Technology and Society Perspectives (TACIT) Vol. 4, No. 3, November 2026-February 2027, pages 805–819

Green Infrastructure and Urban Climate Resilience: A Narrative Review of Ecological Performance, Planning, and Governance

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ARTICLE INFO

Article history:
Received: 12 September 2026
Revised: 20 October 2026
Accepted: 02 November 2026

DOI:
10.61100/tacit.v4i3.418

Keywords:
Green Infrastructure, Urban Climate Resilience, Climate Change Adaptation, Nature-based Solutions, Spatial Planning, Urban Governance

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ABSTRACT

Green infrastructure is increasingly recognized as an important strategy for strengthening urban resilience to climate change. However, its effectiveness depends on ecological performance and the conditions supporting implementation. This study employs a narrative literature review to examine the contribution of green infrastructure to urban climate resilience, drawing on 20 identified scientific publications from 2020 to 2025. The review focuses on urban heat mitigation, stormwater management, flood risk reduction, ecosystem services, spatial planning, and governance. The synthesis indicates that green infrastructure can reduce environmental pressures through cooling, infiltration, and ecological regulation. Nevertheless, these benefits vary according to intervention design, location, maintenance, and institutional capacity. The study develops an integrative conceptual framework connecting green infrastructure characteristics, ecological performance, and urban resilience, with planning, governance, and environmental equity as enabling conditions. The findings emphasize that effective climate adaptation requires integrated, context-sensitive, and equitable green infrastructure strategies supported by long-term institutional commitment.

ABSTRAK

Infrastruktur hijau semakin mendapat perhatian sebagai strategi untuk memperkuat ketahanan kota terhadap perubahan iklim. Namun, keberhasilannya tidak hanya ditentukan oleh kemampuan ekologis, tetapi juga oleh kondisi yang mendukung penerapannya. Penelitian ini menggunakan pendekatan tinjauan literatur naratif dengan mengkaji 20 publikasi ilmiah yang diidentifikasi pada periode 2020–2025. Pembahasan difokuskan pada pengurangan panas perkotaan, pengelolaan limpasan air hujan, pengendalian risiko banjir, jasa ekosistem, perencanaan ruang, dan tata kelola. Hasil sintesis menunjukkan bahwa infrastruktur hijau berpotensi mengurangi tekanan lingkungan melalui pendinginan alami, peningkatan infiltrasi, dan pengaturan fungsi ekologis. Namun, manfaat tersebut berbeda menurut desain, lokasi, pemeliharaan, dan kapasitas kelembagaan. Penelitian ini mengembangkan kerangka konseptual yang menghubungkan karakteristik infrastruktur hijau, kinerja ekologis, dan ketahanan kota, dengan perencanaan, tata kelola, serta keadilan lingkungan sebagai faktor pendukung. Temuan ini menegaskan bahwa adaptasi iklim memerlukan pengembangan infrastruktur hijau yang terintegrasi, sesuai kondisi lokal, berkeadilan, dan didukung komitmen kelembagaan secara berkelanjutan.

1. INTRODUCTION

Climate change is increasingly shaping how cities function and how people experience everyday urban life. Rising temperatures, intense rainfall, prolonged dry periods, and recurring floods are no longer concerns limited to environmental planning. They also affect public health, economic activity, transportation, housing, and the reliability of essential services. These pressures are particularly difficult to manage in rapidly growing cities, where urban expansion often replaces vegetation and permeable land with buildings, roads, and other impervious surfaces. According to the Intergovernmental Panel on Climate Change (IPCC, 2022), more than half of the world's population already lives in urban areas, and the proportion is expected to exceed two-thirds by 2050. The report also indicates that urban expansion and the loss of green spaces can intensify

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local warming, with urban heat island effects adding up to 2°C to local temperatures. These conditions suggest that urban resilience depends not only on a city's ability to recover from climate-related disasters but also on how its physical environment is planned and managed before such events occur.

The relationship between urban development and climate vulnerability is particularly evident in cities experiencing rapid land-use change. As residential areas, commercial facilities, and transportation networks expand, natural surfaces that once absorbed rainwater and moderated temperature are frequently reduced. This creates two interconnected problems. During heavy rainfall, limited infiltration increases surface runoff and places additional pressure on drainage systems. During hot periods, dense buildings and paved surfaces retain heat, making outdoor environments increasingly uncomfortable and potentially dangerous for vulnerable residents. Wang et al. (2024) discuss urban resilience in the context of climate change, emphasizing the need to understand the relationship between environmental pressures and urban systems. These concerns are especially relevant to developing countries, where infrastructure development, population growth, and limited municipal resources may occur simultaneously. For cities in Indonesia and other rapidly urbanizing regions, the challenge is therefore not simply to provide more infrastructure, but to reconsider what kinds of infrastructure can support urban development without further increasing environmental vulnerability.

One approach receiving growing attention is green infrastructure, which refers to interconnected natural and semi-natural spaces designed or managed to provide ecological and social benefits. In urban settings, green infrastructure may include urban forests, public parks, green corridors, vegetated drainage systems, rain gardens, wetlands, green roofs, and other landscape features that support ecosystem functions. Unlike conventional infrastructure, which generally addresses a particular service through engineered structures, green infrastructure can provide several benefits within the same urban space. A vegetated area, for example, may offer shade, support rainwater infiltration, improve habitat connectivity, and provide recreational opportunities for residents. Salih & Báthoryné Nagy (2024) examine the contribution of urban green infrastructure to climate resilience, particularly through its influence on urban microclimates and building-scale thermal conditions. Their work reinforces the importance of treating vegetation and ecological systems as functional components of urban infrastructure rather than merely as aesthetic additions to the built environment.

The potential contribution of green infrastructure becomes particularly important when cities face extreme heat. Conventional responses to high temperatures often rely heavily on mechanical cooling, yet these solutions do not necessarily address the environmental conditions responsible for heat accumulation in public spaces. Urban vegetation can influence local temperatures through shading and evapotranspiration, while the distribution and configuration of green spaces can affect the extent to which cooling benefits reach surrounding neighborhoods. Petzold & Mose (2023) discuss urban greening in relation to climate-related heat risks, highlighting the social and geographical dimensions of adaptation. Similarly, Sobhaninia et al. (2025) examine methods for identifying suitable locations for green infrastructure intended to reduce heat and stormwater risks. These studies suggest that the effectiveness of urban greening cannot be judged solely by the amount of vegetation added to a city. Its location, spatial arrangement, surrounding land use, and the needs of exposed populations are equally important. A large park located far from densely populated neighborhoods, for instance, may provide ecological benefits without adequately reducing heat exposure among residents who face the greatest risks.

