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Review Paper

Evaluating Green Infrastructure Interventions for Land Surface Temperature Reduction: A PRISMA-Based Systematic Review

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ABSTRACT

Rapid urbanization has intensified land surface temperatures (LST) in cities worldwide, exacerbating the urban heat island effect and increasing risks to thermal discomfort, public health, and energy demand. Green infrastructure (GI), including street trees, urban parks, green roofs, vertical greenery, and blue–green systems has emerged as a key nature-based strategy for mitigating urban surface heat. This study presents a PRISMA-guided systematic review combined with bibliometric analysis to evaluate the effectiveness of GI interventions in reducing LST within built environments. A comprehensive search of the Web of Science Core Collection identified 211 records, of which 61 peer-reviewed studies published between 2012 and 2026 met the predefined inclusion criteria. Bibliometric analysis using VOSviewer reveals a rapidly expanding research field, characterized by exponential growth ($R^2 = 0.9135$) and strong thematic convergence around keywords such as green infrastructure, land surface temperature, urban heat island, and built environment. Keyword co-occurrence mapping identifies multiple interconnected research clusters, highlighting integration across thermal regulation, urban morphology, climate adaptation, and methodological innovation, while also revealing the relative underrepresentation of social and equity-focused dimensions. Geographically, research output is concentrated in Asia, Europe, and Australia, indicating regional imbalances in evidence generation. The systematic synthesis shows that tree-based green infrastructure and urban parks consistently produce the largest LST reductions, commonly ranging from 2–4°C, with higher localized reductions, whereas green roofs and vertical greenery systems deliver more localized but critical cooling benefits in high-density urban areas. Cooling effectiveness is strongly context-dependent, shaped by climate zone, urban morphology, vegetation structure, and spatial configuration. Notably, several studies demonstrate that small-scale GI interventions can significantly reduce surface heat stress in informal settlements, suggesting potential equity implications, particularly in heat-vulnerable urban areas, although systematic evidence remains limited. By integrating bibliometric mapping with PRISMA-based content analysis, this review provides a context-sensitive, design-aware, and climate-responsive synthesis to support evidence-based urban heat mitigation and climate-resilient planning.

1. INTRODUCTION AND BACKGROUND

1.1. Urban Heat Challenges and Land Surface Temperature (LST)

Urbanization has substantially transformed natural landscapes, replacing vegetation and permeable surfaces with impervious materials such as asphalt, concrete, and metal (Mohan & Kandya, 2015; Seto et al., 2012). This transformation has led to the amplification of Land Surface Temperature (LST) in cities, a phenomenon closely associated with the Urban Heat Island (UHI) effect (Evola et al., 2017; Nath, 2025; Vyas et al., 2014). The UHI effect is characterized by higher daytime and nighttime temperatures in urban areas relative to surrounding rural environments, driven primarily by solar heat absorption, limited evapotranspiration, anthropogenic heat emissions, and reduced ventilation (Gorai et al., 2024; Halder, Kumar, Deepak, Kumar, et al., 2025). Elevated LST is associated with increased surface heat exposure and can contribute to conditions that influence thermal discomfort, energy demand, and heat-related risks, although it does not directly represent human thermal experience (Abuwaer et al., 2023; Ullah et al., 2024; Ullah & Al-Ghamdi, 2023).

Understanding the dynamics of LST is therefore critical for developing effective urban heat mitigation strategies. Temperature gradients between built and natural areas vary with urban density, building materials, surface albedo, and local climate conditions (Azmeer et al., 2024a; Halder, Kumar, Deepak, Mandal, et al., 2025). High-density urban fabrics, particularly compact high-rise districts, are prone to intensified heat accumulation due to restricted airflow and increased radiation trapping. Conversely, urban open spaces and low-density areas benefit from higher convective cooling and larger potential for integrating vegetation-based interventions (Kanwal et al., 2026; Kumar, Maurya, Mandal, Halder, et al., 2025).

