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Green Infrastructure as a Strategy for Enhancing Urban Climate Resilience: A Literature Review

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Abstract: Cities face an increasing range of compound climate risks, including more frequent heat waves, flash flooding, biodiversity collapse and declining environmental quality. Green infrastructure (GI) the planned networks of natural and semi-natural features embedded in urban fabrics, has emerged as a central paradigm for addressing these challenges while delivering multiple co-benefits. This literature review synthesises empirical and conceptual scholarship primarily published between 2015 and 2024 to evaluate the evidence base for GI as a climate resilience strategy in three key areas of urban climate resilience: urban heat island (UHI) mitigation, stormwater and flood management, and urban biodiversity and ecosystem services. Using studies from cities across Europe, North America, Asia-Pacific and the Global South, the review finds strong evidence that well-designed GI interventions can reduce urban air temperatures by 0.3-3 °C, attenuate stormwater runof f by 40-85% and substantially increase urban biodiversity and human well-being. However, the review also highlights persistent gaps in the literature such as geographical bias toward the Global North, limited long-term monitoring data, limited attention to the dimensions of equity and under-representation of integrated GI network assessments. The paper concludes with a research agenda for the future which stresses the necessity for the integration of GI into more comprehensive, governance-led urban climate adaptation frameworks.

Keywords: Green infrastructure, urban climate resilience, urban heat island, stormwater management, urban biodiversity, nature-based solutions, ecosystem services.

Introduction - Urbanization and climate change are accelerating, increasing environmental risks in cities such as extreme heat, flooding and ecological degradation. Cities are facing increasing challenges from rising temperatures, changing precipitation patterns and growing exposure to climate hazards, with more than half of the world's population living in urban areas and with urban growth expected to continue (United Nations, 2018; Elmqvist et al., 2019). Climate resilience is now front and centre of urban planning and governance due to these pressures.

Green infrastructure (GI) has become a major approach for addressing these issues by incorporating ecological processes into urban systems. Unlike traditional grey infrastructure designed for single hazards, GI is a network of natural and semi-natural elements, such as parks, urban forests, street trees, wetlands, bioswales and green roofs that offers multiple environmental and social benefits (Benedict & McMahon, 2006; Pauleit et al., 2017). GI is increasingly viewed not only as an amenity but also as a type of functional infrastructure that can offer measurable climate adaptation benefits.

The idea of GI has moved from landscape ecology and biodiversity conservation to a wider concept addressing ecosystem services and nature-based solutions (Cohen-Shacham et al., 2016). Consequently, GI is now recognised as a major component of urban climate resilience, providing multiple benefits of temperature regulation, flood mitigation, biodiversity conservation and human well-being at the same time.

Although there has been a significant increase in research on GI, the evidence remains patchy in thematic domains and geographically skewed towards cities in the Global North. Many studies focus on cooling, flood management or biodiversity separately, limiting understanding of their combined contribution to urban resilience. Furthermore, it is not clear whether the findings are transferable to rapidly urbanising regions in Asia, Africa and Latin America (Nagendra et al., 2018).

This review therefore provides a synthesis of recent literature published mainly in the period 2015–2024 towards assessing the role of green infrastructure in improving urban climate resilience. The review has three major focuses: urban heat island mitigation, stormwater and flood management, and biodiversity and ecosystem services. It also identifies important research gaps and identifies priorities for future research.

Conceptual Foundations: Green Infrastructure and Urban Climate Resilience: Green infrastructure (GI) is a network of natural and semi-natural elements that provide environmental, social and economic benefits in urban areas. These include parks, urban forests, wetlands, green roofs, bioswales, and ecological corridors that function in concert rather than as isolated green spaces (Benedict & McMahon, 2006; Ahern, 2013). From an infrastructure perspective, these features are planned and managed to deliver particular ecosystem functions and climate-related services.

