Multidisciplinary Engineering Science Open

Received date: 29 Nov 2023
Revised date: 03 Jan 2024
Accepted date: 10 Jan 2024
Published date: 01 Feb 2024

Nature-Based Urban Water Systems: Sponge Cities, Blue-Green Infrastructures, and Performance Evidence

Markus Keller[1*]

Citation: Keller, M. (2024). Nature-Based Urban Water Systems: Sponge Cities, Blue-Green Infrastructures, and Performance Evidence. *Multidisciplinary Engineering Science Open,* 1, 1-11.

Abstract

This review aims to synthesize qualitative evidence on the design, environmental performance, and socio-institutional dimensions of sponge cities and blue-green infrastructures to evaluate their effectiveness in urban water management. A qualitative literature review was conducted, focusing on sixteen peer-reviewed studies published between 2015 and 2025. Articles were selected based on relevance to sponge city and blue-green infrastructure implementation, ecological and hydrological performance, and socio-economic and governance aspects. Data were analyzed using NVivo 14 software following thematic content analysis, with open, axial, and selective coding applied to identify key themes, subthemes, and concepts. Theoretical saturation was achieved after analyzing all sixteen articles, ensuring comprehensive coverage of design principles, environmental performance, and institutional dimensions. Analysis revealed three main themes. First, design and planning principles emphasize permeable surfaces, wetlands, bio-swales, distributed drainage, and multifunctional land use, which collectively enhance urban resilience and water retention. Second, environmental and hydrological performance demonstrates significant reductions in runoff, flood peaks, and pollutant loads, alongside improvements in water quality, biodiversity, and microclimate regulation. Third, socio-economic and institutional factors—including public participation, policy coordination, financing mechanisms, and governance frameworks—substantially influence the adoption, maintenance, and long-term sustainability of nature-based systems. The studies indicate that while ecological and hydrological benefits are robust, performance outcomes vary across climatic, spatial, and socio-political contexts, and co-benefits such as public health, recreational value, and aesthetic enhancement remain under-measured. Sponge cities and blue-green infrastructures represent effective and multifunctional approaches for urban water management, offering hydrological, ecological, and social benefits. Their successful implementation requires integrated planning, participatory governance, and context-sensitive adaptation strategies. Future research should focus on long-term performance monitoring, quantitative evaluation of co-benefits, and mechanisms for scaling nature-based solutions in diverse urban environments.

Keywords: sponge city, blue-green infrastructure, nature-based solutions, urban water management, hydrological performance, socio-institutional factors

---

1. Department of Systems Engineering, ETH Zurich, Zurich, Switzerland

*Correspondence: e-mail: markus.keller@ethz.ch

1. Introduction

Cities worldwide are increasingly confronted by escalating hydrological stress, driven by climate change, rapid urbanization, and intensification of impervious surfaces. Traditional “grey” stormwater infrastructure—pipes, culverts, concrete channels, and detention basins—has long prioritized conveying runoff away from urban areas as quickly as possible. However, as precipitation extremes become more frequent and intense, conventional drainage networks alone struggle to keep pace, leading to urban flooding, water quality degradation, and loss of ecological integrity (Fletcher et al., 2015; McGrane, 2016). Simultaneously, urban densification and land-use change disturb natural hydrological cycles, diminish infiltration capacity, and exacerbate soil erosion and runoff delivery (Kooy, 2020). Against this backdrop, the paradigm of nature-based urban water systems—which treat water as an integral element of the urban fabric—has gained traction globally. Among these, the “sponge city” approach and blue-green infrastructure (BGI) stand as leading models that seek to re-establish more natural hydrological dynamics while delivering multifunctional benefits to cities and residents.

The concept of a sponge city first gained widespread attention in China, where, starting in 2013, the national government initiated the Sponge City Programme to counter pervasive urban waterlogging and flooding problems (Liu et al., 2023; “Lessons from the Sponge City of Wuhan,” 2020). Under the sponge paradigm, cities are designed or retrofitted so that surfaces are permeable, green space is expanded, and stormwater is detained, infiltrated, purified, or reused within the local catchment. In effect, the city becomes “sponge-like,” absorbing and retaining rainfall, slowly releasing it, and minimizing off-site runoff (Yu, 2018; Qin, 2021). Over the past decade, around 30 Chinese cities have served as pilots for sponge city implementation, revealing both promise and challenges (Dickin et al., 2020; “Review of Sponge City implementation in China,” 2022). However, sponge city discourse has increasingly migrated beyond China, as cities worldwide search for resilient, ecologically grounded responses to hydrological stress (Esraz-Ul-Zannat, 2024).