Green infrastructure also offers opportunities to improve urban water management, particularly in areas affected by increasingly intense rainfall. Traditional drainage systems are designed to collect and transport stormwater, but their capacity can be overwhelmed when rainfall intensity exceeds design assumptions or when urban expansion increases the volume of runoff. Green infrastructure introduces complementary approaches by allowing water to infiltrate, be temporarily stored, or move more slowly through the urban landscape. Rain gardens, bioswales, permeable vegetated areas, and restored wetlands can therefore contribute to managing runoff before it reaches conventional drainage networks. Kim & Kim (2025) examine the development of research on green infrastructure for urban flooding, while Ferrario et al. (2024), through a meta-analysis, evaluate the benefits of nature-based solutions for addressing heatwaves and floods. Together, these studies support the relevance of ecological approaches to urban climate adaptation. Nevertheless, their findings should not be interpreted as evidence that green infrastructure can eliminate flood risks in every setting. Its performance depends on rainfall conditions, soil characteristics, design, maintenance, and integration with existing water management systems.

Beyond temperature regulation and stormwater management, green infrastructure contributes to a broader discussion about the relationship between urban ecosystems and human well-being. Green spaces may provide opportunities for physical activity, social interaction, biodiversity conservation, and improved environmental quality. These benefits are important because climate resilience involves more than protecting buildings and infrastructure from physical damage. It also concerns the ability of communities to maintain acceptable living conditions, access essential resources, and adapt to changing environmental pressures. Johnson et al. (2022), in their review of nature-based solutions for climate change adaptation, provide a broader perspective on how ecosystem-based interventions can contribute to adaptation strategies. However, the presence of multiple potential benefits also raises an important planning question: how can cities determine which green infrastructure interventions are most appropriate for their particular climate risks, environmental conditions, and social needs? Without clear priorities, green infrastructure projects may produce visible improvements in urban landscapes while making only limited contributions to the climate vulnerabilities they were intended to address.

This question becomes more complicated when differences between urban neighborhoods are considered. Climate risks are rarely distributed equally across a city. Low-income communities may live in densely built areas with limited vegetation, inadequate drainage, and restricted access to public green spaces. At the same time, neighborhoods with stronger economic and political influence may be better positioned to attract environmental improvements and public investment. Consequently, increasing the total area of urban greenery does not necessarily guarantee that its benefits will be shared fairly. Sobhaninia et al. (2025) emphasize the importance of green infrastructure siting, while Zarei & Shahab (2025) identify implementation challenges and context-specific conditions affecting nature-based solutions in urban green infrastructure. These perspectives indicate that spatial planning and institutional decision-making are central to climate adaptation. A city cannot be considered genuinely resilient if environmental improvements are concentrated in selected locations while communities facing the greatest climate risks remain underserved. Questions of accessibility, environmental justice, and community participation must therefore become part of the assessment of green infrastructure effectiveness.

Another challenge concerns the gap between planning green infrastructure and maintaining its performance over time. Urban greening initiatives are often visible during the construction or planting stage, but their long-term contribution depends on management arrangements that may receive less attention. Trees require suitable growing conditions and maintenance, vegetated drainage systems need regular inspection, and urban wetlands must be protected from pollution and inappropriate land conversion. Poorly maintained interventions may lose their ecological functions or fail to provide the expected benefits. Zarei & Shahab (2025), through a systematic review of 90 peer-reviewed articles, examine the factors supporting and constraining the implementation of nature-based solutions. Their findings highlight the importance of understanding implementation conditions rather than assuming that environmental interventions will succeed simply because they are nature-based. From an urban management perspective, this means that green infrastructure should be incorporated into long-term planning, budgeting, monitoring, and coordination across municipal agencies. Its effectiveness depends not only on ecological design but also on the institutional capacity required to sustain that design.

These issues are especially relevant when green infrastructure is examined through the concept of urban resilience. A resilient city is not merely one that experiences fewer environmental disturbances. It is also a city capable of anticipating risks, reducing exposure, adapting its systems, and maintaining essential functions when disruptions occur. Green infrastructure may contribute to these capacities by moderating local temperatures, managing runoff, supporting ecosystem services, and creating more adaptable urban environments. Yet the relationship between green infrastructure and resilience is neither automatic nor uniform. An intervention that performs well in one neighborhood may be less effective elsewhere because of differences in climate, land cover, urban density, soil conditions, or institutional arrangements. Ferrario et al. (2024) provide evidence of the adaptation benefits associated with nature-based solutions, whereas Sobhaninia et al. (2025) draw attention to the methods used to prioritize intervention locations. Read together, these studies indicate that evaluating green infrastructure requires consideration of both its environmental performance and the conditions under which its benefits can be realized.

Existing research has made substantial contributions to understanding individual dimensions of green infrastructure and climate adaptation. Salih & Báthoryné Nagy (2024) focus on heat mitigation and microclimatic performance, while Kim & Kim (2025) examine the development of knowledge concerning

green infrastructure and urban flooding. Ferrario et al. (2024) assess adaptation benefits across heatwave and flood-related interventions, and Sobhaninia et al. (2025) investigate methods for determining where green infrastructure should be located. Meanwhile, Zarei & Shahab (2025) address the institutional and practical challenges of implementing nature-based solutions. Although these studies offer valuable insights, they approach the subject from different analytical perspectives. Some emphasize ecological performance, others focus on spatial planning, and others examine implementation processes. This diversity creates an opportunity to bring these perspectives together and explain how green infrastructure contributes to urban resilience as a broader outcome of climate adaptation.

The research gap addressed in this study therefore concerns the need for a more integrated understanding of the relationship between green infrastructure functions, spatial planning, governance capacity, and urban climate resilience. This gap does not imply that these dimensions have never been examined together. Rather, it reflects the value of synthesizing existing evidence to clarify the conditions under which green infrastructure can contribute meaningfully to urban adaptation. A narrow assessment based only on vegetation coverage or temperature reduction may overlook issues of flood management, equitable access, maintenance, and institutional coordination. Conversely, discussions of governance may remain disconnected from the ecological mechanisms that make green infrastructure effective. Bringing these dimensions into a common analytical framework can provide a more balanced understanding of both the opportunities and limitations of green infrastructure in climate-resilient urban development.

