobardi, A., & Schmalz, B. (2023). SuDS as a climate change adaptation strategy: Scenario-based analysis for an urban catchment in northern Italy. *Urban Climate*, *51*. https://doi.org/10.1016/j.uclim.2023.101596

Debele, S. E., Leo, L. S., Kumar, P., Sahani, J., Ommer, J., Bucchignani, E., Vranić, S., Kalas, M., Amirzada, Z., Pavlova, I., Shah, M. A. R., Gonzalez-Ollauri, A., & Di Sabatino, S. (2023). Nature-based solutions can help reduce the impact of natural hazards: A global analysis of NBS case studies. *Science of the Total Environment*, *902*. https://doi.org/10.1016/j.scitotenv.2023.165824

Diana, D., & Angga Mukti, A. (2025). AI-Driven Digital Twin for Predictive Maintenance in Urban Infrastructure: Enhancing Structural Resilience and Sustainability. *Civil Engineering Science and Technology (CEST)*, *1*(1). https://doi.org/10.51903/3c72e647

García Sánchez, F., & Govindarajulu, D. (2023). Integrating blue-green infrastructure in urban planning for climate adaptation: Lessons from Chennai and Kochi, India. *Land Use Policy*, *124*. https://doi.org/10.1016/j.landusepol.2022.106455

Gargiulo, C., Battarra, R., & Tremiterra, M. R. (2020). Coastal areas and climate change: A decision support tool for implementing adaptation measures. *Land Use Policy*, *91*. https://doi.org/10.1016/j.landusepol.2019.104413

Goonesekera, S. M., & Olazabal, M. (2022). Climate adaptation indicators and metrics: State of local policy practice. *Ecological Indicators*, *145*. https://doi.org/10.1016/j.ecolind.2022.109657

Gupta, K. (2020). Challenges in developing urban flood resilience in India. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *378*(2168). https://doi.org/10.1098/rsta.2019.0211

Kabisch, N., Frantzeskaki, N., & Hansen, R. (2022). Principles for urban nature-based solutions. *Ambio*, *51*(6), 1388–1401. https://doi.org/10.1007/s13280-021-01685-w

Kumar, P., Debele, S. E., Sahani, J., Aragão, L., Barisani, F., Basu, B., Bucchignani, E., Charizopoulos, N., Di Sabatino, S., Domeneghetti, A., Edo, A. S., Finér, L., Gallotti, G., Juch, S., Leo, L. S., Loupis, M., Mickovski, S. B., Panga, D., Pavlova, I., … Zieher, T. (2020). Towards an operationalisation of nature-based solutions for natural hazards. In *Science of the Total Environment* (Vol. 731). Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2020.138855

Kwon, S. H., Lee, W. J., Kang, J. H., & Jun, H. (2025). Incorporating Pipe Age and Sizes into Pipe Roughness Coefficient Estimation for Urban Flood Modeling: A Scenario-Based Roughness Approach. *Sustainability (Switzerland)*, *17*(17). https://doi.org/10.3390/su17177989

Laino, E., & Iglesias, G. (2023). Extreme climate change hazards and impacts on European coastal cities: A review. In *Renewable and Sustainable Energy Reviews* (Vol. 184). Elsevier Ltd. https://doi.org/10.1016/j.rser.2023.113587

Lemes de Oliveira, F. (2025). Nature in nature-based solutions in urban planning. In *Landscape and Urban Planning* (Vol. 256). Elsevier B.V. https://doi.org/10.1016/j.landurbplan.2024.105282

McClymont, K., Fernandes Cunha, D. G., Maidment, C., Ashagre, B., Vasconcelos, A. F., Batalini de Macedo, M., Nóbrega dos Santos, M. F., Gomes Júnior, M. N., Mendiondo, E. M., Barbassa, A. P., Rajendran, L., & Imani, M. (2020). Towards urban resilience through Sustainable Drainage Systems: A multi-objective optimisation problem. *Journal of Environmental Management*, *275*. https://doi.org/10.1016/j.jenvman.2020.111173

Mohammadiun, S., Yazdi, J., Hager, J., Salehi Neyshabouri, S. A. A., Sadiq, R., Hewage, K., & Alavi Gharahbagh, A. (2020). Effects of bottleneck blockage on the resilience of an urban stormwater drainage system. *Hydrological Sciences Journal*, *65*(2), 281–295. https://doi.org/10.1080/02626667.2019.1690657

