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블루-그린 인프라를 활용한 지속 가능한 도시 개발: 홍수 완화, 열 감소 및 수질 개선에 대한 종합적인 검토

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Sustainable Urban Development using Blue-Green Infrastructure: A Review of Flood Mitigation, Heat Reduction, and Water Quality Enhancement

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요 약

도시화와 기후변화로 인한 환경문제는 도시 회복력 강화를 위한 지속가능한 해결책을 요구하고 있다. 블루-그린 인프라는 도시 열섬현상, 도시홍수, 수질개선 등의 도시환경문제에 효과적으로 대응할 수 있는 대안으로 주목받고 있다. 그러나 BGI에 대한 보편적 실행지침이 존재하지 않아 적용이 확대되고 있지 않다. 본 연구는 국내외의 다양한 BGI 사례를 종합적으로 검토하여 BGI 구현을 위한 통합 프레임워크를 개발하고자 수행되었다. 본 프레임워크는 BGI 기술이 대응하고자 하는 주요 환경문제 식별, 대상지역의 특성 평가 및 적합한 BGI 유형을 선택하는 과정을 포함한다. 이어서 구체적인 설계 및 모델이 개발되고, 시뮬레이션을 통해 해당 BGI의 효과성과 영향이 평가된다. 시뮬레이션 결과가 긍정적인 경우 관련기관의 승인절차를 거쳐 BGI의 구축이 진행되며, 필요시 설계보완이 이루어진다. BGI 구축 후에는 체계적인 모니터링 및 유지관리와 지속적인 개선이 필수적이다. 본 연구에서는 제도적, 기술적, 사회문화적 측면에서의 주요 장애요인을 도출하고, 이를 극복하기 위한 개선 방안을 제시하였다. 이러한 장애요인의 해소는 한국 도시 내 BGI의 통합적 적용을 촉진하며, 기후변화에 대응하는 도시 회복력 강화에 기여할 수 있을 것으로 기대된다.

핵심용어 : 블루-그린 인프라, 자연기반해법, 지속가능성, 도시 복원력

Abstract

Given the increasing environmental challenges due to urbanization and climate change, blue-green infrastructure (BGI) presents a sustainable solution for urban resilience, focusing on urban heat island (UHI) effects, urban flooding, and water quality improvement. BGI concepts remain underexplored due to the lack of universally established guidelines for their implementation. Thus, a review of the functions of BGI in global and Korean applications was conducted, resulting in the development of a framework for BGI implementation. The developed framework

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potentially offers step-by-step guidance for urban planners, policymakers, and researchers. The process begins with identifying the primary environmental problem that the BGI technology will address, followed by evaluating site characteristics and selecting the appropriate BGI type. A detailed design and model are then developed, with simulations conducted to assess the impacts and effectiveness of the BGI. If the simulation results are positive, approval from relevant institutions is sought, leading to construction. If necessary, the design is retrofitted to meet the required standards. Post-construction monitoring, maintenance, and continuous improvements are essential for ensuring the longevity of the BGI system. Additionally, the paper identifies key barriers to BGI adoption, including institutional, technical, and socio-cultural challenges, and proposes improvement measures applicable to Korean cities. By addressing such barriers, the integration of BGI can be enhanced, fostering climate resilience and improving urban livability in the face of climate change.

Key words : blue-green infrastructure, nature-based solutions, sustainable development, urban resilience

1. 서 론

Temperature continues to rise at an accelerating rate despite the various efforts made to counter the increasingly evident human-induced climate change impacts in urban areas (IPCC, 2022). According to United Nations Environment Programme (2024), the urban population contributes the most in greenhouse gas emissions and approximately 70% of global carbon dioxide emissions. As a result, cities are dealing with environmental impacts resulting to property damage, economic losses, and health risks leading to death. It is projected that 68% of the global population will reside in urban areas by 2050, which will significantly affect current environmental problems including urban heat island (UHI), flood, air pollution, water pollution and shortage, biodiversity loss, and soil contamination and degradation (Shreevastava et al., 2019). Such pressing issues on climate change indicate a need for improved and more innovative mitigation plans in urban areas.

Based on the analysis of six international datasets, the global average increase in surface temperature in 2024 was 1.55° C (± 0.13° C) (World Meteorological Organization, 2025). The temperature in Korea is expected to climb more sharply than global temperatures. Moreover, the mean temperature in Seoul has increased by 2.3° C over the past decade, and the Korea Meteorological Administration forecasts the number of heatwaves to 69 days yearly by 2027 if greenhouse gas emissions will continue to raise at its current rate (An & Dedekorkut-Howes, 2025). The record-breaking heat calls for accelerated climate action in 2025 and the upcoming years.

One of the causes of the aforementioned issue is impermeable surfaces that have taken the place of natural landscapes in urban areas (Haddad et al., 2025). Traditional infrastructures, also known as grey infrastructures, are the established ways of coping up with the urban stormwater management. However, the increasing population means that water use also rises and the urbanization is leading to land scarcity, especially in urban areas. Thus, such infrastructures usually fail due to overload, leading to flooding comprised of both the stormwater and untreated water in rivers (Haddad et al., 2025). Moreover, gray infrastructures, although essential in sustaining urban resilience and functionality, often have large carbon footprint for its construction and maintenance while also disrupting ecosystems (Orak & Smail, 2025). Thus, replicating the natural catchment it provides will help in reducing runoff volume. Natural mimicry includes blue-green infrastructure (BGI) that delivers multiple benefits (Haddad et al., 2025).

The integration of blue and green technologies to create a BGI is gaining recognition as an effective approach to address the impacts of climate change in urban environments and reduce vulnerability to risks such as flooding, heat stress, and water shortages, while delivering a range of additional co-benefits to the environment and society (O'Donnell et al., 2021). BGIs can be defined as either man-made or natural infrastructures that addresses urban water management by incorporating vegetation which results to an increase in the amount of ecosystem services in a city, thereby enhancing the quality of life (Sin-Ampol et al., 2025; Yüksel & Hepcan, 2025). Various organizations and researchers have also provided their own definitions of BGI which share key characteristics in describing BGI as an interconnected, integrated, or combination of blue and green spaces or infrastructures (Mell & Scott, 2023; Cruijsen, 2015). The importance of BGI in providing a range of ecosystem services that aid in addressing urban issues including flooding, climate change, and urban heat island impacts is emphasized as well (Balany et al., 2022; Voskamp & Van de Ven, 2015). Several definitions highlight the integration of natural elements (e.g. vegetation, water bodies) with built environments (e.g. infrastructure, urban planning), while others mention that BGI offers multiple benefits, such as water management, flood control, microclimate regulation, biodiversity conservation, and improved air quality (Ghofrani et al., 2016; de Macedo et al., 2021). Some studies interchange the terms blue and green, and the term becomes green-blue infrastructures or GBI. It is also crucial to consider the connection of individual BGIs to a network of blue and green elements known as blue-green network (BGN) to enhance urban resilience. BGI has drawn attention in the research community in the last 5 years, but its application is still restricted since there is still no universally accepted definition as well as a set of guidelines for its implementation (Yuanita & Sagala, 2025). However, BGI faces institutional, social, and technical limitations and remains understudied.