Closely related concepts such as nature-based solutions (NbS) and ecosystem-based adaptation have broadened GI research. Within this framework, GI is often seen as an operational version of NbS that includes ecological processes in urban planning to face climate challenges and produce multiple co-benefits (Cohen-Shacham et al., 2016; Lafortezza et al., 2018).

Urban climate resilience is the analytical framework to understand the role of GI in adaptation. Resilience is the capacity of urban systems to absorb, adapt to and recover from climate shocks and stresses while still providing critical functions (Meerow et al., 2016). Ecological networks are an important element of resilience as cities function as socio-ecological systems and contribute to reducing vulnerability to heat, flooding and environmental degradation.

The ecosystem services framework further explains the benefits created by GI. Urban green infrastructure provides regulating services, such as temperature moderation, stormwater retention and air purification, as well as cultural and supporting services, such as recreation, biodiversity and human well-being (Elmqvist et al., 2015). Its main advantage is its multifunctionality, that is, one intervention can provide multiple environmental and social benefits simultaneously, often delivering more overall value than single-purpose grey infrastructure (Kabisch et al., 2016).

Table 1

GI Type	Primary Functions
Urban parks and green spaces	Cooling, recreation, biodiversity
Street trees and urban forests	Shading, air quality improve -ment, runoff interception
Green roofs and walls	Cooling, insulation, stormwater retention
Bioswales and rain gardens	Flood mitigation and water filtration
Permeable pavements	Runoff reduction and groundwater recharge
Urban wetlands and green corridors	Flood control, biodiversity, blue-cooling
Community gardens	Food security and social well-being

Green Infrastructure and Urban Heat Island Mitigation: One of the most widespread consequences of Urbanization and climate change is the urban heat island (UHI) effect, which causes cities to have higher temperatures than the surrounding rural areas due to the presence of impervious surfaces and anthropogenic heat emissions (Santamouris, 2020). Higher temperatures increase heat stress, energy demand and health risks, especially for vulnerable populations.

Green infrastructure mitigates UHI through evapotranspiration, shading and modifying surface energy balances. Urban vegetation evapotranspires sensible heat to latent heat and tree canopies reduce solar radiation reaching built surfaces. Green roofs and walls further add to thermal regulation by offering insulation and evaporative cooling (Zölch et al., 2016).

There is a considerable body of evidence to show the cooling potential of GI in a wide range of urban settings. Bowler et al. (2010) found that urban parks are, on average, almost 1°C cooler than their surrounding built-up areas. Likewise, Zölch et al. (2016) found that urban trees can reduce peak temperatures by up to 2.5°C, whereas increasing tree canopy cover substantially reduces surface temperatures. Global evidence synthesised by Santamouris (2020) shows that GI interventions decrease ambient air temperatures by about 0.3–3°C, with cooling effects depending on vegetation type, spatial configuration and climatic conditions. Large parks and urban forests are generally more effective in providing cooling, with studies from rapidly urbanising Chinese cities reporting reductions in UHI intensity of up to 3.5°C (Kong et al., 2022).

However, the efficiency of GI depends on urban morphology, vegetation types and local weather conditions. Urban centers that are densely populated and have limited space for vegetation may need to employ innovative ways such as green roofs and vertical greening systems to improve cooling performance (Meerow& Newell, 2017). Therefore, the effectiveness of GI-based heat mitigation depends on context-sensitive planning and integration within broader urban climate adaptation strategies.