Against this background, this study aims to examine the role of green infrastructure in enhancing urban resilience to climate change through a narrative literature review. Specifically, it explores how green infrastructure contributes to urban heat mitigation, stormwater and flood management, and the provision of ecosystem services, while also examining the spatial, social, and institutional factors influencing its effectiveness. The study further seeks to develop an integrative conceptual framework linking ecological functions, planning decisions, governance arrangements, and urban resilience outcomes. Its main contribution lies in moving beyond the question of whether green infrastructure provides environmental benefits toward a more critical examination of how, where, and under what conditions those benefits strengthen a city's capacity to cope with climate-related pressures. By doing so, the study is expected to offer a useful conceptual foundation for urban planners, policymakers, and researchers seeking to develop climate adaptation strategies that are environmentally effective, socially inclusive, and sustainable over time.

2. THEORETICAL FRAMEWORK AND HYPOTHESES

2.1. Green Infrastructure and Climate Change Adaptation

Green infrastructure has become an important part of urban climate adaptation as cities face increasing environmental pressures. Unlike conventional infrastructure, which generally relies on engineered structures, green infrastructure uses natural and semi-natural systems to support environmental functions. Urban forests, public parks, green roofs, rain gardens, wetlands, and green corridors are among the interventions commonly used to address climate-related challenges. These elements are not simply intended to improve the appearance of urban areas. They can also help regulate temperature, manage stormwater, and maintain ecological functions that are increasingly threatened by urban development. Salih & Báthoryné Nagy (2024) explain the contribution of urban green infrastructure to climate resilience, particularly through its role in mitigating heat at microclimatic and building scales.

Green infrastructure is closely associated with nature-based solutions (NBS), although the two concepts have different emphases. Green infrastructure generally refers to interconnected ecological spaces and assets, whereas nature-based solutions focus on using natural processes to address specific environmental and societal problems. Johnson et al. (2022) examine the contribution of nature-based solutions to climate change adaptation, demonstrating the relevance of ecosystem-based approaches in responding to environmental risks. This relationship is important because the effectiveness of green infrastructure should not be judged simply by how much green space a city provides. Its contribution also depends on whether the intervention addresses actual climate risks and supports the environmental needs of surrounding communities.

One of the main advantages of green infrastructure is its ability to provide multiple environmental benefits. Vegetation can reduce heat exposure through shading and evapotranspiration, while permeable landscapes can improve rainwater infiltration and reduce surface runoff. However, these benefits are not necessarily achieved at the same level in every location. Sobhaninia et al. (2025) show that research on green infrastructure planning for heat mitigation and stormwater management often follows different approaches.

Their findings suggest that urban adaptation requires more integrated planning, particularly when cities experience several climate-related risks simultaneously.

2.2. Urban Resilience and the Role of Green Infrastructure

Urban resilience refers to the capacity of cities to anticipate, withstand, adapt to, and recover from disturbances while maintaining essential functions. In the context of climate change, resilience involves more than protecting buildings and infrastructure from extreme weather. It also concerns the ability of urban environments, institutions, and communities to respond to changing environmental conditions. Wang et al. (2024) discuss urban resilience as a multidimensional concept involving interconnected urban systems. This perspective suggests that climate resilience cannot be achieved through physical infrastructure alone, because ecological conditions and institutional capacity also influence how cities respond to environmental pressures.

Green infrastructure contributes to urban resilience primarily through its ecological functions. Urban trees and green spaces can moderate local temperatures, while rain gardens, vegetated drainage systems, and wetlands can help regulate stormwater. Ferrario et al. (2024) examine the benefits of nature-based solutions in addressing heatwaves and floods, supporting their relevance as climate adaptation measures. Nevertheless, the presence of green infrastructure does not automatically make a city resilient. Its effectiveness depends on environmental conditions, intervention design, and the extent to which its benefits reach areas exposed to climate risks.

The relationship between green infrastructure and urban resilience also has a social dimension. Climate-related risks are not experienced equally across urban populations. Neighborhoods with limited vegetation, dense buildings, and inadequate drainage may face greater environmental pressures than areas with better infrastructure and access to green spaces. Petzold & Mose (2023) discuss the social and geographical dimensions of urban greening in relation to heat risks. Their perspective indicates that green infrastructure should be planned not only to improve environmental performance but also to reduce differences in climate vulnerability across urban communities. Therefore, the contribution of green infrastructure to urban resilience depends on both its ecological effectiveness and the distribution of its benefits.

2.3. Green Infrastructure Planning and Governance

The success of green infrastructure depends not only on its ecological characteristics but also on how it is planned, implemented, and maintained. Urban development creates competition for land, making it difficult to allocate sufficient space for ecological interventions. At the same time, climate risks vary across neighborhoods, requiring planners to determine which locations should receive priority. Sobhaninia et al. (2025) emphasize the importance of selecting green infrastructure locations based on heat exposure, stormwater risks, and relevant spatial conditions. Their findings indicate that increasing vegetation coverage without considering local vulnerabilities may limit the effectiveness of urban climate adaptation.

Governance is equally important because green infrastructure often involves several institutions with different responsibilities. Urban planning agencies, environmental departments, public works authorities, and local communities may all contribute to implementation and maintenance. Zarei & Shahab (2025) identify governance coordination, financing, technical capacity, stakeholder participation, and spatial justice as important conditions for implementing nature-based solutions. These factors demonstrate that green infrastructure should be treated as a long-term urban management responsibility rather than a one-time environmental development project.

Maintenance and equitable access are particularly relevant to the sustainability of green infrastructure. Trees, urban wetlands, and vegetated drainage systems require regular management to preserve their ecological functions. Meanwhile, the concentration of green infrastructure in selected neighborhoods may leave vulnerable communities without adequate protection against climate-related risks. Zarei & Shahab (2025) emphasize the importance of implementation conditions, while Petzold & Mose (2023) highlight the social dimensions of urban greening. Taken together, these perspectives suggest that green infrastructure is most likely to strengthen urban resilience when ecological design is supported by effective governance, appropriate spatial planning, and fair access to environmental benefits.

Based on this literature, the present study views green infrastructure as an urban adaptation strategy whose contribution to resilience depends on three interconnected elements: ecological performance, spatial planning, and governance capacity. Ecological performance determines the environmental benefits that

green infrastructure can provide, spatial planning influences where those benefits are delivered, and governance capacity affects whether the interventions remain effective over time. This perspective provides the conceptual foundation for examining the role of green infrastructure in strengthening urban resilience to climate change.

3. RESEARCH METHOD

3.1 Research Design

This study employs a narrative literature review to examine the role of green infrastructure in enhancing urban resilience to climate change. The review integrates findings from previous research to identify the ecological functions of green infrastructure, its contribution to climate adaptation, and the planning and governance conditions that influence its effectiveness. Rather than estimating a single statistical effect, the study develops an integrated understanding of the relationship between green infrastructure and urban climate resilience. The review is organized into four stages: literature identification, screening and selection, thematic categorization, and narrative synthesis.