Thus, the study aims to develop a clear and structured conceptual framework of the steps in implementing BGI within a BGN in urban areas focusing on water quality, urban heat island, and urban flooding, present impacts of domestic and international cases of BGI, determine the limitations and challenges of building BGI in Korean cities, and offer improvement measures on planning and construction of BGI.

2. Materials and Methods

Scopus is a highly trusted bibliographic database widely used in review papers due to its rigorous content selection, comprehensive metadata, and global coverage of peer-reviewed literature (Baas et al., 2020). It is described as the largest searchable citation and abstract source with over 49 million records, including peer-reviewed journals, trade publications, open-access journals, conference proceedings, and book series (Chadegani et al., 2013). Its broad coverage makes Scopus particularly useful for more inclusive or wide-ranging analyses (Wang & Waltman, 2016). Thus, research articles from the Scopus database were employed. The methodology framework is presented in Figure 1. A search query was conducted on April 2025 using the search string TITLE-ABS-KEY ("blue green infrastructure*" OR "blue-green infrastructure*" OR "green blue infrastructure*" OR "green-blue infrastructure*" OR "blue green network*" OR "blue-green network*" OR "green blue network*" OR "green-blue network*") AND ("urban water qualit*" OR "urban heat island*" OR "urban flood*") AND ("evaluat*" OR "perform*") and was limited to English language. The relevant contributions of the research articles in urban BGI were assessed. 습지

To ensure the relevance and specificity of the literature included, a set of inclusion and exclusion criteria was applied. Articles that focused broadly on nature-based solutions (NbS) without specific reference to the integration of BGI were excluded, as the scope of the study centers on the application of both elements. Similarly, studies that discussed green infrastructure or blue infrastructure in isolation were not considered. In addition, publications that primarily explored the social, cultural, or economic dimensions of BGI, without evaluating its environmental or functional performance, were also excluded from the analysis. The selected articles were limited to the papers that offered scientific or technical analyses of integrated BGI systems, including studies that assessed BGI effectiveness in addressing key urban environmental issues such as urban heat island (UHI) mitigation, water quality enhancement, and urban flood control.

The selected studies were utilized to create a framework through the analysis of the concept, construction technologies, application techniques and strategies, effects or performance, and challenges in establishing BGI within a BGN in both domestic and international cases.

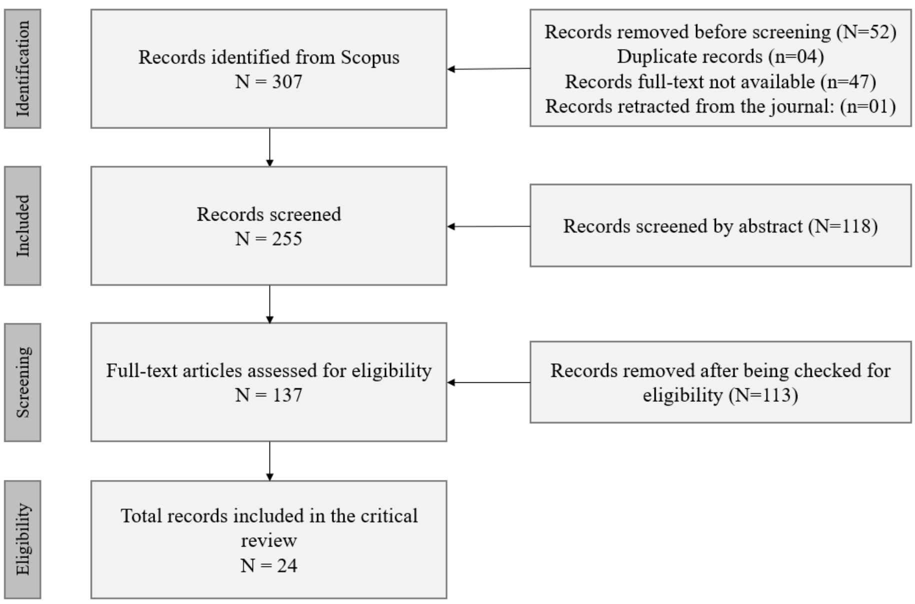

Fig. 1. Method Framework of the Review Study

3. Results and Discussion

3.3 BGI Establishment Framework

The framework shown in Figure 2 shows the steps in establishing BGI from choosing the main goal of the application to its maintenance and continuous monitoring based on the existing studies. The flow of the BGI implementation flowchart is grounded in a multi-stage, interdisciplinary process that integrates ecological context, data-driven planning, and governance coordination.

The first step, identifying the primary environmental challenges such as urban flooding, UHI, or water pollution, is essential for targeted BGI deployment. As Naumann et al. (2011) emphasized, recognizing multifunctional goals and ecological issues at the outset ensures relevance and effectiveness in design. Consequently, Sörensen et al. (2021) advocated for spatial data analysis to map existing blue-green systems and identify connectivity gaps using Geographic Information Systems (GIS), laying the groundwork for networked rather than fragmented infrastructure. Once the site is assessed, the framework proceeds to integrating site-specific constraints and opportunities, which aligns with Bakhshipour et al. (2019), who argue for careful spatial and hydrological analysis when modeling hybrid green-blue-gray systems. Naumann et al. (2011) and Bakhshipour et al. (2019) then stress the steps of selecting suitable BGI types, modeling potential scenarios, and simulating their hydrologic and systemic impacts as part of adaptive, feedback-oriented design. Institutional coordination and governance, as highlighted by Hansen et al. (2019), are then addressed to ensure regulatory compliance and policy alignment. Finally, monitoring and long-term data collection, is underscored by Sörensen et al. (2021), who identified data infrastructure and cross-sectoral access as essential for evaluating and maintaining BGI performance and ecosystem service delivery. Such structured approach, supported by each of the four studies, reflects a practical and evidence-based sequence for implementing integrated BGI within urban BGNs.