Table 2. Selected Evidence on Green Infrastructure and Urban Heat Island Mitigation

Study	Main Findings
Bowler et al. (2010)	Urban parks are approximately 0.94°C cooler than surrounding areas
Zölch et al. (2016)	Urban trees reduce peak temperatures by up to 2.5°C
Santamouris (2020)	GI lowers air temperatures by 0.3–3°C
Kong et al. (2022)	Large parks reduce UHI intensity by 1.8–3.5°C
Meerow and Newell (2017)	Cooling performance varies with urban form and climate

Green Infrastructure for Stormwater and Flood Management: The rapid pace of Urbanization and climate change is making urban flooding an increasingly serious problem. Traditional grey infrastructure often has difficulties in dealing with the increasing intensity of rainfall and the increase in impervious surfaces. Green infrastructure

controls stormwater through interception, infiltration, retention and evapotranspiration, which reduces runoff volumes and delays peak flows (Berland et al., 2017; Shafique et al., 2018). The most common GI elements for stormwater management are green roofs, bioswales, rain gardens and urban wetlands. Green roofs have shown retention rates from 40% to 90% based on the vegetation and substrate characteristics (Shafique et al., 2018). Rain gardens and bioswales are good at capturing and filtering runoff at the neighbourhood scale, while integrated blue-green networks provide wider catchment-scale benefits. Evidence from international case studies shows that GIs are effective in reducing the risk of floods. Nature-based interventions can reduce flood peaks by 20–80% (Keesstra et al., 2018). In China, Sponge City projects led to runoff reductions of 57–85% in pilot areas (Qin et al., 2019) and Singapore's ABC Waters Programme reduced peak storm discharge by 18–35% and enhanced urban water quality (Lim et al., 2020). Urban trees also help with stormwater management, as mature canopies intercept a significant portion of the annual runoff (Berland et al., 2017). Hybrid approaches combining green and grey infrastructure are increasingly seen as the most pragmatic ways of improving the resilience of cities to flooding. Such approaches improve performance and longevity of existing drainage systems while providing ecological and social co-benefits at the same time. GI is therefore increasingly recognised as an important element of sustainable urban water management and climate adaptation.

Table 3. Selected Evidence on Green Infrastructure and Stormwater Management

Study	Main Findings
Shafique et al. (2018)	Green roofs retain 40–90% of rainfall
Berland et al. (2017)	Urban trees reduce annual runoff
Keesstra et al. (2018)	Nature-based solutions reduce flood peaks by 20–80%
Qin et al. (2019)	Sponge City projects achieve runoff reductions of 57–85%
Lim et al. (2020)	Blue-green corridors reduce peak discharge by 18–35%

Urban Biodiversity and Ecosystem Services: Urbanization is a key driver of biodiversity loss through habitat fragmentation and ecological degradation. However, well-planned green infrastructure can improve habitat quality and increase species diversity in urban areas. Biodiversity outcomes are strongly affected by factors such as patch size, connectivity and vegetation composition, with interconnected green networks generally providing greater ecological benefits than isolated green spaces (Beninde et al., 2015).

Native vegetation and structurally diverse habitats support increased numbers of birds, insects and other species. Urban forests and green corridors can provide important refugia for biodiversity, and green roofs and other vegetated spaces can provide additional habitat in highly built environments (Aronson et al., 2017).

Beyond biodiversity conservation, GI provides a broad range of ecosystem services that underpin urban sustainability and human well-being. They include temperature regulation, air quality improvement, carbon sequestration, recreation and mental health benefits (Elmqvist et al., 2015). Research has shown that regular exposure to urban green spaces is associated with better mental health and reduced stress levels, and that environments with high biodiversity provide greater well-being benefits than species-poor landscapes (Shanahan et al., 2015; Dallimer et al., 2012).

Urban vegetation also plays a role in climate mitigation through carbon storage and sequestration. Urban trees and green spaces, although less important than natural forests in total, are important components of municipal climate strategies and ecosystem service provision (Nowak et al., 2018).