3.2. Literature Search Strategy

The literature search is designed to cover scientific publications from 2020 to 2026, using Google Scholar, Crossref, and academic publisher platforms. The main search terms include "green infrastructure", "urban resilience", "climate change adaptation", "nature-based solutions", "urban heat", "stormwater management", and "urban flooding". These terms are combined using Boolean operators AND and OR to identify research addressing the ecological, spatial, and institutional dimensions of urban climate adaptation. A total of 20 primary articles is established as the target for narrative synthesis. Supporting conceptual and methodological references are treated separately from the primary review corpus.

3.3. Inclusion and Exclusion Criteria

Literature selection is based on publication relevance, scientific credibility, research context, and the availability of sufficient information for critical analysis. The criteria are presented in Table 1.

Table 1. Literature Inclusion and Exclusion Criteria

Aspect	Inclusion criteria	Exclusion criteria
Publication period	2020–2026	Outside the selected period
Literature sources	Verifiable scientific publications	Unverifiable sources
Publication type	Empirical, conceptual, and review articles	News, editorials, and nonacademic materials
Research focus	Green infrastructure, nature-based solutions, and climate resilience	Studies unrelated to urban climate adaptation
Environmental functions	Heat mitigation, stormwater management, flooding, and ecosystem services	Studies without relevant environmental outcomes
Research context	Urban and metropolitan environments	Exclusively rural contexts
Information availability	Sufficient methodological and substantive information	Insufficient information for critical synthesis

Source: Authors' literature selection framework (2026).

3.4. Literature Selection Process

The literature selection process followed the PRISMA 2020 reporting framework developed by Page et al. (2021), which provides guidance for transparently documenting the identification, screening, eligibility assessment, and inclusion of scientific publications. Although PRISMA was originally developed for systematic reviews, its flow diagram was adapted to organize and present the selection process within this narrative literature review. A total of 85 records were identified through Google Scholar (n = 50), Crossref (n = 20), and academic publisher platforms (n = 15). After removing 15 duplicate records, 70 publications remained for title and abstract screening. During this stage, 35 publications were excluded because they did not sufficiently address green infrastructure, urban environments, or climate change adaptation. The remaining 35 articles underwent full-text eligibility assessment. Of these, 15 articles were excluded because they provided insufficient discussion of urban climate resilience (n = 9) or lacked adequate methodological and substantive information (n = 6). Consequently, 20 articles were included in the final narrative synthesis, representing 23.53%

of the initially identified records. The selection process is illustrated in Figure 1, showing the progression from initial identification to final inclusion.

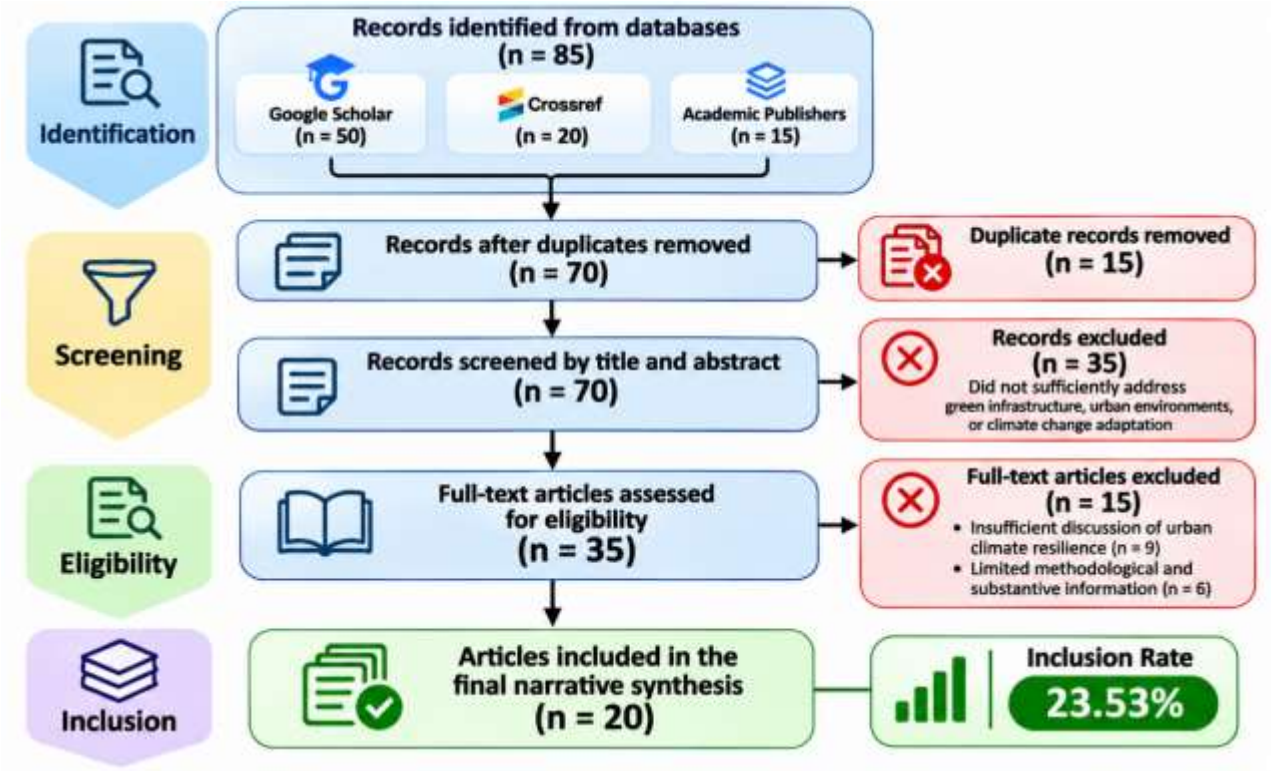


Figure 1. PRISMA-Inspired Literature Selection Process

3.5. Literature Analysis and Synthesis

The 20 targeted articles are organized into a literature matrix covering authorship, publication year, research focus, methods, key findings, and implications for urban resilience. The narrative synthesis examines four main themes: green infrastructure and urban heat mitigation; stormwater management and flood-risk reduction; ecosystem services and urban resilience; and spatial planning, governance, and environmental equity. The analysis compares findings across different urban contexts to identify recurring patterns, differences, implementation barriers, and research gaps. These findings are subsequently integrated into a conceptual framework linking green infrastructure characteristics, ecological performance, planning and governance conditions, and urban climate resilience. The proposed relationships are interpreted as a conceptual synthesis rather than causal effects established through new empirical testing.