These climatic and urban morphological complexities underscore the need for targeted, context-specific approaches to mitigate urban heat, particularly in rapidly urbanizing regions experiencing extreme temperatures (Sweta Rupapara et al., 2025). The evidence from past decades suggests that green infrastructure (GI) interventions offer a promising solution for passive cooling by leveraging natural processes (J. Huang et al., 2022; Jin et al., 2024). GI is an effective strategy for urban heat mitigation, although its performance varies significantly depending on climatic conditions, urban morphology, and intervention type. In this study, the term GI is used as an umbrella concept encompassing urban greenery, including trees, parks, green roofs, vertical greenery systems, and blue–green infrastructure

1.2. Green Infrastructure as a Nature-Based Solution

GI encompasses a diverse array of interventions, including street trees, parks, urban forests, green roofs, and vertical greenery systems, which collectively aim to reduce urban heat and improve thermal comfort (Halder et al., 2026; Wong et al., 2021). The primary mechanisms through which GI reduces LST are shading, which limits direct solar radiation on urban surfaces, and evapotranspiration, whereby plants release water vapor to dissipate heat into the surrounding atmosphere (de Quadros & Mizgier, 2023; Ying, 2022). Together, these mechanisms contribute to significant surface and air temperature reductions, often producing perceptible cooling benefits for urban residents. Figure 1 illustrates the dual mechanisms through which GI reduces urban temperatures: shading reduces heat absorption at the surface, while evapotranspiration dissipates heat into the atmosphere, collectively lowering LST.

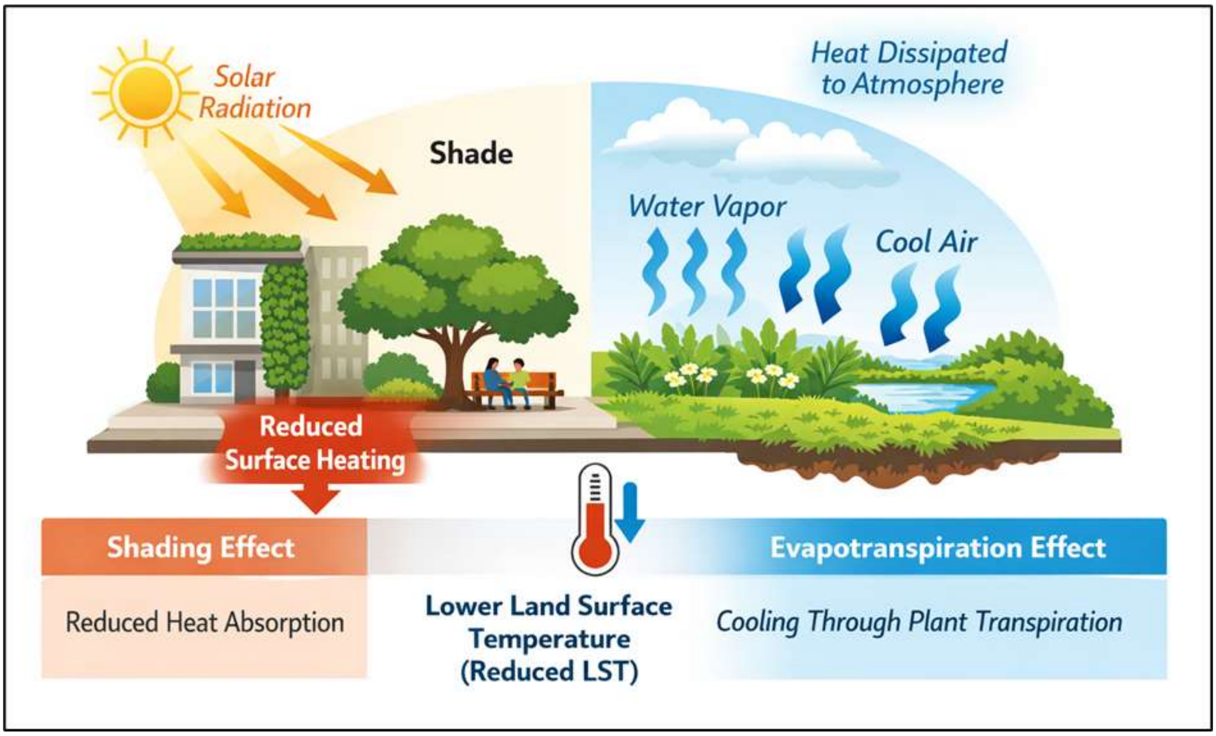

Figure 1. Mechanisms of Green Infrastructure LST Reduction.