3.3.1. Identification of Main Goal

Establishing a clear and structured goal is the foundational step in successfully implementing BGI. Defining the primary environmental issue ensures that all subsequent design, planning, and evaluation stages align with the objective. The study narrows its focus to three key concerns: urban flooding, urban heat island effect, and water quality degradation, which are especially critical in fast-growing and climate-vulnerable cities.

Urban flooding has become increasingly severe due to climate change and the proliferation of impervious surfaces that prevent natural water infiltration. Inadequate drainage infrastructure has been unable to cope with extreme rainfall events, as seen in the August 2022 Seoul flood. BGI interventions like rain gardens, bioretention systems, green roofs, and permeable pavements have demonstrated effectiveness in mitigating

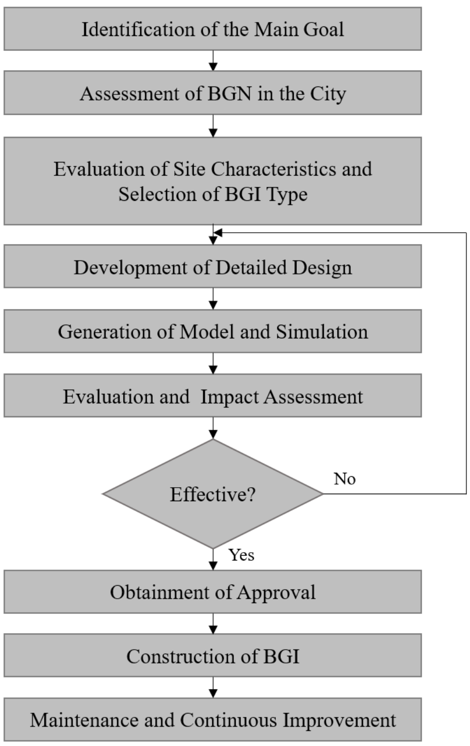

Fig. 2. Developed framework for BGI implementation

stormwater volumes and reducing combined sewer overflows (CSOs) (Montoya-Coronado et al., 2024). Such solutions are especially valuable in dense urban settings where land availability is limited. When integrated with grey infrastructure, BGI can achieve greater cost-efficiency and performance in managing runoff (Yuanita & Sagala, 2025).

The UHI effect and water quality deterioration are equally pressing issues. The UHI effect, caused by heat-retaining materials and urban activity, exacerbates heat-related risks, especially in cities like Daegu. Although initial policies exist, many remain underdeveloped or lack measurable targets. At the same time, stormwater runoff, especially from industrial areas, carries heavy metals and other pollutants into local water bodies. BGI measures such as vegetated swales and bioretention cells improve water quality by filtering pollutants before discharge. Combining BGI with Low-Impact Development (LID) and traditional sewer systems offers a robust strategy to improve ecological conditions while enhancing urban resilience and sustainability (Wartalska et al., 2025).

3.3.2. Assessment of Blue-Green Network in the City

BGI serve as physical components of BGN, enabling ecosystem-based adaptation and providing crucial services such as flood mitigation, habitat connectivity, and improved public health through access to green and blue spaces (Mayr et al., 2017). In particular, features like bioswales, rain gardens, and permeable pavements demonstrate how BGI elements within BGN contribute to water quality improvement and stormwater management. Further, BGN depends on clean rainwater and utilizes urban ecohydrology techniques which are mimicked by BGI (Wagner et al, 2013).

The European Commission (2018) defines BGN as an “urban space development concept defining a network of blue areas and green areas, as a basis of spatial planning of cities that will provide sustainable development and adaptation to global change.” Another definition of BGN describes it as “a spatial planning approach that integrates water-based ("blue") and vegetation-based ("green") elements with sustainable technologies and low-carbon, climate-resilient infrastructure to enhance urban resilience and ecological functionality” (Mayr et al., 2017). Thus, the researcher suggests a definition of BGN focused on urban areas with a view on improving water quality, urban flooding mitigation, and urban heat island mitigation. Hence, BGN can be defined as an urban planning strategy that integrates all natural or man-made water and vegetation elements within a city designed to address stormwater management, urban heat island, and water quality issues reducing peak runoff volume while simultaneously removing pollutants and lowering land surface temperature.

Blue elements include streams, wetlands, and stormwater systems, while green elements consist of parks, street trees, greenways, and forests, all working together to form a connected system that extends across and beyond city boundaries. The network structure of blue and green elements serves as a foundational framework for organizing urban development at the city, neighborhood, and community levels by linking ecological, hydrological, and social systems through coordinated planning of blue, green, and grey spaces.

In urban BGI planning, it is essential to approach natural and built systems as interdependent components of a broader BGN, rather than as isolated features. As Ghofrani et al. (2017) emphasized, the multifunctional benefits of BGI such as flood regulation, biodiversity conservation, and water purification are only fully realized when individual components are planned and connected as part of an integrated network. Zhou et al. (2025) further demonstrated that multi-level BGI networks, which link large ecological zones with small urban green and blue patches, can significantly improve ecological connectivity even in densely built environments. By spatially identifying fragmented corridors, underutilized water bodies, and isolated parks through resistance surface modeling and hotspot analysis, planners can prioritize strategic infill interventions. Simple measures such as transforming vacant lots into rain gardens or integrating canals into green corridors can reestablish flow paths and enhance landscape-scale resilience. Ultimately, each BGI element strengthens the collective system, enabling cities to address ecological degradation, climate vulnerabilities, and social well-being in a more coordinated and adaptive manner.

3.3.3. Application Methods Based on Site Characteristics

Site characteristics are important factors in developing blue-green infrastructures in urban areas. According to Cruijsen (2015), blue-green sites can be classified depending on where it is located such as surface, sub-surface, and aboveground. Another classification of the BGI is based on extent of its application scale namely the micro, meso, and macro-scales (Zaręba et al., 2022). Micro scale includes applications on a single-family house. Meso scale, on the other hand, may either be applied in a street scale or district scale. Moreover, macro scale includes citywide applications such as increasing the retention capacity of rivers, filtration basins covered with vegetation, hydrophytic ponds, dry reservoirs with constant flow and trough, vegetation on water bodies as buffers, restoration of watercourses to attain appropriate terrain, and a system of interconnected mesoscale and microscale.