4. DATA ANALYSIS AND DISCUSSION

4.1. Overview of the Reviewed Literature

The literature on green infrastructure and urban climate resilience has developed across several interconnected research areas. Some studies examine how vegetation and ecological systems reduce environmental pressures, particularly extreme heat and urban flooding. Others focus on the planning and management of green infrastructure, including its spatial distribution, technical performance, public acceptance, and institutional implementation. Although these studies approach the subject from different perspectives, they share an important concern: cities need adaptation strategies that can respond to climate-related risks without creating additional environmental and social problems. The 20 studies assembled for this review cover four major areas: urban heat mitigation, stormwater and flood management, ecosystem services, and planning and governance. Their approaches include systematic literature reviews, bibliometric analyses, modelling-oriented studies, and broader conceptual assessments. This diversity provides an opportunity to examine green infrastructure beyond individual environmental functions and consider its wider contribution to urban resilience. However, the studies should not be treated as providing identical forms of evidence. Research

examining runoff reduction through hydrological modelling differs from studies investigating social acceptance or institutional barriers. Similarly, findings from one geographical setting cannot automatically be transferred to another city with different climate conditions, land-use patterns, or governance arrangements. These differences are considered throughout the synthesis.

Table 2. Literature Matrix on Green Infrastructure and Urban Climate Resilience

No.	Author(s)	Research focus	Main contribution to the synthesis
1	Venkataramanan et al. (2020)	Public knowledge, attitudes, and behavior concerning green infrastructure for flood management	Highlights the social and behavioral conditions influencing implementation
2	Reu Junqueira et al. (2021)	Modelling green infrastructure under extreme rainfall conditions	Identifies approaches for assessing flood-mitigation performance under current and future rainfall
3	Johnson et al. (2022)	Nature-based solutions for climate adaptation	Provides a broader synthesis of ecosystem-based adaptation approaches
4	Han et al. (2023)	Sponge cities, urban flooding, and water shortages	Examines integrated urban water management through sponge-city approaches
5	Ariyarathna et al. (2023)	Blue–green infrastructure for urban flood mitigation	Discusses the integration of ecological and water-management functions
6	Korkou et al. (2023)	Multifunctionality in green infrastructure planning	Explains the importance of integrating multiple ecosystem services into planning
7	Wang et al. (2023)	Ecosystem services of green stormwater infrastructure	Examines the opportunities and challenges of multifunctional stormwater systems
8	Petzold & Mose (2023)	Urban greening and heat-related risks	Highlights the social and geographical dimensions of urban heat adaptation
9	Huang (2024)	Planning principles for green infrastructure and stormwater	Identifies planning considerations for effective stormwater management
10	Herath et al. (2023)	Green infrastructure and urban floodplains	Examines the potential use of urban floodplains for ecological infrastructure
11	Salih & Báthoryné Nagy (2024)	Green infrastructure and urban heat mitigation	Reviews thermal performance at microclimatic and building scales
12	Wang et al. (2024)	Urban resilience under climate change	Provides a broader understanding of resilience across interconnected urban systems
13	Ferrario et al. (2024)	Nature-based solutions for heatwaves and floods	Evaluates adaptation benefits across two major climate hazards
14	Esraz-Ul-Zannat et al. (2024)	Nature-based infrastructure and urban flood-risk mitigation	Reviews the effectiveness of ecological approaches to flood management
15	Valencia-Félix et al. (2024)	Green water systems and urban flood resilience	Discusses the relationship between green water systems, technical approaches, and flood resilience
16	Abuismail et al. (2024)	Public attitudes toward stormwater green infrastructure	Examines factors influencing residents' acceptance of green infrastructure
17	Kim & Kim (2025)	Research evolution in green infrastructure for urban flooding	Maps the development of research themes and approaches
18	Sobhaninia et al. (2025)	Spatial prioritization for heat and stormwater mitigation	Identifies differences between siting approaches and the need for integrated planning
19	Zarei & Shahab (2025)	Implementation of nature-based solutions	Examines governance, financing, participation, and implementation challenges
20	Ali et al. (2025)	Green infrastructure and urban flood modelling	Reviews implementation challenges and modelling approaches for urban flood management

Source: Authors' thematic literature compilation (2026), based on the publications identified for this review.

The literature matrix reveals three important patterns. First, research on green infrastructure has increasingly moved beyond the environmental performance of individual interventions toward broader questions of multifunctionality and urban adaptation. Second, flood management remains a prominent research area, with substantial attention given to hydrological modelling, stormwater regulation, and the integration

of ecological systems with conventional drainage. Third, the literature increasingly recognizes that technical performance alone is insufficient to explain successful implementation. Public acceptance, spatial priorities, institutional coordination, and long-term maintenance also influence whether green infrastructure can deliver meaningful adaptation benefits. These patterns provide a useful starting point for discussing the relationship between green infrastructure and urban resilience. Rather than assuming that all green infrastructure projects produce similar outcomes, the following sections examine how environmental functions interact with planning and governance conditions.

4.2. Green Infrastructure and Urban Heat Mitigation

Urban heat has become a growing concern as climate change interacts with rapid urban development. Dense buildings, paved surfaces, and limited vegetation can intensify local heat accumulation, particularly in neighborhoods where natural cooling opportunities have been reduced. These conditions affect more than outdoor comfort. They can increase cooling demand, influence public health, and make everyday activities more difficult for residents exposed to prolonged high temperatures. Green infrastructure can help address these pressures through shading, evapotranspiration, and changes in surface energy exchange. Urban trees, parks, green roofs, and vegetated corridors influence the way heat is absorbed, stored, and released within the built environment. Salih & Báthoryné Nagy (2024) examine these mechanisms through research on green infrastructure and heat mitigation at microclimatic and building scales. Their review supports the relevance of ecological design in reducing heat-related pressures. However, the cooling performance of green infrastructure cannot be explained simply by the presence of vegetation. The type and structure of vegetation, surrounding building density, local climate, and availability of water may influence the magnitude and distribution of cooling benefits. A densely shaded street, for example, may provide immediate relief from solar exposure, while a large open green space may influence thermal conditions differently depending on its vegetation composition and surrounding landscape.