Empirical studies have shown that tree canopies can reduce surface temperatures by up to 10°C, while urban parks create localized “cool islands” with air temperature reductions of 1–3°C. Green roofs and green walls, although generally providing smaller reductions in pedestrian-level temperatures, contribute to surface cooling, energy efficiency in buildings, and improvement of local microclimate conditions (Hurduc et al., 2024; Kanga et al., 2022; Luo & Wu, 2021; Rahman et al., 2020; Weng et al., 2004). The effectiveness of these interventions is highly sensitive to factors such as vegetation type, canopy density, spatial arrangement, and species selection.

Also, multi-layered vegetation strategies, integrating trees, shrubs, and ground cover, enhance thermal performance by increasing the leaf area index and creating diverse microclimates. Proper planning of vegetation layout, including tree spacing and canopy continuity, has been shown to produce 20–30% higher cooling efficiency compared to scattered, single-layer plantings (D. Chen et al., 2022; Gherri, 2023; Perini & Magliocco, 2014). Selecting drought-tolerant and native species ensures both thermal performance and long-term sustainability, especially in arid and semi-arid urban regions (Lee & Jim, 2018; X. Yang & Ma, 2024).

1.3. Empirical Evidence on LST Reduction

Research on the thermal impact of GI has expanded considerably over the last decade, employing both field measurements and simulation-based approaches. Field studies capture local microclimatic variations and validate thermal performance at the pedestrian scale, while simulation models such as ENVI-met, CFD, and coupled urban climate-energy models enable scenario testing and optimization of vegetation placement (Battista et al., 2016; Chow et al., 2016; Z. Liu et al., 2023; Pandey et al., 2021; Toparlar et al., 2017; S. Yang et al., 2023).

Cooling effectiveness has been found to vary according to climatic context, with hot-arid cities benefiting the most from evapotranspiration due to low atmospheric humidity and high solar radiation (Bowen et al., 2024; Cheung et al., 2021). In contrast, hot-humid climates rely more heavily on shading, as moisture saturation limits latent heat flux from evapotranspiration (Cheung & Jim, 2018; J. Yang et al., 2023). Urban density also plays a significant role: medium-density areas often achieve optimal cooling by balancing vegetation coverage with airflow, whereas high-density districts may experience constrained benefits due to limited ventilation (Kumar & Shukla, 2022). Spatial configuration of vegetation within urban canyons, including street orientation, tree height, and canopy coverage, further modulates thermal outcomes. Studies have demonstrated that continuous canopies produce greater reductions in pedestrian-level LST than scattered plantings, while multi-layered arrangements combining trees, shrubs, and ground cover yield the largest cumulative cooling benefits (Ornelas et al., 2023; Pradeep Kumar et al., 2023; Zhou et al., 2011). These findings underscore the necessity as influenced by urban morphology considerations into green infrastructure planning for maximum effectiveness.

It is important to distinguish between LST and human thermal comfort. While LST provides a spatially explicit measure of surface heat patterns, it does not directly capture air temperature, mean radiant temperature, or human thermal indices such as PET or UTCI. Therefore, LST should be interpreted as a proxy indicator of surface heat exposure rather than a direct measure of human thermal stress.

1.4. Integration with Urban Morphology and Planning

The effectiveness of GI in reducing LST is inseparable from the geometrical and functional characteristics of the built environment. Urban morphology variables, including building height, spacing, and street canyon geometry, influence wind flow, solar exposure, and heat accumulation, which in turn affect vegetation performance (Y. Chen et al., 2021; C. Huang et al., 2025; Jiang et al., 2021). Optimizing vegetation placement within these morphological constraints enhances both shading and convective cooling effects, yielding more effective LST mitigation (Kikon et al., 2023; X. Zhang et al., 2003).