Mugume, S. N., Kibibi, H., Sorensen, J., & Butler, D. (2024). Can Blue-Green Infrastructure enhance resilience in urban drainage systems during failure conditions? *Water Science and Technology*, *89*(4), 915–944. https://doi.org/10.2166/wst.2024.032

Nelson, D. R., Bledsoe, B. P., Ferreira, S., & Nibbelink, N. P. (2020). Challenges to realizing the potential of nature-based solutions. In *Current Opinion in Environmental Sustainability* (Vol. 45, pp. 49–55). Elsevier B.V. https://doi.org/10.1016/j.cosust.2020.09.001

O'Donoghue, S., Lehmann, M., Major, D., Major-Ex, G., Sutherland, C., Motau, A., Haddaden, N., Kibria, A. S., Costanza, R., Groves, C., Behie, A., & Johnson, K. (2021). Adaptation to climate change in small coastal cities: The influence of development status on adaptation response. *Ocean and Coastal Management*, *211*. https://doi.org/10.1016/j.ocecoaman.2021.105788

Omar, P. J., Gaur, S., Dwivedi, S. B., & Dikshit, P. K. S. (2020). A Modular Three-Dimensional Scenario-Based Numerical Modelling of Groundwater Flow. *Water Resources Management*, *34*(6), 1913–1932. https://doi.org/10.1007/s11269-020-02538-z

O'Sullivan, F., Mell, I., & Clement, S. (2020). Novel Solutions or Rebranded Approaches: Evaluating the Use of Nature-Based Solutions (NBS) in Europe. *Frontiers in Sustainable Cities*, *2*. https://doi.org/10.3389/frsc.2020.572527

Palomo, I., Locatelli, B., Otero, I., Colloff, M., Crouzat, E., Cuni-Sanchez, A., Gómez-Baggethun, E., González-García, A., Grêt-Regamey, A., Jiménez-Aceituno, A., Martín-López, B., Pascual, U., Zafra-Calvo, N., Bruley, E., Fischborn, M., Metz, R., & Lavorel, S. (2021). Assessing nature-based solutions for transformative change. *One Earth*, *4*(5), 730–741. https://doi.org/10.1016/j.oneear.2021.04.013

Putra Jaya, R., & Tommy Hendryarto, K. (2025). Optimization of Soil Stabilization Techniques Using Nanomaterials for Enhanced Foundation Performance. *Civil Engineering Science and Technology (CEST)*, *1*(1). https://doi.org/10.51903/0h45k090

Setyadi Tommy, A. (2025). The Use of Drones for Surveying and 3D Modeling in Construction Projects. *Civil Engineering Science and Technology (CEST)*, *1*(1). https://doi.org/10.51903/ccspb273

Sharan, A., Datta, B., & Lal, A. (2023). Integrating numerical modelling and scenario-based sensitivity analysis for saltwater intrusion management: case study of a complex heterogeneous island aquifer system. *Environmental Monitoring and Assessment*, *195*(5). https://doi.org/10.1007/s10661-023-11159-z

Sowińska-Świerkosz, B., & García, J. (2021). A new evaluation framework for nature-based solutions (NBS) projects based on the application of performance questions and indicators approach. *Science of the Total Environment*, *787*. https://doi.org/10.1016/j.scitotenv.2021.147615

Sowińska-Świerkosz, B., & García, J. (2022). What are Nature-based solutions (NBS)? Setting core ideas for concept clarification. *Nature-Based Solutions*, *2*. https://doi.org/10.1016/j.nbsj.2022.100009

Wannewitz, M., Ajibade, I., Mach, K. J., Magnan, A., Petzold, J., Reckien, D., Ulibarri, N., Agopian, A., Chalastani, V. I., Hawxwell, T., Huynh, L. T. M., Kirchhoff, C. J., Miller, R., Musah-Surugu, J. I., Nagle Alverio, G., Nielsen, M., Nunbogu, A. M., Pentz, B., Reimuth, A., … Garschagen, M. (2024). Progress and gaps in climate change adaptation in coastal cities across the globe. *Nature Cities*, *1*(9), 610–619. https://doi.org/10.1038/s44284-024-00106-9

Wijaya, N., Nitivattananon, V., Shrestha, R. P., & Kim, S. M. (2020). Drivers and benefits of integrating climate adaptation measures into urban development: Experience from coastal cities of Indonesia. *Sustainability (Switzerland)*, *12*(2). https://doi.org/10.3390/su12020750

Wu, T. (2021). Quantifying coastal flood vulnerability for climate adaptation policy using principal component analysis. *Ecological Indicators*, *129*. https://doi.org/10.1016/j.ecolind.2021.108006