Table 4. Selected Evidence on Biodiversity and Ecosystem Services

Study	Main Findings
Aronson et al. (2017)	Urbanization reduces species richness
Beninde et al. (2015)	Patch size and connectivity determine biodiversity
Elmqvist et al. (2015)	GI provides multiple ecosystem services
Shanahan et al. (2015)	Nature exposure improves mental health
Dallimer et al. (2012)	Biodiversity positively influences well-being
Nowak et al. (2018)	Urban forests contribute to carbon sequestration

Cross-Cutting Themes: Governance, Equity, and Economic Valuation: Good governance is key to the effective implementation of green infrastructure. Mainstreaming GI into urban planning needs cross-sector coordination, supportive policies and long-term institutional commitment (Pauleit et al., 2017; Kabisch et al., 2016). Lessons learned from cities such as Singapore and New York show that integrated governance frameworks and policy support can enable large-scale GI deployment.

Equity has emerged as a key issue in the GI literature. Research suggests that inequalities in the distribution of high-quality green space are common, with disadvantaged communities receiving less environmental benefit (Jennings et al., 2016). Furthermore, some greening initiatives may result in rising property values and displacement, signifying problems related to green gentrification (Gould & Lewis, 2017). Thus, equitable distribution of the gains of climate resilience calls for prudent planning and community involvement.

In recent years the economic justification for GI has gained significant importance. Along with the environmental benefits, GI also reduces energy use, improves air quality, improves public health and increases property values. Given these co-benefits, green infrastructure often provides higher

value than traditional grey infrastructure (Brander &Koetse, 2011; Nowak et al., 2018). Further development of standardised valuation approaches is, however, needed to support evidence-based decision making.

Table 5. Key Themes in Green Infrastructure Implementation

Theme	Main Issues
Governance	Institutional coordination and policy integration
Equity	Unequal access to green space and environmental justice
Green gentrification	Potential displacement associated with urban greening
Economic valuation	Multiple co-benefits strengthen investment rationale
Planning	Need for integrated and long-term strategies

Research Gaps and Future Directions: There is growing evidence for the role of green infrastructure in climate adaptation, but there remain several important gaps. Research on GI is mainly European, North American and Australian, constraining understanding of GI performance in fast-urbanising regions of the Global South where climate vulnerability is often greatest (Nagendra et al., 2018).

Another limitation is the number of short-term studies. Long-term monitoring is required to assess the effects of vegetation growth, maintenance and changing climatic conditions on green infrastructure performance over time (Pauleit et al., 2017). There is a need for more emphasis on climate specific design strategies especially for tropical, arid and semi-arid environments.

The majority of studies have focused on single GI elements rather than on interconnected networks. Therefore, the overall impacts of integrated green infrastructure systems are still poorly understood (Meerow& Newell, 2017). In addition, social equity, governance, and benefit distribution issues need to be further studied so that climate adaptation can be effective and socially just (Jennings et al., 2016; Gould & Lewis, 2017).

Future research should focus on long-term assessments, network-wide analyses and context-specific studies that support the integration of GI into urban climate resilience planning.

Table 6. Major Research Gaps and Future Needs

Gap Area	Future Research Priorities
Geographic bias	More studies in the Global South
Long-term performance	Monitoring over extended periods
Climate specificity	Design guidelines for diverse climates
Integrated networks	City-scale analyses and cumulative effects
Equity and justice	Distributional impacts and community participation
Governance	Comparative institutional frameworks
Economic valuation	Improved assessment of ecosystem service benefits

Conclusion: One strategy identified is improving urban climate resilience through green infrastructure. Evidence suggests that GI plays a leading role in mitigating urban heat islands, stormwater management, biodiversity conservation and ecosystem services. Unlike traditional grey infrastructure, its multifunctionality enables the simultaneous provision of environmental, social and economic benefits.

The success of GI, however, is dependent upon appropriate design, governance and long-term management. To maximise climate resilience outcomes, institutional coordination, equitable benefit distribution and integration into wider urban planning frameworks are essential.

There remain significant gaps in knowledge to address, especially around long-term performance, effects at a network scale and use in the Global South, but the extant evidence strongly supports the role of green infrastructure in climate adaptation policies. As climate risks are increasing, the growth and efficient management of urban green infrastructure will be more and more important to promote sustainable and resilient cities.

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