Local Climate Zone (LCZ) classifications provide a framework for assessing and comparing green infrastructure performance across diverse urban forms (Kotharkar & Bagade, 2018). Integration of GI with urban planning enables performance-based strategies, such as prescribing minimum canopy coverage, spatial distribution, and multi-layered planting to achieve targeted cooling outcomes (Fang et al., 2023). In addition, urban planners and policymakers can leverage these strategies to align GI interventions with broader goals, including energy efficiency, air quality improvement, and has potential implications for thermal comfort (Z. Liu et al., 2021; O'Donnell et al., 2017; Shao et al., 2021). Sustainable urban design approaches also advocate combining GI with complementary measures such as reflective pavements, water features, and shading structures to maximize overall thermal comfort (de Oliveira et al., 2022; Derkzen et al., 2017; Tzoulas et al., 2007). This holistic perspective ensures that vegetation interventions are not only effective in isolation but synergistically contribute to a cooler, more livable urban environment.

1.5. Knowledge Gaps and Study Rationale

Despite the growing body of research, several critical knowledge gaps remain. Many studies focus on single intervention types, isolated urban contexts, or short-term temperature reductions, which limits the generalizability of findings (Hunter et al., 2015; Mittermüller et al., 2021). Additionally, methodological heterogeneity, including differences in measurement techniques (satellite-derived vs. ground-based LST), simulation assumptions, and temporal scales, complicates cross-study comparisons (Feng, 2022; H. Zhang et al., 2024).

A systematic synthesis is therefore required to consolidate evidence on GI interventions and their effectiveness in LST reduction, considering the influence of climate, urban morphology, and vegetation type. This study adopts a PRISMA-guided systematic review to:

- Map the current state of research on GI and LST reduction.
- Evaluate methodologies and measurement approaches used in existing studies.
- Assess cooling effectiveness across different urban forms and climatic contexts.
- Identify gaps in knowledge and provide evidence-based recommendations for future research and urban planning.

By focusing on these objectives, the study aims to provide a comprehensive, climate-sensitive understanding of GI performance, supporting urban designers and policymakers in implementing effective LST mitigation strategies. This aligns with the study objective of identifying research gaps and supports the need for more context-sensitive and human-centered evaluation frameworks.

Unlike previous reviews, this study not only consolidates empirical evidence on LST reduction by GI but also categorizes interventions by urban morphology, vegetation type, and climate zone, offering a more context-specific understanding of cooling effectiveness. Furthermore, by applying the PRISMA framework systematically, this review enhances transparency, reproducibility, and methodological rigor, providing an updated reference for policymakers, urban planners, and researchers designing evidence-based urban cooling strategies.

2. MATERIALS AND METHODS

In this research, a mixed-methods approach was adopted by combining a PRISMA-based systematic review with bibliometric analysis using VOSviewer. This approach integrates qualitative synthesis of the literature with quantitative mapping of research trends to examine the relationship between GI and LST across built environments (Arruda, 2022; Kirby, 2023; Page et al., 2021a; van Eck, 2010). PRISMA process leading to the selection of the papers used for both qualitative synthesis and bibliometric analysis. The mixed-methods approach has been instrumental in achieving the objectives of this study (Li et al., 2022). Expanding upon previous discussions, this study integrates the structured qualitative depth of a systematic review with the quantitative insights of bibliometric analysis to examine the relationship between green infrastructure (GI) and land surface temperature (LST) across built environments. The research protocol for the study is shown in figure 2 on how the study is progressing. Study follows PRISMA guidelines and checklist (Page et al., 2021b).