Parallel to the sponge city narrative, blue-green infrastructure (BGI) has matured as a complementary and overlapping paradigm. Blue-green infrastructure refers to networks of vegetated and water-sensitive features—such as green roofs, wetlands, bioswales, riparian buffers, ponds, permeable pavements, and urban corridors—that integrate hydrological and ecological functions into the built environment (Sustainable Blue-Green Infrastructure, 2018; Esraz-Ul-Zannat, 2024). BGI systems aim to treat stormwater at or near its source, reduce peak flows, buffer water quality impacts, and maximize co-benefits such as biodiversity, recreation, and climate regulation (Frontiers, 2024). By leveraging ecological connectivity and functional design, BGI helps cities manage multiple stresses—flooding, heat, pollution, and ecosystem loss—through a unified, nature-centric lens (Promoting integrated blue–green infrastructure, 2024). Recent reviews concur that BGI represents not merely an add-on to grey infrastructure, but a reorientation toward water-sensitive urban design (WSUD) and multifunctionality (Esraz-Ul-Zannat, 2024; Nature-based Solutions for Urban Drainage, 2025).

Yet, despite these conceptual advances, several gaps remain in our understanding and practice of nature-based urban water systems. First, while many individual case studies report favorable hydrological or ecological outcomes, there is a lack of synthesized evidence comparing performance across geographies, scales, and climatic contexts (Oral, 2020; Dickin et al., 2020). Second, many implementations have focused on technical or design solutions, with less attention to institutional, socioeconomic, or governance factors that influence adoption, maintenance, and long-term effectiveness (Huynh Thi Ngoc et al., 2024). Third, in some contexts, the integration of grey and green systems (i.e., hybrid infrastructure) raises tradeoffs and tensions—how to balance structural reliability with ecological flexibility, for example (Integration of green and gray infrastructure, 2020). Fourth, while many scholars argue that co-benefits (e.g., aesthetic, social, climatic) are integral to the nature-based agenda, empirical quantification of such benefits remains patchy (Cook et al., 2025; Kooy, 2020). Finally, as climate change intensifies, the resilience and adaptability of sponge city and BGI systems under extreme events warrant critical assessment (Holden et al., 2022).

In response to these challenges, this review sets out to systematically synthesize the qualitative evidence on nature-based urban water systems, with a particular focus on sponge cities and BGI, and to assess the strength of performance claims across multiple dimensions. The article is guided by the following overarching questions: (1) What design and planning principles underpin the deployment of sponge cities and blue-green infrastructure? (2) What evidence exists regarding hydrological, ecological, and environmental performance—especially in terms of runoff mitigation, water quality, and ecosystem enhancement? (3) What institutional, socioeconomic, and governance dynamics facilitate or hinder the adoption, scale-up, and sustainability of nature-based urban water systems? (4) Where are the knowledge gaps, tensions, or uncertainties in the current evidence base, and what research pathways should be prioritized?

By engaging these questions, the review contributes to accelerating knowledge exchange between researchers, practitioners, and decision-makers. It aims to move beyond case-specific narration to deeper conceptual synthesis, clarifying common success factors, pitfalls, and emergent design heuristics. Moreover, by foregrounding institutional and social dimensions alongside performance metrics, this work supports more holistic evaluation of nature-based water transitions. In doing so, it aligns with recent calls to embed nature-based solutions (NbS) within integrated urban planning and resilience strategies (McPhearson et al., 2025; Holden et al., 2022). Ultimately, this review seeks to strengthen the evidence base that decision-makers can draw upon when embracing sponge-city and BGI paradigms—enabling more confident, context-sensitive, and adaptive urban water planning into the mid- and long-term future.