Sobhaninia et al. (2025) provide an important perspective by examining how green infrastructure locations are selected to address heat and stormwater risks. Their review indicates that location-selection methods differ across environmental objectives, creating challenges for cities seeking to develop multifunctional adaptation strategies. This finding suggests that increasing the total area of urban greenery does not necessarily ensure that cooling benefits reach the neighborhoods experiencing the greatest heat exposure. The social dimension of heat adaptation is equally important. Petzold & Mose (2023) discuss urban greening in relation to the geographical and social characteristics of heat risks. Their perspective highlights the importance of understanding who experiences heat exposure and whether green infrastructure is accessible to those populations.

This issue becomes particularly relevant in densely populated urban areas. Neighborhoods with narrow streets, limited public spaces, and extensive impervious surfaces may face greater difficulties in accommodating large green infrastructure projects. Yet these are often the locations where cooling interventions are especially needed. If greening programs concentrate on areas with available land rather than areas with substantial heat exposure, environmental improvements may remain unevenly distributed. The literature therefore suggests that the contribution of green infrastructure to heat resilience should be assessed through three related considerations: its measurable thermal performance, the suitability of its location, and the distribution of benefits among urban populations. These considerations help distinguish the expansion of urban greenery from genuine improvements in climate adaptation. The main implication is that successful heat adaptation requires cities to consider not only how much green infrastructure is developed, but also where it is located and whose exposure to extreme heat it reduces.

4.3. Green Infrastructure and Urban Flood Resilience

Urban flooding is another major area in which green infrastructure can contribute to climate adaptation. As urban development replaces natural surfaces with roads, buildings, and other impervious materials, rainfall infiltration often decreases while surface runoff increases. During intense rainfall, these changes can place additional pressure on drainage systems and increase the likelihood of flooding. Green infrastructure provides opportunities to manage stormwater through natural processes. Rain gardens, vegetated swales, permeable landscapes, restored wetlands, and green roofs can support infiltration, temporary water storage, and slower runoff movement. These interventions are particularly relevant when incorporated into broader urban drainage and water-management strategies.

Research on green infrastructure and flood management has developed substantially. Kim & Kim (2025) identify 813 publications in their bibliometric dataset covering 2015–2024, demonstrating the scale and diversity of research in this area. Their analysis also highlights the increasing attention given to integrated green infrastructure systems and climate-related flood challenges. Earlier studies provide additional perspectives on the technical dimensions of this field. Reu Junqueira et al. (2021) examine approaches for modelling the current and future effects of extreme rainfall using green infrastructure. Their work is relevant because the performance of stormwater interventions must be considered under changing rainfall conditions rather than only under historical assumptions. Han et al. (2023) discuss China's sponge-city approach, which seeks to improve urban water management through a combination of infiltration, storage, and ecological interventions. This approach illustrates how green infrastructure can be incorporated into a wider urban development strategy rather than implemented only as isolated landscape projects. Ariyarathna et al. (2023) examine blue–green infrastructure as an approach to urban flood mitigation, while Esraz-Ul-Zannat et al. (2024) review the effectiveness of nature-based infrastructure in reducing urban flood risks. These studies reinforce the importance of integrating ecological functions into urban water management.

However, the effectiveness of green infrastructure depends on local hydrological conditions. Soil permeability, groundwater levels, rainfall intensity, slope, drainage connectivity, and maintenance can all influence performance. An intervention that reduces runoff during moderate rainfall may provide limited protection during exceptionally intense events. Ali et al. (2025) discuss prevailing implementation issues and modelling approaches in urban flood management. Their work draws attention to the technical and management challenges involved in translating green infrastructure concepts into practical interventions.

The findings suggest that green infrastructure should not be considered a complete substitute for conventional drainage systems. Instead, ecological and engineered infrastructure can play complementary roles. Conventional drainage provides essential conveyance capacity, while green infrastructure may reduce runoff volumes, delay peak flows, or support temporary storage. This relationship is particularly important in densely developed cities where large-scale restoration of natural landscapes may not be feasible. Smaller interventions distributed across streets, public spaces, and residential areas may contribute to stormwater management when they are appropriately connected and maintained. Huang (2024) examines planning principles for green infrastructure in urban stormwater management, while Herath et al. (2023) discuss opportunities for integrating green infrastructure into urban floodplains. These perspectives indicate that flood resilience depends not only on the technical characteristics of individual interventions but also on their relationship with surrounding landscapes and drainage networks.

The literature therefore supports a more integrated understanding of flood resilience. The relevant question is not whether green infrastructure can eliminate urban flooding, but how ecological interventions can reduce selected flood risks and complement existing infrastructure under particular environmental conditions. Green infrastructure contributes most meaningfully to urban flood resilience when its hydrological functions are matched with local risks, supported by appropriate modelling, and integrated into broader water-management systems.

4.4. Ecosystem Services, Spatial Planning, and Governance

The contribution of green infrastructure extends beyond heat mitigation and flood management. Ecological interventions can also support biodiversity, habitat connectivity, environmental quality, and recreational opportunities. These functions are relevant to urban resilience because they influence the environmental conditions in which communities live and adapt to changing climatic pressures. Korkou et al. (2023) examine the concept of multifunctionality in urban green infrastructure planning. Their work highlights the importance of considering multiple ecological and social functions rather than evaluating interventions through a single environmental objective. Similarly, Wang et al. (2023) examine ecosystem services associated with green stormwater infrastructure, including the opportunities and challenges involved in realizing multiple benefits. Nevertheless, multifunctionality should not be interpreted as evidence that every intervention can achieve all environmental objectives equally well. A rain garden designed primarily for stormwater retention may provide limited shade, while an urban tree canopy may improve thermal comfort without substantially increasing flood-storage capacity.

These differences make spatial planning particularly important. Cities must consider which environmental problems require the greatest attention, where interventions can perform effectively, and how different green infrastructure elements can function together. Sobhaninia et al. (2025) emphasize the need for better

integration between planning approaches for heat and stormwater mitigation. Their findings suggest that climate adaptation planning can become fragmented when individual environmental risks are addressed through separate decision-making processes.

The challenge becomes more complicated when land availability and social vulnerability are considered. Urban neighborhoods do not have equal access to public green spaces, and locations with high climate exposure may also face severe land constraints. Consequently, projects selected primarily because they are easy to implement may not provide the greatest benefits to vulnerable populations. Governance plays a central role in addressing these challenges. Green infrastructure projects commonly involve several municipal agencies responsible for planning, public works, environmental management, and community development. Their responsibilities may overlap, while budgets and institutional priorities may differ. Zarei & Shahab (2025) examine the factors influencing the implementation of nature-based solutions in urban green infrastructure. Their review identifies governance coordination, financing, technical capacity, stakeholder participation, and spatial justice as important considerations.