A structured data extraction framework was developed to ensure consistency across the reviewed studies. Each study was coded based on predefined variables, including:

(i) type of green infrastructure (e.g., trees, parks, green roofs, blue–green systems),
(ii) urban morphology (e.g., compact, high-density, suburban),
(iii) climatic or geographical context,
(iv) LST measurement method (e.g., remote sensing, simulation, field measurement), and
(v) reported cooling outcomes.

These categories were defined based on common classifications used in urban climate and green infrastructure literature and were applied consistently across all included studies.

2.1. The PRISMA Framework

The PRISMA framework was employed to systematically collect, screen, and analyse articles from the Web of Science (WOS) database. This review is based on the WOS database, which, while ensuring high-quality and peer-reviewed sources, may not capture all relevant studies indexed in other databases such as Scopus or Google Scholar. This represents a limitation in terms of literature coverage. This method enhances transparency and reproducibility, which are vital for academic rigor (Chaudhuri & Kumar, 2022; Fu et al., 2022). A web search was done on January 04, 2026, as the initial step. Boolean operators (AND, OR) were applied to refine the results and ensure the selection of pertinent studies. The search string was designed to balance comprehensiveness and specificity by incorporating multiple synonymous terms related to land surface temperature, urban heat, and green infrastructure. The selected terms were chosen to ensure alignment with the core research objectives while minimizing retrieval of irrelevant studies. "LST" is first introduced in this paper and is a widely used metric in urban climate and remote sensing studies, particularly for assessing surface heat patterns and urban heat island effects. Furthermore, comprehensive relevant literature retrieval is built on LST in GI and Built Environment. Alternative terms such as ‘urban greening’ or ‘ecosystem services’ were considered but were not included to maintain focus on studies explicitly addressing thermal performance. Criteria for eligible literature through WOS are further classified in Table 1. The specific search query used in basic search mode; the search term was - ("Land Surface Temperature" OR "LST" OR "Surface Temperature" OR "Urban Heat" OR "UHI") AND ("Green Infrastructure" OR "Urban Greenery" OR "Urban Green Space") AND ("Urban Environment*" OR "Built Environment") and then search method topic was selected.

Table 1. Criteria for eligible literature through WOS (excluded if not meeting these criteria).

No.	Criteria	
1	Search Terms (Topic/Title/Abstract)	("Land Surface Temperature" OR "LST" OR "Surface Temperature" OR "Urban Heat" OR "UHI") AND ("Green Infrastructure" OR "Urban Greenery" OR "Urban Green Space") AND ("Urban Environment*" OR "Built Environment")
2	Document Type	Article
3	Language	English
4	Database	Web of Science (WOS) database
5	Irrelevant Disciplines	Subject categories retrieved excluding: *Pharmacology, toxicology, and pharmaceutics;* Physics and Astronomy; Chemical Engineering; Computer Sciences; Biochemistry, Genetics and Molecular Biology; Decision Sciences Pharmacology, toxicology, and pharmaceutics;

The WOS core collection database provided 211 journal articles using this search. Figure 2 illustrates the PRISMA 2020-compliant study selection process, detailing the number of records at each stage (identification, screening, eligibility, and inclusion), along with explicit reasons for exclusion. This ensures transparency and reproducibility of the review process. The process began with the identification stage, where 211 records were retrieved from the WOS database. This broad search aimed to capture a wide range of relevant studies within the research scope. During this phase, 26 articles were excluded because they were not in English, were review papers, or were categorized as early access articles, resulting in 185 records proceeding to the next phase.

The screening stage involved a structured evaluation of the remaining records based on predefined inclusion criteria. A total of 65 studies were excluded due to disciplinary misalignment. The remaining records were assessed for relevance, defined as explicit examination of the relationship between GI and LST within urban or built environments.

Screening was conducted sequentially at title, abstract, and full-text levels to ensure consistency and minimize subjectivity. Following this process, 120 studies were retained for further assessment, of which 59 were excluded due to lack of alignment with the research scope. The final selection comprised 61 studies that met all inclusion criteria.