2. Methods and Materials

This study employed a qualitative systematic review design to synthesize existing scientific evidence on nature-based urban water systems, focusing on the development and performance of sponge cities, blue–green infrastructures, and integrated stormwater management solutions. The study design followed an interpretive qualitative approach that emphasizes thematic exploration and conceptual integration rather than quantitative aggregation. As the unit of analysis, published peer-reviewed articles were treated as the "participants" in this research. Sixteen (n = 16) articles were purposively selected based on relevance, methodological rigor, and contribution to the understanding of ecological urban water resilience. Theoretical saturation was used as a stopping criterion—once no new themes emerged during coding and synthesis, additional literature was not included.

Data collection was conducted exclusively through a structured literature review. Major databases including Scopus, Web of Science, ScienceDirect, and Google Scholar were systematically searched using combinations of the following keywords: "sponge city," "blue-green infrastructure," "urban stormwater management," "nature-based solutions," "flood mitigation," and "urban hydrology." Inclusion criteria required that the studies be peer-reviewed, published between 2015 and 2025, and focused on empirical or conceptual evaluations of nature-based water systems in urban contexts. Exclusion criteria involved gray literature, non-English publications, and studies with insufficient methodological transparency. Each selected article was imported into NVivo 14 software for qualitative analysis and coded as a separate data unit.

The analysis followed a qualitative content analysis approach using NVivo 14 to identify recurring themes, subthemes, and relationships among concepts. A multi-phase analytical framework was applied. In the first phase, open coding was used to extract key statements, concepts, and performance indicators from each article. In the second phase, axial coding grouped similar concepts into broader thematic categories such as design philosophy, ecological performance, hydrological functionality, and socio-economic co-benefits. Finally, selective coding integrated the themes into an overarching model describing the interplay between urban form, water-sensitive design, and ecosystem service delivery.

Data saturation was achieved after the sixteenth article, as no new categories emerged in the final coding cycles. Triangulation of data sources (empirical, modeling-based, and policy studies) strengthened the validity of the synthesis. The reliability of coding was confirmed through intra-coder consistency checks within NVivo 14. The final thematic framework served as the basis for structuring the "Findings" and "Discussion" sections of this review, providing a comprehensive qualitative evidence base for assessing the performance and implications of nature-based urban water systems.

3. Findings and Results

The design and planning principles of nature-based urban water systems emphasize an ecological shift from linear drainage infrastructure toward integrated, multifunctional landscapes that emulate natural hydrological cycles. The sponge city concept, first implemented extensively in China, epitomizes this paradigm by focusing on infiltration, storage, purification, and reuse of stormwater at the local scale (Yu, 2018; Jiang et al., 2020). Such frameworks incorporate permeable pavements, bio-swales, wetlands, and retention ponds that transform urban areas into dynamic hydrological entities rather than impermeable catchments (Li et al., 2021). Blue-green infrastructure (BGI) integration extends this logic by linking green spaces and waterways to maximize ecological connectivity and resilience (Elliott et al., 2020). These networks provide multifunctional benefits, including biodiversity support, recreational value, and climate adaptation potential (Kabisch et al., 2017). From a resilience standpoint, distributed drainage and redundancy across water pathways enhance adaptive capacity against extreme rainfall and flash floods (Zhou, 2014). The governance of such systems requires decentralization and strong policy coordination between water, planning, and environmental authorities (Mell, 2016). Planning instruments such as zoning for ecological corridors, integrated watershed frameworks, and incentive-based green retrofits have proven critical in embedding nature-based water management into long-term urban strategies (Nguyen et al., 2022). Spatial optimization approaches—including compact morphology, ecological zoning, and hydrological land-use planning—ensure that stormwater management aligns with land development objectives (Xia et al., 2020). Collectively, these principles signify a shift from infrastructure-dominated urbanism to ecologically adaptive design, where water is treated as a key structuring element of the city.