Various types of BGI are available for integration into urban environments, each with specific suitability and spatial considerations. The specifications mentioned are adapted from EPA (2004), Czyża & Kowalczyk (2024), Alves et al. (2024), and Zaręba et al. (2022). Urban tree boxes or tree pits, implemented at the meso scale and surface level, are most suitable in public areas with groundwater depths exceeding one meter. Rain harvesting systems are typically micro-scale and can be installed on the surface, subsurface, or aboveground, depending on roof type, canopy coverage, and available space which makes them ideal for rooftops, gardens, and underground storage systems. Porous pavements, applied at the meso scale and surface level, are appropriate for locations with high soil permeability and low traffic volume, such as residential driveways, parking lots, pedestrian trails, and bike paths, but should be avoided in areas with high sediment loads.

Blue-green roofs, which are micro-scale and aboveground, depend on the structural capacity of the roof, wind and slope conditions, and plant suitability based on local climates. Further, they are viable for new or existing buildings across residential, commercial, and industrial zones. Grassed filter strips function at the meso scale and surface level, and are effective in areas with gentle slopes (2–6%) and sufficient topsoil and infiltration rates, such as roadways and parking lots. Bioretention systems, also meso and surface-level, are suitable for compact urban environments with at least a 0.61-meter groundwater table and are commonly placed in street medians, rooftops, and redevelopment sites. Bioswales, another meso-scale surface solution, accommodate up to 5% slopes and require at least 1% of the total catchment area, functioning well in roadsides, public parks, bicycle paths, and unpaved or open surfaces. Infiltration trenches, installed at meso scale and surface level, range from 1 to 2 meters in depth and are designed for areas near recreational fields or open spaces, avoiding areas with contaminated groundwater or near buildings. Lastly, green bus stops are a hybrid aboveground/surface intervention typically found in city centers or urbanized areas near transit hubs. Their dimensions vary by design, with a typical capture area of 60 m^2 , effectively managing runoff from adjacent pavements. The aforementioned BGI elements offer flexible, site-specific solutions to enhance water management, reduce urban heat, and improve public accessibility and ecological health in dense urban landscapes.

Many studies highlight the importance of strategically placing BGI on publicly owned properties such as government, school, and religious lands due to easier access and regulatory compatibility. Ensuring public accessibility and integration with urban systems like transportation enhances BGI effectiveness, with site suitability often assessed using metrics like Floor Area Ratio (FAR) and built-up coverage (Arthur & Hack, 2022; Ambily & Chithra, 2025). In dense cities where land is limited, small- to medium-scale solutions like green roofs, rain gardens, and permeable pavements are effective, and vertical space utilization is becoming an essential consideration.

3.3.4. Detailed Design, Modelling, Simulation, Performance Evaluation, and Impact Assessment

The implementation of BGI requires identifying suitable

Table 1. List of modelling tools for the design and simulation of BGI within a BGN.

Modelling Tool	Description	Reference
Geographic Information System (GIS)	Determination of locations most appropriate for the implementation of BGI through suitability analysis; Integration of five identified criteria namely slope, hydrologic soil group, potential drainage density, land cover, and proximity to roads and showed overall suitability of BGI in the study area.	(Kaur & Gupta, 2022)
InVEST model	Establishment of multi-indicator evaluation method focusing on the interaction between resource elements of watershed sponges, offered an innovative strategy for evaluating the suitability of watershed sponge construction.	(Wu et al., 2025)
CommunityViz 5.2 integrated with ArcGIS	Runoff generation using the curve number method and CBGI storage simulation through terrain analysis; Development of twelve scenarios according to rainfall intensities, management objectives, managing activities, and land use and climate changes	(Li et al., 2025)
Urban Multi-scale Environmental Predictor (UMEP)	Simulation of the spatio-temporal patterns of urban shade throughout the day; Comparison of the discrepancies in cooling effects between shading, blue-green spaces, and building height based on multi-source data	(Zou et al., 2024)
SWMM-UrbanEVA	Establishment of a transferable framework for categorizing different BGI types, enabling accurate representation of relevant characteristics in the model, and highlighting importance of considering plant-specific evapotranspiration and soil characteristics in BGI modeling	(Hörnschemeyer et al., 2023)
PALM-4U	Development of urban climate models (UCMs) in a range from mesoscale (up to 50 m grid size) to microscale (up to 1m grid size); Calculation of the surface temperature and heat flux of green and non-green ground and building surfaces, determined the effect of BGI in the courtyard, and showed the effects of vegetation and water elements on the microclimatic conditions in the two courtyards	(Beier et al., 2022)

ecological components and indicators for effective monitoring and evaluation. Factors such as land cover, soil type, vegetation, slope, and BGI size significantly influence performance in terms of water quality and stormwater management, and should be tailored to local climate conditions. Stormwater runoff mitigation can be assessed by distinguishing between detention (temporary storage and slow release) and retention measures (either through infiltration into the ground or water storage in low-infiltration basins) (Cruijsen, 2015). For urban heat island (UHI) mitigation, three main assessment methods exist: field air temperature measurement, remote sensing of land surface temperature, and numerical modeling of air temperature (Budzik et al., 2025). Each method is suited for different scales and scenarios, with remote sensing best for existing BGI at local scales, field measurements ideal for micro-scale applications, and simulations valuable for mesoscale or predictive modeling. Further, based on the site characteristics and application method chosen, a detailed design and model that captures spatial integration, multi-scalar planning, and network connectivity is vital.

Running both baseline and intervention scenarios to simulate BGI performance individually and within the BGN is necessary. Performance indicators such as runoff reduction, temperature changes, and pollutant removal are evaluated, and the collective impact of BGI elements within the BGN is analyzed using spatial or multi-criteria decision-making tools. Once deemed ineffective based on the guidelines for water quality, runoff reduction, and UHI mitigation, optimizations and iterations in the modelling are required. Possible tools are listed in table 1.

3.3.5. Obtainment of Approval, Construction of BGI, and Maintenance and Continuous Improvement

Once a BGI technology has been validated through modeling and simulation, the next important step is to secure the necessary permits and approvals from relevant authorities before any construction begins. The step ensures that the project not only complies with legal standards but also aligns with the intended environmental, social, and economic goals, especially when it is a part of a BGN within the city. Organizing a collaborative meeting with key stakeholders including planners, engineers, city officials, and contractors is highly recommended. Such discussions help clarify the objective of the project, delegate responsibilities, and align everyone on the expected outcomes since collaborative approach fosters transparency and minimizes miscommunication during the implementation phase. A common hurdle in BGI projects is the limited technical experience of some construction teams. To bridge the aforementioned gap, it is essential to clearly explain the purpose and technical details of both the BGI and BGN design to ensure proper execution. Equipping the team with a full understanding of the system helps prevent costly errors and supports long-term performance. Equally important is establishing a strategy for monitoring and routine maintenance after construction, supported by developing specific guidelines for maintaining

Table 2. Domestic and international applications of BGI.