In the eligibility stage, the full texts of the 61 remaining records were reviewed against predefined criteria, including relevance to the research themes of LST, GI and the built environment. Finally, the inclusion stage resulted in 61 studies being selected for detailed analysis. These studies formed the foundation of the systematic review, providing critical insights into key themes, methodologies, and research gaps.

By employing the PRISMA framework, this review ensured a structured and reliable process, yielding a robust dataset that highlights both the methods adopted and research gaps in the field. This approach not only synthesizes existing knowledge but also facilitates future research by systematically identifying synergies and challenges in urban greenery and thermal comfort.

In the supplementary material, a comprehensive list of all 61 studies included in the systematic review is presented, along with citation details. Each study is systematically documented with information such as authors, year of publication, title, and number of citations, providing a transparent overview of the research corpus. The meticulous application of the PRISMA framework ensures that all selected studies are highly relevant to the study’s themes and research objectives.

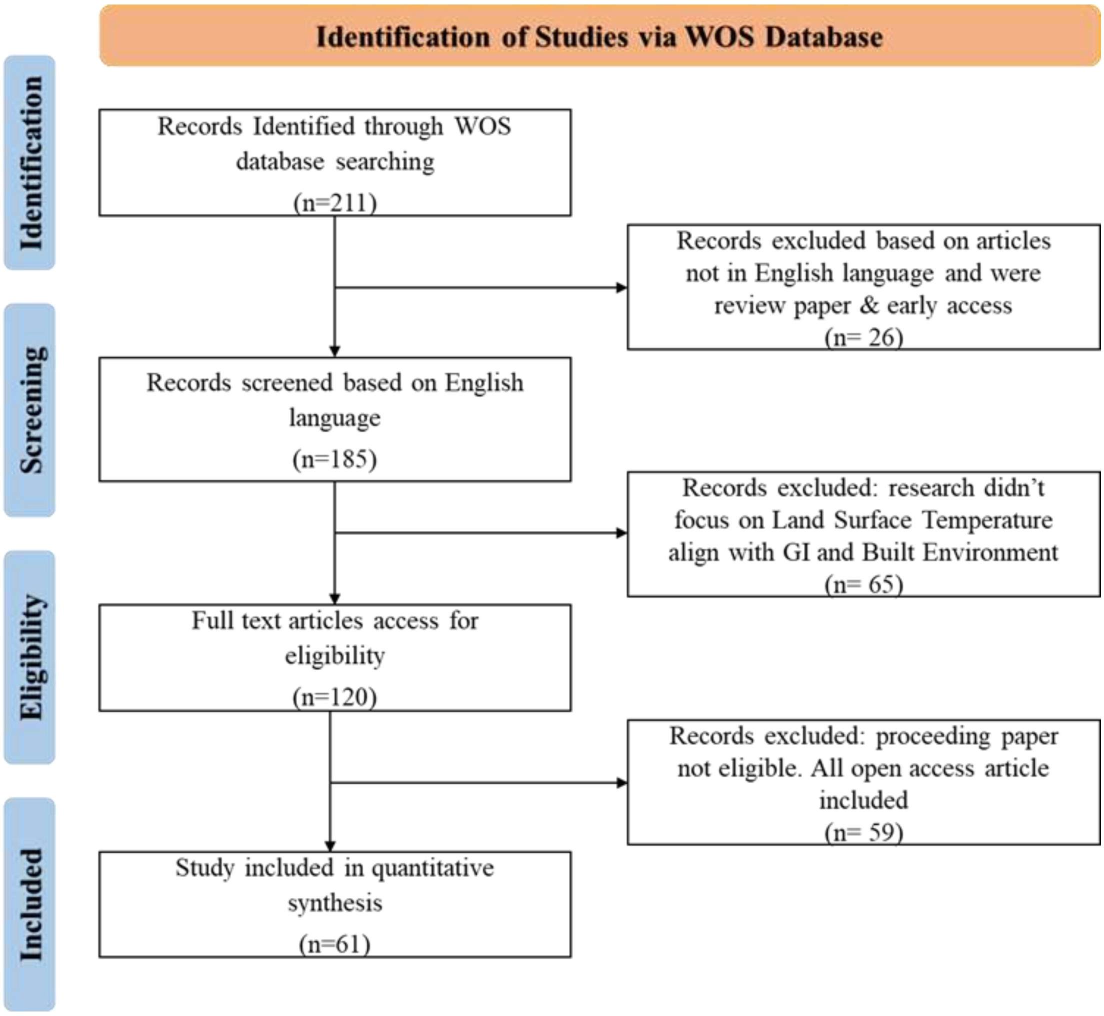

Figure 2. PRISMA framework of the study, Source: PRISMA 2020 (Page et al., 2021a)

To make sure the papers included in systematic reviews are of high quality, Dyba and Dingsoyr (2008) developed a checklist of questions (Dybå & Dingsøyr, 2008). Three primary criteria serve as the foundation for these inquiries: relevance, rigor, and credibility. Data were extracted systematically from each study, including GI type, urban morphology, climate context, LST measurement method, and reported cooling effects. While no formal numerical quality scoring or sensitivity analysis was conducted, the review carefully considered the scope, methodology, and context of each study to identify patterns and trends. Potential limitations, such as geographic concentration of studies or methodological variability, were acknowledged and considered in the synthesis. This assessment informed the interpretation of results and helped identify potential sources of bias, including limitations related to data sources, spatial scale, and modeling assumptions. Given the heterogeneity of study designs and outcomes, a qualitative assessment approach was considered more appropriate than a standardized scoring system.

This structured approach ensured a robust and transparent review, providing a comprehensive overview of the current evidence on the effects of green infrastructure on urban LST, while highlighting research gaps and opportunities for future studies. A complete list of all included studies, with citation details, is provided in the supplementary material.

2.2. Bibliometric Analysis