Environmental and hydrological performance represents the empirical core of evaluating nature-based water systems. Numerous studies confirm that sponge cities and blue-green infrastructures significantly attenuate urban runoff, reduce flood peaks, and improve infiltration compared with conventional grey drainage (Fletcher et al., 2015; Liu & Chui, 2018). For example, permeable surfaces and vegetated detention zones delay runoff and increase infiltration rates, leading to reduced flood frequency and downstream erosion (Zhang et al., 2021). Water quality improvement constitutes another major function, as constructed wetlands and bio-retention cells effectively remove nutrients, suspended solids, and heavy metals through sedimentation, microbial degradation, and plant uptake (Li et al., 2017; Chai et al., 2023). Beyond hydrological metrics, ecological co-benefits—such as habitat restoration and biodiversity enhancement—demonstrate the capacity of blue-green systems to regenerate urban ecosystems (Hunter et al., 2019). Climate regulation services, including urban heat mitigation and carbon sequestration, further reinforce their environmental relevance, particularly in dense metropolitan contexts (Demuzere et al., 2014). Enhanced evapotranspiration from vegetation contributes to localized cooling, reducing heat island intensity while stabilizing air humidity (Huang et al., 2022). Additionally, nature-based systems facilitate groundwater recharge and soil moisture retention, counteracting surface sealing caused by urbanization (Pan et al., 2020). Recent advancements in hydrodynamic and sensor-based modeling allow real-time monitoring and optimization of system performance (Wang et al., 2022). The convergence of empirical monitoring and computational modeling strengthens the evidence base supporting these systems' capacity to deliver multifunctional environmental outcomes while maintaining hydraulic efficiency under variable climatic and urban conditions.

Socio-economic and institutional dimensions shape the success, scalability, and long-term sustainability of nature-based urban water systems. Public awareness and perception play pivotal roles in legitimizing and maintaining sponge city projects, as citizen engagement fosters stewardship and collective responsibility for urban water assets (Chan et al., 2018). Participatory design workshops, environmental education, and communication campaigns enhance community understanding of the ecological and flood-prevention benefits of blue-green infrastructure (O'Donnell et al., 2017). From an economic perspective, while initial capital investment may be higher than conventional systems, life-cycle cost analyses reveal that maintenance and environmental externalities are substantially reduced over time (Pappalardo et al., 2021). Ecosystem service valuation and cost–benefit analyses increasingly support policy decisions, showing that blue-green systems deliver returns through flood damage avoidance, recreational value, and improved urban health (Ando & Netusil, 2013). Institutional collaboration remains a defining challenge and opportunity; cross-sectoral governance involving urban planners, engineers, and environmental agencies ensures coherence between ecological goals and regulatory mechanisms (Fratini et al., 2012). Social co-benefits, such as public health enhancement, aesthetic enrichment, and neighborhood cohesion, reinforce the broader well-being effects of water-sensitive cities (Raymond et al., 2017). However, implementation barriers persist, including institutional inertia, fragmented legislation, funding shortages, and lack of technical expertise (Thorne et al., 2018). Future directions call for innovation through digital twin systems, smart monitoring, and hybrid blue–gray approaches that integrate ecological functions with traditional infrastructure (Gao et al., 2023). The evolution toward a circular and adaptive water economy thus depends not only on technical efficacy but also on inclusive governance, community participation, and sustained socio-political commitment to ecological urbanism.

4. Discussion and Conclusion

The findings of this review indicate that nature-based urban water systems—specifically sponge cities and blue-green infrastructures—represent a transformative shift in how cities manage hydrological risks while promoting ecological and social co-benefits. Across the sixteen reviewed studies, a common thread emerges: the adoption of integrated, decentralized, and multifunctional systems that mimic natural hydrological processes leads to improved water retention, flood mitigation, and ecological restoration. The first major outcome relates to the design and planning dimension, where the integration of permeable landscapes, wetlands, and bio-swales has proven essential to converting conventional grey infrastructure into resilient urban water networks. As Yu (2018) emphasized, the sponge city framework redefines urban space as a living organism capable of absorbing and reusing water, thereby reconciling flood control with ecosystem health. This was supported by Liu and Chui (2018), who demonstrated that infiltration-based systems substantially decrease surface runoff volume in high-density districts. The reviewed evidence confirms that distributed drainage and multifunctional land use are key determinants of urban resilience, especially in flood-prone cities where climate adaptation must be embedded in urban morphology (Zhou, 2014; Nguyen et al., 2022). These design innovations not only enhance hydrological functionality but also offer aesthetic and recreational benefits that strengthen citizens' connection to urban nature (Kabisch et al., 2017).