Country/City	Project Name	Description	Reference
Korea (Seoul)	Cheonggyecheon Stream Restoration	Transformation of a once-buried stream into a vibrant blue-green corridor by introducing riparian vegetation, leading to improved biodiversity and water quality.	(Lee et al., 2020)
Korea (Busan)	Eco-Delta City	Integration of BGI systems within a smart eco-city design to support sustainable urban living.	(Smart City Korea, 2024)
Korea (Gandong-gu)	Eco-friendly rain village	Installation of rain gardens and storage facilities to enhance stormwater reuse.	(Hyorin, 2021)
Korea (Suwon)	Smart City Innovative Technology Exploration Project	Installation of permeable pavement blocks in parking lots to help circulate and manage rainwater effectively.	(Smart City Korea, 2022)
Denmark (Copenhagen)	Cloudburst Management	Incorporation of green parks with water retention capabilities, demonstrating resilience against heavy rainfall.	(Fereshtehpour & Najafi, 2025)
Berlin	Sponge City	Integration of green, grey, and blue infrastructure to enhance rainwater reuse and promote urban sustainability.	(Fereshtehpour & Najafi, 2025)
Vancouver	Rain City Strategy (RCS)	Utilization of BGI such as permeable pavement, bioswales, engineered wetlands, rain gardens, absorbent landscapes, green roofs, and modular systems to safeguard water quality and boost resilience with sustainable water management practices.	(Gupta & Shukla, 2024)
Singapore	Active, Beautiful, Clean (ABC) Waters Program	Establishment of a bioretention trough near the Kallang River in Potong Pasir, Sedimentation basin in Clementi, a waterway improvement project on the Kallang River in Potong Pasir, a cleansing biotope at Bishan-Ang Mo Kio Park, a community space on the Alexandra Canal.	(Liao, 2019)

vegetation, managing stormwater, or tracking water quality. In addition, implementing an integrated evaluation framework allows for regular performance assessments, making it easier to identify and resolve issues such as system clogging or vegetation stress. Such proactive measures are key to ensuring that BGI installations function cohesively within the BGN and continue to deliver their intended benefits over time.

3.4. Existing Applications

Various adaptation of BGI technologies was seen in the studied articles. The summarized existing domestic and international applications of BGI are listed in table 2. Such applications collectively illustrate how BGI can be adapted to diverse urban contexts to enhance sustainability and resilience.

In South Korea, BGI is increasingly being incorporated into both newly developed and existing urban environments, primarily to address flood mitigation, stormwater management, and water reuse. The initiatives are generally site-specific, focusing on infrastructure retrofitting or small-scale pilot projects, often aligned with smart city frameworks and urban regeneration efforts. In contrast, international applications of BGI tend to adopt a more holistic and system-oriented approach, integrating BGI into comprehensive, long-term strategies for urban climate resilience. Such projects are frequently embedded within city-wide plans that emphasize multifunctionality, ecological connectivity, and adaptive capacity. Despite the contextual differences, both Korean and international cases utilize nature-based solutions to strengthen urban resilience and improve ecosystem functions. To enhance the scalability and long-term success of BGI in Korea, it is essential to advance policy integration, foster intersectoral collaboration, and promote active community engagement, thereby aligning domestic efforts with globally recognized best practices.

3.5. Challenges and Improvement Measures

The number of infrastructures incorporating BGI are expected to increase in the future (Ghofrani et al., 2017). However, various challenges restrain the broad implementation of BGIs connected with a city-wide BGN, especially in Korean cities. In line with this, the barriers or challenges in BGI establishment can be divided into three (3) categories namely: the institutional, governance, and funding; technical knowledge and experience; and socio-cultural barriers.

3.5.1. Institutional, Governance, and Funding

Institutional and governance challenges are among the primary barriers to implementing BGI, particularly when considering the larger scale and interconnected nature of BGNs. Existing centralized regulatory systems and rigid policies are often not designed to support the multi-scalar, cross-jurisdictional coordination required for BGI development (Sadegh Koohestani et al., 2025). In Korea, although national adaptation plans exist under the Framework Act on Low Carbon, Green Growth (2010), they lack concrete provisions for implementing integrated BGIs, resulting in unclear responsibilities between national and local governments and fragmented coordination (An & Dedekorkut-Howes, 2025). Institutional gaps hinder efforts to treat BGI as networked systems rather than isolated projects. Political and financial hurdles such as short-term governance priorities and a lack of recognition of the long-term ecological and social benefits of BGN connectivity further impede funding and stakeholder engagement. While some cities like Copenhagen have successfully justified BGI through cost-benefit analyses (Fereshtehpour & Najafi, 2025), broader adoption is still impeded by funding cycle misalignments and social equity concerns, especially when public willingness to support BGI varies based on perceived risk and benefit (Toxopeus & Polzin, 2021; Haddad et al., 2025; Zhu et al., 2014).

3.5.2. Technical Knowledge and Experience

Despite growing interest in BGI through theoretical and experimental studies, real-life application and performance assessments remain limited, largely relying on isolated case studies without sufficient long-term or diverse local data (Sadegh Koohestani et al., 2025). Most existing frameworks are either too general or fail to account for the interdependencies between green, blue, and grey systems, making integration into broader urban planning systems difficult (Li et al., 2017). The lack of specific framework is especially problematic when BGIs must be designed to serve multiple functions across nodes and corridors in a BGN, such as stormwater control, thermal mitigation, and habitat connectivity (Ghofrani et al., 2017; Zhou et al., 2021). Technical uncertainty about long-term hydrological performance and the lack of trained specialists further weaken confidence in BGI projects. Moreover, engineers and planners are often hesitant to adopt BGI solutions at the network scale due to limited local data and a lack of reliable tools to simulate the cascading effects of interconnected systems (Copeland, 2016). Without comprehensive monitoring systems and performance benchmarks, it becomes difficult to assess degradation over time or adaptively manage BGN components. Strengthening technical capacity and establishing localized standards that reflect the interconnected nature of BGNs is essential to scale implementation.