For the bibliometric analysis, this study utilized VOSviewer software (version 1.6.19) in conjunction with the WOS database. VOSviewer was employed to generate visual bibliometric maps (Arruda, 2022; van Eck, 2010), illustrating the co-occurrence of keywords and emerging research trends in literature related to LST and GI across built environments. This technique allowed for the identification of frequently used terms, research foci, and linkages between concepts, offering insights into the conceptual structure of the field. In addition to keyword analysis, the study examined the geographic distribution of research by analyzing country affiliations contributions. Publication trends were also assessed to determine the temporal evolution of scholarly interest in the topic. These bibliometric insights complement the qualitative synthesis by mapping the scope and trajectory of academic engagement, thereby strengthening the review's capacity to identify research gaps and emerging areas of focus. For keyword co-occurrence analysis, author keywords were extracted from the selected studies. A minimum occurrence threshold was applied to include only frequently used terms, ensuring robustness of the network. Co-occurrence relationships were normalized using the association strength method, and clustering was performed using the VOSviewer clustering algorithm to group related themes.

Given the diversity of study designs, spatial scales, climatic contexts, and outcome metrics (as summarized in Table 2), a formal meta-analysis was not considered appropriate. Instead, a structured quantitative synthesis approach was adopted to systematically compare reported LST reductions across studies.

3. RESULTS

3.1. Publication trends

The publication trend illustrated in Figure 3 reveals a clear and accelerating growth in scholarly interest in GI interventions for LST reduction over the past decade. From 2012 to 2019, research output in this field remained relatively sparse, with only one publication recorded in each of the selected early years. This limited output suggests that, during this period, GI–LST relationships were still an emerging research niche, often embedded within broader studies on urban climate, land use, or sustainability rather than being a primary focus. A notable shift occurs from 2020 onwards, where the number of publications increases substantially. The annual output rises from three studies in 2020 to eight in 2021, followed by sustained growth through 2022 and 2023. This surge coincides with growing global concern over urban heat islands, climate change impacts, and heat-related health risks, as well as improved access to high-resolution remote sensing data and geospatial analytical tools. These developments have enabled more robust and spatially explicit assessments of how green roofs, urban forests, parks, and other GI strategies influence LST.