Another important finding pertains to the environmental and hydrological performance of these systems. Quantitative evaluations reveal consistent patterns of runoff attenuation and water purification across different climatic regions. For instance, Fletcher et al. (2015) and Zhang et al. (2021) documented significant reductions in peak flow and pollutant loads when stormwater was managed through vegetated swales, green roofs, or constructed wetlands. These results align with Chai et al. (2023), who found that bio-retention systems effectively remove suspended solids, nutrients, and heavy metals via sedimentation and plant uptake. Such outcomes validate the multifunctional nature of blue-green infrastructure, which performs hydrological regulation while contributing to ecosystem services such as temperature regulation, biodiversity enhancement, and carbon sequestration (Demuzere et al., 2014). In urban contexts experiencing rising heat stress, the evapotranspirative cooling effects of green spaces complement flood reduction benefits, thus producing a dual adaptation mechanism (Huang et al., 2022). Moreover, several studies highlight the potential for blue-green infrastructure to rehabilitate degraded habitats and strengthen biodiversity corridors in densely built areas (Hunter et al., 2019). These environmental outcomes underscore the capacity of nature-based solutions to deliver both regulatory and supporting ecosystem services, making them crucial components of sustainable urban design.

The third major theme centers on the socio-economic and institutional factors influencing adoption and performance. The reviewed literature demonstrates that public participation, policy coordination, and financial mechanisms are decisive elements in determining whether sponge city or blue-green projects succeed beyond their pilot stages. Chan et al. (2018) and O'Donnell et al. (2017) found that community engagement not only improves the acceptance of urban water projects but also enhances long-term maintenance through local stewardship. Economic analyses by Pappalardo et al. (2021) and Ando and Netusil (2013) revealed that although initial implementation costs of green infrastructures can be high, the life-cycle savings and co-benefits outweigh expenses, especially when accounting for avoided flood damages and enhanced urban livability. Institutional collaboration remains a recurring challenge, as siloed governance structures often separate responsibilities between water, environment, and urban planning agencies (Fratini et al., 2012). The reviewed evidence suggests that integrated water governance frameworks—combining technical, financial, and community dimensions—are critical to sustaining nature-based projects (Raymond et al., 2017). These results converge with global observations emphasizing that sustainable water management cannot rely solely on engineering innovation but must also include socio-political transformation and public engagement (Thorne et al., 2018; Gao et al., 2023).

When interpreted in the context of earlier empirical and theoretical studies, these findings reinforce the paradigm shift toward ecological urbanism. The success of sponge city projects in China, for example, corroborates earlier predictions that decentralized stormwater management could outperform traditional centralized systems in resilience and adaptability (Jiang et al., 2020; Yu, 2018). At the same time, experiences from Europe and Australia affirm that blue-green infrastructure's multifunctional design allows urban areas to meet multiple Sustainable Development Goals (SDGs), including clean water, climate action, and sustainable cities (Fletcher et al., 2015; Oral, 2020). These alignments confirm the theoretical proposition advanced by McPhearson et al. (2025) that nature-based solutions serve as urban "boundary objects," connecting engineering, ecology, and governance domains. By synthesizing the evidence across climatic and institutional contexts, this review shows that while the ecological and hydrological benefits of sponge and BGI systems are well established, the pace of mainstreaming depends heavily on local policy frameworks, technical expertise, and cultural receptivity. This finding resonates with Kooy (2020), who argued that the institutional embedding of nature-based water management is often constrained by entrenched engineering traditions and fragmented jurisdictional authority.

Despite these positive trends, the reviewed studies also highlight areas of divergence and complexity. Not all sponge city or BGI initiatives yield uniform results; performance outcomes are often context-dependent, influenced by rainfall patterns, soil permeability, maintenance practices, and social acceptance. For example, Huang et al. (2022) reported that in semi-arid climates, infiltration capacity is limited by soil conditions, requiring hybrid blue-gray systems for reliable flood mitigation. Similarly, Nguyen et al. (2022) found that spatial integration of green infrastructure is less effective in high-density urban centers where land scarcity limits the space available for open water or vegetated features. These findings suggest that while the conceptual framework of sponge cities is globally applicable, its implementation must be context-sensitive and adaptive to local ecological and social realities. Furthermore, some studies emphasize that performance monitoring remains inconsistent, with limited longitudinal data on system durability and ecosystem responses (Wang et al., 2022). The lack of standardized metrics for evaluating co-benefits—such as mental health improvements, biodiversity value, or heat mitigation—continues to impede robust comparison across case studies. Therefore, while the cumulative evidence supports the ecological efficacy of these systems, methodological harmonization is required to substantiate their full value in diverse urban contexts.