These findings suggest that the effectiveness of green infrastructure depends on more than ecological design. Long-term maintenance, institutional responsibilities, and financial continuity influence whether interventions remain functional after construction. Public acceptance also deserves attention. Venkataramanan et al. (2020) review knowledge, attitudes, intentions, and behavior associated with green infrastructure for flood management. Abuismail et al. (2024) further examine factors influencing residents' attitudes toward implementing stormwater green infrastructure. These studies demonstrate why community perspectives should be considered in planning and implementation.

Residents may support ecological interventions when they recognize their environmental benefits, but they may also have concerns about maintenance, land use, safety, or other local conditions. Such concerns should not automatically be interpreted as resistance to climate adaptation. They may instead reveal practical issues that require attention during project design and communication. The broader implication is that green infrastructure should be managed as a long-term urban adaptation system. Its performance depends on the relationship between environmental functions, spatial priorities, institutional coordination, and community needs. A city cannot be considered more resilient simply because it has expanded its green spaces. Resilience becomes more meaningful when ecological improvements reduce actual climate risks, remain functional over time, and provide benefits to communities that need them.

4.5. Integrative Framework for Green Infrastructure and Urban Climate Resilience

The synthesis of the 20 identified studies provides a basis for developing an integrated understanding of green infrastructure and urban climate resilience. Although the studies examine different environmental and institutional dimensions, their findings suggest that ecological performance alone cannot fully explain the contribution of green infrastructure to urban adaptation. Three interconnected dimensions emerge from the literature. The first concerns green infrastructure characteristics, including intervention type, vegetation structure, spatial distribution, connectivity, and maintenance. These characteristics influence the ecological functions that an intervention can provide.

The second dimension concerns ecological and adaptation performance, particularly heat mitigation, stormwater regulation, flood-risk reduction, and ecosystem service provision. These functions represent the more direct environmental contributions of green infrastructure. The third dimension concerns urban climate resilience, understood as the broader capacity of cities to reduce vulnerability, adapt to environmental pressures, and maintain essential functions during climate-related disturbances. The relationship between these dimensions is influenced by spatial planning, governance capacity, and environmental equity. These conditions affect where interventions are implemented, whether sufficient resources are available, and whether adaptation benefits reach communities facing substantial climate risks.

Table 3. Integrated Dimensions of Green Infrastructure and Urban Climate Resilience

Dimension	Key components	Contribution to urban resilience
Green infrastructure characteristics	Intervention type, vegetation, connectivity, and maintenance	Determines potential ecological functions
Heat mitigation	Shading, evapotranspiration, and local thermal regulation	Reduces selected heat-related pressures
Stormwater and flood management	Infiltration, retention, runoff regulation, and drainage integration	Supports flood-risk reduction

Ecosystem services	Biodiversity, habitat connectivity, and environmental quality	Strengthens urban environmental functions
Spatial planning	Risk mapping, site selection, and land-use integration	Directs adaptation benefits toward priority locations
Governance capacity	Coordination, financing, technical expertise, and maintenance	Supports implementation and long-term effectiveness
Environmental equity	Accessibility, participation, and distribution of benefits	Connects adaptation outcomes with social vulnerability
Urban climate resilience	Reduced exposure, adaptive capacity, and continuity of essential functions	Represents the broader adaptation outcome

Source: Authors' conceptual synthesis of the reviewed literature (2026).

Table 3 brings together the ecological and institutional dimensions discussed in the preceding sections. The framework distinguishes the physical characteristics of green infrastructure from the environmental benefits it produces and the broader resilience outcomes those benefits may support. This distinction is important because project outputs, environmental performance, and resilience outcomes are not interchangeable. Planting trees or constructing rain gardens represents a physical intervention. Reducing local temperatures or managing stormwater represents an environmental performance outcome. Strengthening urban resilience requires further consideration of whether these improvements reduce vulnerability and help urban systems function under climate-related pressures. Figure 2 presents the integrative conceptual framework developed from this synthesis. The framework illustrates how green infrastructure characteristics influence ecological and adaptation performance, which may subsequently contribute to urban climate resilience. Spatial planning, governance capacity, and environmental equity are positioned as enabling conditions that influence whether these relationships produce meaningful and sustainable outcomes.

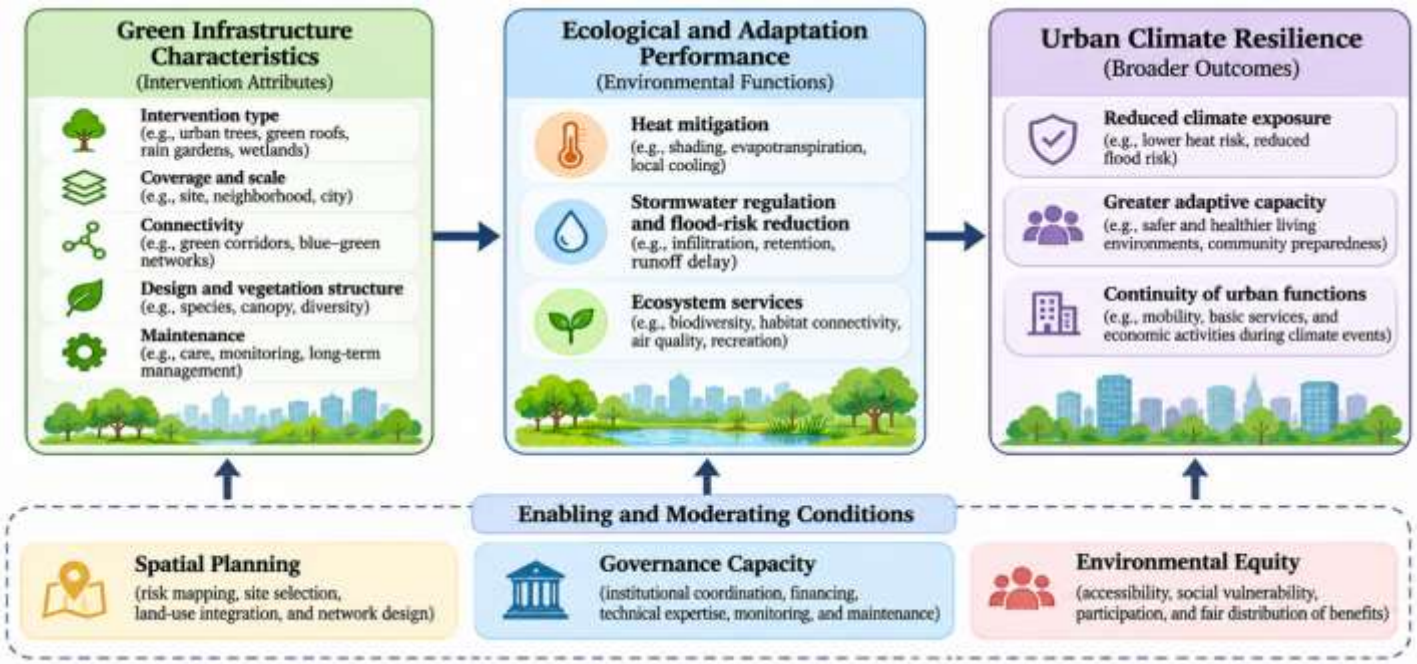


Figure 2. Integrative Conceptual Framework of Green Infrastructure and Urban Climate Resilience.
Source: Authors' conceptual synthesis (2026).