3.5.3 Socio-cultural barriers

Effective operation and long-term performance of BGI heavily rely on good governance and active community involvement

Table 3. Improvement measures for each barrier type (Zhu et al., 2014; Fereshtehpour & Najafi, 2025; Mugume & Nakyanzi, 2024).

Barrier Type	Recommendations
Institutional, Governance, and Funding	• Align urban planning policies across sectors and modify local laws to allow more flexibility in adopting BGI • Strengthen coordination between different levels of government • Create consistent budget planning covering both setup and upkeep • Encourage long-term investment models, including collaboration between public and private sectors
Technical Knowledge and Experience	• Apply digital tools for mapping, simulation, and infrastructure planning and adopt freely available simulation and modeling platforms • Offer specialized training for practitioners • Focus on collecting and analyzing data over time for better decision-making • Set up systems for accessible and shared environmental data
Socio-cultural barriers	• Increase public understanding and acceptance of BGI through outreach campaigns • Ensure fair access to BGI benefits for marginalized populations and underserved areas • Involve local communities in decision-making and maintenance of BGI projects

(Yuanita & Sagala, 2025). In Ningbo, China, the national government sets the direction through standards and funding, while local authorities play a crucial role in on-the-ground coordination and delivery (O'Donnell et al., 2021). Meanwhile, cities like Rotterdam, Portland, and Newcastle emphasize locally driven strategies, where municipal leadership and strong multi-agency partnerships are central to advancing BGI, reflecting a more decentralized and collaborative approach to urban sustainability (O'Donnell et al., 2021). Thus, governance ensures that proper policies, funding, and institutional coordination are in place to support BGI implementation and upkeep. However, even with strong governance structures, BGI cannot thrive without the support and participation of the local community. Many BGI initiatives face resistance or indifference from the public due to limited awareness and understanding of the benefits such systems offer (Deely et al., 2020). The lack of awareness hinders the willingness of the people to adopt or maintain BGI, especially in densely populated urban areas. Stakeholders such as landowners, developers, investors, and financial institutions also play a critical role and must be engaged early in the planning process to ensure alignment of goals (Sadegh Koohestani et al., 2025). Public attitudes, including misconceptions or concerns about costs and land use, often pose additional barriers to widespread adoption. Therefore, effective BGI implementation must be accompanied by educational campaigns, participatory planning, and community-based maintenance strategies that build trust and shared responsibility.

3.5.4. Improvement measures

The barriers mentioned in the previous section require appropriate actions to ensure the successful implementation of BGI technologies within a BGN in urban areas, especially in Korean cities.

4. Conclusions and Future Perspectives

The impacts of climate change, including intensified Urban Heat Island (UHI) effects and increased urban flooding, are increasingly evident in urban environments, particularly in cities like Seoul. As a result, BGI presents a promising solution for mitigating such challenges while also enhancing water quality in urban areas. The paper provides a framework for the implementation of BGI within a BGN, which serves as a valuable guide for urban planners, policymakers, and researchers aiming to integrate BGI technologies into cities.

The proposed BGI establishment framework outlines a step-by-step process, beginning with the identification of the primary environmental issue the BGI aims to address. From there, it proceeds to evaluate site-specific characteristics and select appropriate BGI types based on the identified problem. Detailed designs and models are then developed, followed by simulation and evaluation to assess the potential impacts of the BGI. If the results demonstrate the effectiveness of technology, the next step is to seek approval from relevant authorities, allowing for construction to commence. If the simulation results indicate the BGI system may not meet the desired outcomes, the design will be retrofitted to improve its performance. Following construction, monitoring, maintenance, and continuous improvement are critical to ensuring the long-term functionality and sustainability of the BGI system. The paper also reviews existing domestic and international BGI applications, identifying the key barriers to implementation, which include institutional, governance, and funding challenges, technical knowledge and experience gaps, and socio-cultural obstacles. Furthermore, the paper proposes specific improvement measures that could be applied to Korean cities to overcome the barriers and enhance the adoption of BGI technologies. Such measures are designed to foster a more effective integration of BGI into urban planning, ultimately contributing to the resilience of cities against climate change impacts and improving urban livability.

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References

Ahmed, S., Meenar, M., & Alam, A. (2019). Designing a Blue-Green Infrastructure (BGI) network: Toward water-sensitive urban growth planning in Dhaka, Bangladesh. Land, 8(9), 138. https://doi.org/10.3390/land8090138

Alves, A., van Opstal, C., Keijzer, N., Sutton, N., & Chen, W. S. (2024). Planning the multifunctionality of nature-based solutions in urban spaces. Cities, 146, 104751. https://doi.org/10.1016/j.cities.2023.104751

Ambily, P., & Chithra, N. R. (2025). A novel framework for prioritization and spatial suitability assessment of Blue-Green infrastructure for urban pluvial flood resilience. Journal of Hydrology, 655, 132976. https://doi.org/10.1016/j.jhydrol.2025.132976

An, S., & Dedekorkut-Howes, A. (2025). The Heat Is on: How Well Are Densely Populated Korean Cities Adapting to Increased Temperatures and Urban Heat Island Effect?. Environments, 12(3), 87. https://doi.org/10.3390/environments12030087

Arthur, N., & Hack, J. (2022). A multiple scale, function, and type approach to determine and improve Green Infrastructure of urban watersheds. Urban Forestry & Urban Greening, 68, 127459. https://doi.org/10.1016/j.ufug.2022.127459

Baas, J., Schotten, M., Plume, A., Côté, G., & Karimi, R. (2020). Scopus as a curated, high-quality bibliometric data source for academic research in quantitative science studies. Quantitative science studies, 1(1), 377-386. https://doi.org/10.1162/qss_a_00019

Bakhshipour, A. E., Dittmer, U., Haghighi, A., & Nowak, W. (2019). Hybrid green-blue-gray decentralized urban drainage systems design, a simulation-optimization framework. Journal of environmental management, 249, 109364. https://doi.org/10.1016/j.jenvman.2019.109364

Balany, F., Muttil, N., Muthukumaran, S., Wong, M. S., & Ng, A. W. (2022). Studying the effect of blue-green infrastructure on microclimate and human thermal comfort in melbourne's central business district. Sustainability, 14(15), 9057. https://doi.org/10.3390/su14159057

Beier, M., Gerstendörfer, J., Mendzigall, K., Pavlik, D., Trute, P., & von Tils, R. (2022). Climate impact and model approaches of blue-green infrastructure measures for neighborhood planning. Sustainability, 14(11), 6861. https://doi.org/10.3390/su14116861

Budzik, G., Sylla, M., & Kowalczyk, T. (2025). Understanding Urban Cooling of Blue–Green Infrastructure: A Review of Spatial Data and Sustainable Planning Optimization Methods for Mitigating Urban Heat Islands. Sustainability, 17(1), 142. https://doi.org/10.3390/su17010142

Chadegani, A. A., Salehi, H., Yunus, M. M., Farhadi, H., Fooladi, M., Farhadi, M., & Ebrahim, N. A. (2013). A comparison between two main academic literature collections: Web of Science and Scopus databases. https://doi.org/10.5539/ass.v9n5p18

Copeland C. (2016) Green Infrastructure and Issues in Managing Urban Stormwater. Washington, DC, USA: Congressional Research Service.