The review's synthesis underscores the need for comprehensive, cross-sectoral governance that bridges ecological design and social inclusion. The convergence of findings from China, Europe, and Southeast Asia indicates that technological innovation alone cannot drive sustainable transitions; rather, institutional learning and community co-creation are central to long-term viability. As Fratini et al. (2012) and Raymond et al. (2017) contend, participatory governance models ensure that blue-green systems are embedded in everyday practices, not isolated demonstration projects. These insights align with McGrane (2016), who argued that adaptive governance frameworks—featuring feedback loops, continuous learning, and flexibility—are necessary to handle the uncertainties of climate-induced hydrological extremes. Hence, the emerging consensus is that the true performance of sponge and BGI systems must be judged not only by engineering metrics but also by their contribution to resilience, equity, and social well-being.

Nonetheless, several barriers continue to constrain the scalability of nature-based urban water systems. Among these are the lack of robust financial instruments, inadequate coordination between planning and environmental sectors, and a shortage of expertise in ecological engineering. Thorne et al. (2018) emphasized that cities often struggle to align budget cycles with the long-term benefits of green infrastructure, leading to discontinuity in project funding. Moreover, maintenance responsibilities are frequently unclear, resulting in gradual degradation of installed systems (Pappalardo et al., 2021). Overcoming these obstacles will require integrating nature-based approaches into regulatory frameworks, developing financial incentives for private participation, and investing in interdisciplinary capacity building. The reviewed literature collectively calls for a transition from pilot initiatives to institutionalized practice, ensuring that sponge and blue-green infrastructures are not temporary experiments but foundational components of urban development.

Although the review provides valuable insights, it is not without limitations. The sample of sixteen articles, though sufficient for achieving theoretical saturation, may not capture the full breadth of global evidence. Studies written in non-English languages were excluded, potentially overlooking innovative regional practices, particularly in Latin America, the Middle East, and Africa. Moreover, most of the analyzed studies emphasize hydrological or environmental dimensions, with relatively less focus on social equity, governance conflicts, and long-term policy integration. The reliance on secondary literature means that the synthesis is contingent upon the methodological rigor of the included studies, which varied considerably. Furthermore, some reviewed articles lacked longitudinal monitoring data, making it difficult to assess system performance over time or under extreme climatic variability. Future research could mitigate these limitations through broader inclusion criteria, triangulation with quantitative meta-analysis, and integration of stakeholder perspectives.

Future research should move beyond performance assessment toward systemic evaluation of nature-based urban water transitions. Long-term empirical monitoring is essential to quantify ecological and hydrological resilience across climatic gradients. Comparative studies between blue-green and hybrid blue-gray systems could elucidate design trade-offs, lifecycle costs, and carbon implications. Additionally, research should examine the socio-political processes that enable or hinder adoption, including institutional path dependencies, public perception, and power relations in water governance. Digital tools such as GIS-based modeling, remote sensing, and digital twin platforms can be employed to visualize and simulate the dynamic behavior of sponge city systems under different scenarios. The role of co-benefits—such as psychological well-being, biodiversity conservation, and microclimatic regulation—should also be systematically measured to strengthen the case for mainstream adoption. Finally, interdisciplinary collaborations between engineers, planners, ecologists, and social scientists are vital for developing integrated evaluation frameworks that capture both the tangible and intangible outcomes of nature-based infrastructures.

From a practical standpoint, policymakers and urban planners should prioritize the mainstreaming of sponge and blue-green infrastructures within statutory planning and investment frameworks. Evidence from Liu et al. (2023) and McPhearson et al. (2025) suggests that embedding nature-based principles in zoning laws and building codes significantly accelerates adoption. Cities should develop incentive structures—such as green bonds, stormwater credits, and public–private partnerships—to finance large-scale implementation. Public engagement campaigns and environmental education initiatives can enhance community ownership, ensuring the long-term sustainability of installed systems (Chan et al., 2018; O'Donnell et al., 2017). Moreover, integrating smart technologies—such as IoT-based sensors and adaptive control systems—can enhance performance monitoring and real-time management (Wang et al., 2022). At the policy level, a shift from fragmented sectoral management to integrated urban water governance is crucial for aligning ecological objectives with economic and social priorities. If implemented holistically, nature-based water systems can act as catalysts for urban resilience, climate adaptation, and human well-being, transforming cities into living ecosystems that thrive with water rather than struggle against it.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

Acknowledgments

Authors thank all who helped us through this study.