As illustrated in Figure 2, the relationship between green infrastructure and urban resilience should not be understood as automatic or universally consistent. The same type of intervention may produce different outcomes depending on climate conditions, land use, technical design, maintenance, and institutional arrangements. For example, an urban park may provide substantial cooling benefits in one setting but have a more limited influence in another because of differences in vegetation structure, surrounding buildings, and local atmospheric conditions. Similarly, stormwater interventions may perform differently across cities with contrasting rainfall patterns, soil characteristics, and drainage systems. These differences reinforce the

importance of context-specific planning. Green infrastructure strategies should respond to local environmental risks rather than rely on standardized designs that assume identical performance across urban areas.

The framework also offers an explanation for why governance and environmental equity matter. Ecological interventions may produce measurable environmental benefits, but their contribution to resilience can remain limited when they are poorly maintained or concentrated in neighborhoods with relatively low climate exposure. Conversely, interventions designed around local vulnerabilities and supported by consistent institutional management may provide meaningful adaptation benefits even when land and financial resources are constrained. The conceptual contribution of this study lies in connecting these dimensions within a single analytical perspective. Previous research has provided valuable evidence concerning cooling, flood management, ecosystem services, spatial planning, and implementation challenges. The present synthesis brings these findings together to explain the conditions under which green infrastructure can contribute to urban climate resilience. However, the framework should not be interpreted as an empirically tested causal model. The included publications use different research methods, geographical contexts, and indicators of environmental performance. Their findings therefore cannot be combined into a single estimate of green infrastructure effectiveness.

Further research is needed to examine whether the relationships proposed in Figure 2 hold across different urban environments. Comparative case studies, spatial analyses, and longitudinal evaluations would be particularly useful for assessing how ecological performance interacts with governance capacity and environmental equity. Overall, the literature indicates that green infrastructure has considerable potential to support urban climate resilience, but its effectiveness depends on the alignment between ecological functions, local climate risks, spatial planning, and institutional capacity. Expanding green infrastructure is therefore only one part of the challenge. The more important task is ensuring that ecological interventions provide measurable, equitable, and lasting contributions to urban adaptation.

5. CONCLUSION, IMPLICATION, SUGGESTION, AND LIMITATIONS

This study highlights the important role of green infrastructure in strengthening urban resilience to climate change, particularly through heat mitigation, stormwater management, flood-risk reduction, and the provision of ecosystem services. The literature suggests that urban trees, green roofs, rain gardens, wetlands, and other nature-based interventions can help cities respond to increasing environmental pressures. However, their effectiveness cannot be determined simply by the amount of green space available. The findings indicate that the contribution of green infrastructure to urban resilience depends on its ecological performance, spatial distribution, and integration into urban planning and governance systems. Interventions that are poorly located, inadequately maintained, or disconnected from local climate risks may produce environmental improvements without substantially reducing urban vulnerability. The conceptual framework developed in this study therefore emphasizes that green infrastructure characteristics, ecological performance, and urban resilience are interconnected, while spatial planning, governance capacity, and environmental equity influence how these relationships develop. Ultimately, green infrastructure should be understood not merely as an urban environmental amenity, but as an important component of a broader climate adaptation strategy.

The findings offer both theoretical and practical implications for urban climate adaptation. From a theoretical perspective, this study contributes to the literature by connecting the ecological functions of green infrastructure with the institutional and social conditions that influence urban resilience. This perspective helps explain why similar interventions may produce different outcomes across cities, even when they are designed to address comparable environmental risks. From a practical perspective, urban planners and policymakers should prioritize the effectiveness and distribution of green infrastructure rather than focusing exclusively on expanding green coverage. Investment decisions need to consider local heat exposure, flood vulnerability, land-use conditions, and the needs of communities facing greater climate risks. Green infrastructure should also be integrated with conventional drainage systems, urban development policies, and long-term maintenance programs. For local governments, the findings emphasize the importance of institutional coordination, adequate financing, and community participation. These measures can help ensure that green infrastructure provides lasting environmental benefits while supporting more inclusive and resilient urban development.

This study has several limitations that should be considered when interpreting its findings. First, the narrative literature review approach allows the integration of research from different disciplines and meth-

odological perspectives, but it does not provide a pooled statistical estimate of green infrastructure effectiveness. Second, the reviewed publications address different geographical contexts, environmental conditions, intervention types, and performance indicators, making direct comparisons difficult. Third, the literature selection framework focuses on publications from 2020 to 2026, which may exclude earlier studies that contributed to the development of green infrastructure and urban resilience research. In addition, the proposed literature selection figures require confirmation through documented database searches and screening records before they can be treated as completed review results. Finally, the conceptual framework presented in this study is derived from literature synthesis and has not been empirically tested. Consequently, the relationships between green infrastructure characteristics, ecological performance, governance conditions, and urban resilience should be interpreted as conceptual propositions rather than established causal effects.

Future research should examine how green infrastructure contributes to measurable improvements in urban climate resilience across different environmental, geographical, and institutional contexts. Particular attention should be given to comparative studies involving cities with different levels of urbanization, climate exposure, financial resources, and governance capacity. Longitudinal research is also needed to understand whether the environmental benefits of green infrastructure can be sustained as vegetation matures, maintenance conditions change, and climate-related pressures intensify. Furthermore, future studies should empirically examine the relationships proposed in the conceptual framework, particularly the influence of spatial planning, governance capacity, and environmental equity on the effectiveness of green infrastructure. Combining spatial analysis, environmental modelling, and community-level assessments could provide a more comprehensive understanding of how ecological improvements translate into reduced vulnerability. Research in rapidly urbanizing cities, especially in developing countries, would be particularly valuable because these areas often face significant climate risks alongside limited land availability and institutional resources. Such evidence could support the development of green infrastructure strategies that are environmentally effective, socially inclusive, and better suited to local adaptation needs.

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