Cruijsen, A. C. (2015). Design opportunities for flash flood reduction by improving the quality of the living environment: A Hoboken City case study of environmental driven urban water management. Web sayfası: https://repository.tudelft.nl/islandora/object/uuid%3Af433a5ce-8249-4976-a43f-a741b4ce2bf9)(Erişim tarihi: Eylül 2020).

Czyża, S., & Kowalczyk, A. M. (2024). Applying GIS in blue-green infrastructure design in urban areas for better life quality and climate resilience. Sustainability, 16(12), 5187. https://doi.org/10.3390/su16125187

de Macedo, L. S. V., Picavet, M. E. B., de Oliveira, J. A. P., & Shih, W. Y. (2021). Urban green and blue infrastructure: A critical analysis of research on developing countries. Journal of Cleaner Production, 313, 127898. https://doi.org/10.1016/j.jclepro.2021.127898

Deely J., Hynes S., Barquín J., Burgess D., Finney G., Silió A., Álvarez-Martínez J. M., Bailly D. & Ballé-Béganton J. (2020) Barrier identification framework for the implementation of blue and green infrastructures, Land Use Policy, 99, 105108. https://doi.org/10.1016/j.landusepol.2020.105108.

EPA U. (2004). Report to congress on impacts and control of combined sewer overflows and sanitary sewer overflows.

European Commission. (2018). Creating blue-green networks. Green Best Practice Community. https://greenbestpractice.jrc.ec.europa.eu/node/399

Fereshtehpour, M., & Najafi, M. R. (2025). Urban stormwater resilience: Global insights and strategies for climate adaptation. Urban Climate, 59, 102290. https://doi.org/10.1016/j.uclim.2025.102290

Framework Act on Low Carbon, Green Growth, Act No. 9931, Statutes of the Republic of Korea (2010).

Ghofrani, Z., Sposito, V., & Faggian, R. (2016). Designing resilient regions by applying blue-green infrastructure concepts. WIT Transactions on Ecology and the Environment, 204, 493-505. https://doi.org/10.2495/SC160421

Ghofrani, Z., Sposito, V., & Faggian, R. (2017). A comprehensive review of Blue-Green Infrastructure concepts. International Journal of Environment and Sustainability, 6(1), 15–36. https://doi.org/10.24102/ijes.v6i1.728

Gupta, A., & Shukla, A. K. (2024). Optimal approaches in global warming mitigation and adaptation strategies at city scale. Discover Sustainability, 5(1), 272.

Haddad, H., Bryden, J., & Connop, S. (2025). Practitioner Perceptions of Mainstreaming Sustainable Drainage Systems (SuDS): A Mixed Methods Study Exploring Direct Versus Indirect Barriers. Sustainability, 17(5), 2093. https://doi.org/10.3390/su17052093

Hansen, R., Olafsson, A. S., Van Der Jagt, A. P., Rall, E., & Pauleit, S. (2019). Planning multifunctional green infrastructure for compact cities: What is the state of practice?. Ecological indicators, 96, 99-110. https://doi.org/10.1016/j.ecolind.2017.09.042

Hörnschemeyer, B., Henrichs, M., Dittmer, U., & Uhl, M. (2023). Parameterization for modeling blue–green infrastructures in urban settings using SWMM-UrbanEVA. Water, 15(15), 2840. https://doi.org/10.3390/w15152840

Hyorin, K. (2021). Gangdong-gu makes 'Eco-friendly rain village.' with inhabitants. Gangdong District Office. Retrieved April 20, 2025, from https://www.gangdong.go.kr/web/eng/bbs/board/5201?cp=67&pageSize=16&sortOrder=BA_REGDATE&sortDirection=DESC&bcId=board&baNotice=false&baCommSelec=false&baOpenDay=false&baUse=true

IPCC. (2022). Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. In IPCC. https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

Kaur, R., & Gupta, K. (2022). Blue–Green Infrastructure (BGI) network in urban areas for sustainable storm water management: a geospatial approach. City Environ Interact 16: 100087. https://doi.org/10.1016/j.cacint.2022.100087

Lee, C. S., Lee, H., Kim, A. R., Pi, J. H., Bae, Y. J., Choi, J. K., ... & Moon, J. S. (2020). Ecological effects of daylighting and plant reintroduction to the Cheonggye Stream in Seoul, Korea. Ecological Engineering, 152, 105879. https://doi.org/10.1016/j.ecoleng.2020.105879

Li, H., Ding, L., Ren, M., Li, C., & Wang, H. (2017). Sponge city construction in China: A survey of the challenges and opportunities. Water, 9(9), 594. https://doi.org/10.3390/w9090594

Li, W., Fu, X., Gao, T., & Wang, X. (2025). Assessing the performance of centralized blue-green infrastructure in dynamic stormwater storage and runoff assignment. Urban Forestry & Urban Greening, 104, 128631. https://doi.org/10.1016/j.ufug.2024.128631

Liao K-H (2019) The socio-ecological practice of building blue-green infrastructure in high-density cities: what does the ABC Waters Program in Singapore tell us? Socio-Ecological Pract Res 1(1):67–81. https://doi.org/10.1007/s42532-019-00009-3

Mayr, M., Alonso, C., & Rouse, C. (2017). Blue-green network planning as a spatial development and climate-resilient strategy - the case of Belmopan, Belize. In *Caribbean Urban Forum 2017, 15th-19th May 2017, Belize City, Belize*. https://unhabitat.org/sites/default/files/download-manager-files/Final%20Paper%20Belmopan.pdf

Mell, I., & Scott, A. (2023). Definitions and context of blue-green infrastructure. In ICE Manual of Blue-Green Infrastructure (pp. 3-22). ICE Publishing.