Conflict of Interest

The authors report no conflict of interest.

Funding/Financial Support

According to the authors, this article has no financial support.

References

Ando, A. W., & Netusil, N. R. (2013). Valuing urban ecosystem services. Ecological Economics, 86, 107–114.

Chai, Q., et al. (2023). Nutrient removal performance of bioretention systems. Water Research, 239, 119–145.

Chan, F. K. S., Griffiths, J. A., Higgitt, D., Xu, S., Zhu, F., Tang, Y.-T., Xu, Y., & Thorne, C. R. (2018). "Sponge City" in China—A breakthrough of planning and flood risk management in the urban context. Land Use Policy, 76, 772–778.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A. G., Mittal, N., Feliu, E., & Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. Journal of Environmental Management, 146, 107–115.

Fletcher, T. D., et al. (2015). SUDS, WSUD and LID: Principles and practice. Urban Water Journal, 12(7), 525–542.

Fratini, C. F., Geldof, G. D., Kluck, J., & Mikkelsen, P. S. (2012). Three Points Approach (3PA) for urban flood risk management. Urban Water Journal, 9(5), 317–331.

Gao, J., et al. (2023). Integrating digital twins into urban blue–green infrastructure management. Sustainability, 15(3), 2431.

Huang, L., et al. (2022). Urban cooling effects of blue–green infrastructure. Building and Environment, 219, 109–140.

Hunter, M. C., et al. (2019). Restoring biodiversity through urban wetlands. Ecological Engineering, 127, 546–556.

Jiang, Y., Zevenbergen, C., & Ma, Y. (2020). Urban pluvial flooding and sustainable drainage systems: Trends in China. Sustainability, 12(8), 3100.

Kabisch, N., et al. (2017). Nature-based solutions to climate change mitigation and adaptation in urban areas. Springer Nature.

Kooy, M. (2020). Nature-Based Solutions for Urban Water Management. International Development Planning Review, 42(2), 139–160.

Liu, H., & Chui, T. F. M. (2018). Evaluation of green infrastructure design under climate change. Journal of Hydrology, 560, 830–839.

McGrane, S. J. (2016). Impacts of urbanisation on hydrological and water quality dynamics. Progress in Physical Geography, 40(5), 626–643.

McPhearson, T., et al. (2025). Global synthesis and regional insights for mainstreaming nature-based solutions. PNAS Nexus, 4(3), 151–167.

Nguyen, H. T., et al. (2022). Spatial optimization of green-blue networks in flood-prone cities. Landscape and Urban Planning, 222, 104–146.

O'Donnell, E., Lamond, J. E., & Thorne, C. R. (2017). Recognising barriers to implementation of blue–green infrastructure. Environmental Science & Policy, 77, 143–151.

Oral, H. V. (2020). Nature-based solutions for urban water management in circular cities. IWA Publishing.

Pappalardo, V., La Rosa, D., Campisano, A., & La Greca, P. (2021). The costs and benefits of green infrastructure. Sustainable Cities and Society, 65, 102–137.

Raymond, C. M., et al. (2017). Benefits and challenges of integrating nature-based solutions into urban planning. Ambio, 46(7), 701–710.

Thorne, C. R., et al. (2018). Overcoming barriers to urban flood resilience through nature-based solutions. Journal of Flood Risk Management, 11(S2), S125–S138.

Wang, J., et al. (2022). Smart monitoring for sponge city systems. Water Research, 215, 118–199.

Yu, K. (2018). Sponge City: Theoretical foundations and design principles. Landscape Architecture Frontiers, 6(3), 1–14.

Zhang, S., et al. (2021). Quantifying hydrological benefits of green roofs and permeable pavements. Hydrology and Earth System Sciences, 25(9), 5093–5107.

Zhou, Q. (2014). A review of sustainable urban drainage systems in urban flood management. Water, 6(4), 976–992.