Montoya-Coronado, V. A., Tedoldi, D., Castebrunet, H., Molle, P., & Kouyi, G. L. (2024). Data-driven methodological approach for modeling rainfall-induced infiltration effects on combined sewer overflow in urban catchments. Journal of Hydrology, 632, 130834. https://doi.org/10.1016/j.jhydrol.2024.130834

Naumann, S., Davis, M., Kaphengst, T., Pieterse, M., & Rayment, M. (2011). Design, implementation and cost elements of Green Infrastructure projects. Final report, European Commission, Brussels, 138. https://doi.org/10.1016/j.jenvman.2019.109364

O'Donnell, E. C., Netusil, N. R., Chan, F. K., Dolman, N. J., & Gosling, S. N. (2021). International perceptions of urban blue-green infrastructure: A comparison across four cities. Water, 13(4), 544. https://doi.org/10.3390/w13040544

Orak, N. H., & Smail, L. (2025). A Bayesian Network model to integrate blue-green and gray infrastructure systems for different urban conditions. Journal of Environmental Management, 375, 124293. https://doi.org/10.1016/j.jenvman.2025.124293

Sadegh Koohestani, S., Mukheibir, P., Wakefield-Rann, R., & Santamouris, M. (2025). Adopting a socio-technical perspective on the challenges and barriers in transitioning to Blue-Green Infrastructure (BGI). Blue-Green Systems, 7(1), 79-94. https://doi.org/10.2166/bgs.2025.011

Shreevastava, A., Bhalachandran, S., McGrath, G. S., Huber, M., & Rao, P. S. C. (2019). Paradoxical impact of sprawling intra-Urban Heat Islets: Reducing mean surface temperatures while enhancing local extremes. Scientific reports, 9(1), 19681. https://doi.org/10.1038/s41598-019-56091-w

Smart City Korea. (2022, April 12). 수원시 스마트시티 혁신기술 발굴사업 대상지 선정. Smart City Korea. Retrieved April 20, 2025, from https://smartcity.go.kr/en/2022/04/12/수원시-스마트시티-혁신기술-발굴사업-대상지-선정/

Smart City Korea. (2024, May 30). Busan Eco Delta Smart City. Smart City Korea. https://smartcity.go.kr/en/프로젝트/국가시범도시/부산-에코델타-스마트시티/

Sörensen, J., Persson, A. S., & Olsson, J. A. (2021). A data management framework for strategic urban planning using blue-green infrastructure. Journal of Environmental Management, 299, 113658. https://doi.org/10.1016/j.jenvman.2021.113658

Toxopeus, H., & Polzin, F. (2021). Reviewing financing barriers and strategies for urban nature-based solutions. Journal of Environmental Management, 289, 112371. https://doi.org/10.1016/j.jenvman.2021.112371

United Nations Environment Programme. (2024). Cities and climate change. United Nations Environment Programme. Retrieved April 20, 2025, from https://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities-and-climate-change

Voskamp, I. M., & Van de Ven, F. H. (2015). Planning support system for climate adaptation: Composing effective sets of blue-green measures to reduce urban vulnerability to extreme weather events. Building and Environment, 83, 159-167. https://doi.org/10.1016/j.buildenv.2014.07.018

Wagner, I., Krauze, K., & Zalewski, M. (2013). Blue aspects of green infrastructure. *Sustainable Development Applications*, *4*, 145-155. https://www.researchgate.net/profile/Kinga-Krauze/publication/261638072_Blue_aspects_of_green_infrastructure/links/00463534e6c87333d2000000/Blue-aspects-of-green-infrastructure.pdf

Wang, Q., & Waltman, L. (2016). Large-scale analysis of the accuracy of the journal classification systems of Web of Science and Scopus. Journal of informetrics, 10(2), 347-364. http://dx.doi.org/10.1016/j.joi.2016.02.003

Wartalska, K., Szymczewski, S., Domalewska, W., Wdowikowski, M., Przestrzelska, K., Kotowski, A., & Kaźmierczak, B. (2025). The Impact of Climate Change on the Functioning of Drainage Systems in Industrial Areas—A Case Study. Atmosphere, 16(3), 347. https://doi.org/10.3390/atmos16030347

World Meteorological Organization. (2025, January 10). WMO confirms 2024 as warmest year on record, about 1.5° C above pre-industrial level. https://wmo.int/news/media-centre/wmo-confirms-2024-warmest-year-record-about-155degc-above-pre-industrial-level

Wu, J., Xu, J., Lu, M., & Ming, H. (2025). An integrated modelling framework for optimization of the placement of grey-green-blue infrastructure to mitigate and adapt flood risk: An application to the Upper Ting River Watershed, China. Journal of Hydrology: Regional Studies, 57, 102156. https://doi.org/10.1016/j.ejrh.2024.102156

Yuanita, C. N., & Sagala, S. (2025). Blue-green infrastructure in Jakarta's fringe: an analysis of accessibility to blue-green spaces as a flood solution in Bekasi City. International Journal of Disaster Risk Reduction, 105425. https://doi.org/10.1016/j.ijdrr.2025.105425

Zaręba, A., Krzemińska, A., Adynkiewicz-Piragas, M., Widawski, K., van der Horst, D., Grijalva, F., & Monreal, R. (2022). Water Oriented City—a '5 scales' system of blue and green infrastructure in sponge cities supporting the retention of the urban fabric. Water, 14(24), 4070. https://doi.org/10.3390/w14244070

Zhou, M., He, Y., & Qiu, Z. (2025). Construction of a multi-level Blue-Green Infrastructure network in a riverside city: A case study of Shaoxing. Ecosystem Health and Sustainability, 11, Article 0287. https://doi.org/10.34133/ehs.0287

Zhu, L., Gao, C., Wu, M., & Zhu, R. (2014). Integrating Blue-Green Infrastructure with Gray Infrastructure for Climate-Resilient Surface Water Flood Management in the Plain River Networks. Land 2025, 14, 634. J. Environ. Manag. https://doi.org/10.3390/land14030634

Zou, Y., Chen, J., & Zong, H. (2024). Is shading a better way to cool down? Evaluation and comparison of the cooling capacity of blue-green spaces and urban shade. Ecological Indicators, 167, 112688. https://doi.org/10.1016/j.ecolind.2024.112688