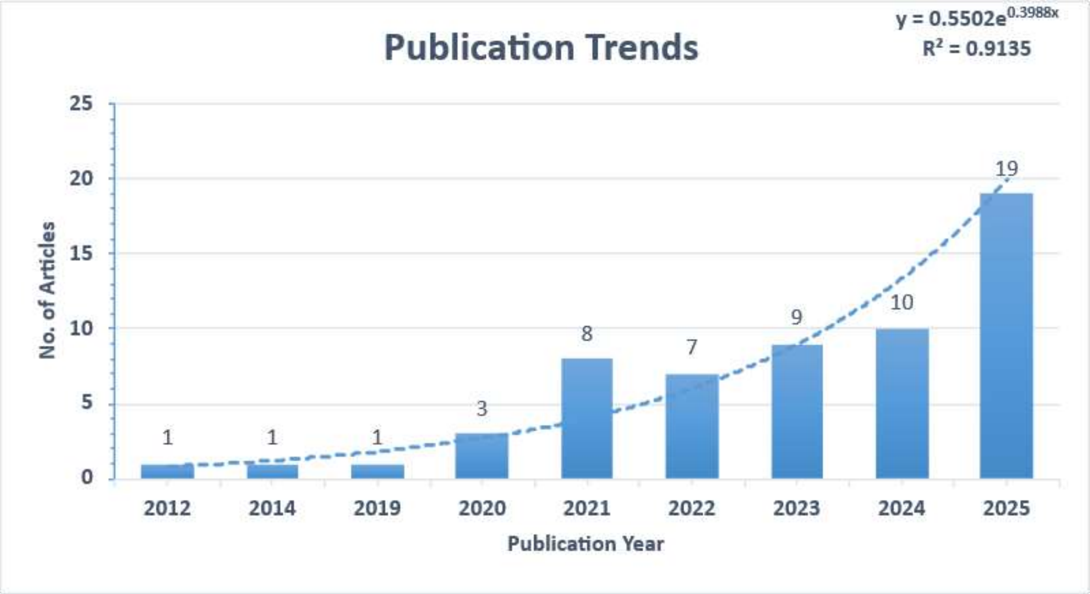

Figure 3. Exponential growth trend of "NBS"- related research and year wise data.

The upward trajectory becomes particularly pronounced after 2023, reaching 19 publications in 2025, the highest value in the review period. The fitted exponential trendline ($R^2 = 0.9135$) indicates a strong and consistent growth pattern, suggesting that research in this domain is not only increasing but accelerating. This reflects the consolidation of GI-based thermal mitigation as a critical research theme within urban climate adaptation and sustainable city planning. Overall, the observed publication trend underscores the timeliness and relevance of this PRISMA-based systematic review. The rapid increase in recent studies highlights the need for a structured synthesis to evaluate the effectiveness of different green infrastructure interventions, identify methodological patterns and gaps, and inform evidence-based urban planning and climate resilience strategies.

3.2. Analysis of co-occurring keywords and Density Visualization

The keyword co-occurrence network (Figure 4), generated using VOSviewer, illustrates the conceptual structure of the research field by mapping the frequency and strength of relationships between terms. The co-occurring keyword map produced using VOSviewer offers a nuanced representation of the conceptual structure and thematic breadth of research on GI and LST reduction. Based on 501 author keywords, the network is organized into 23 clusters, with a total link strength of 5209, indicating a highly connected and mature body of literature. The identified clusters represent groups of closely related keywords that frequently co-occur within the literature, indicating dominant thematic areas. Total link strength reflects the overall degree of connectivity among keywords, with higher values indicating stronger conceptual integration across the research field.

At the center of the network, keywords such as green infrastructure, temperature, urban environment, climate change, and built environment exhibit the highest connectivity, reflecting their foundational role in shaping the discourse. Their prominence suggests that GI–temperature interactions are most often examined within broader discussions of urban climate dynamics and the physical characteristics of cities. The dense interlinkages among these core terms indicate strong conceptual integration rather than fragmented thematic development.

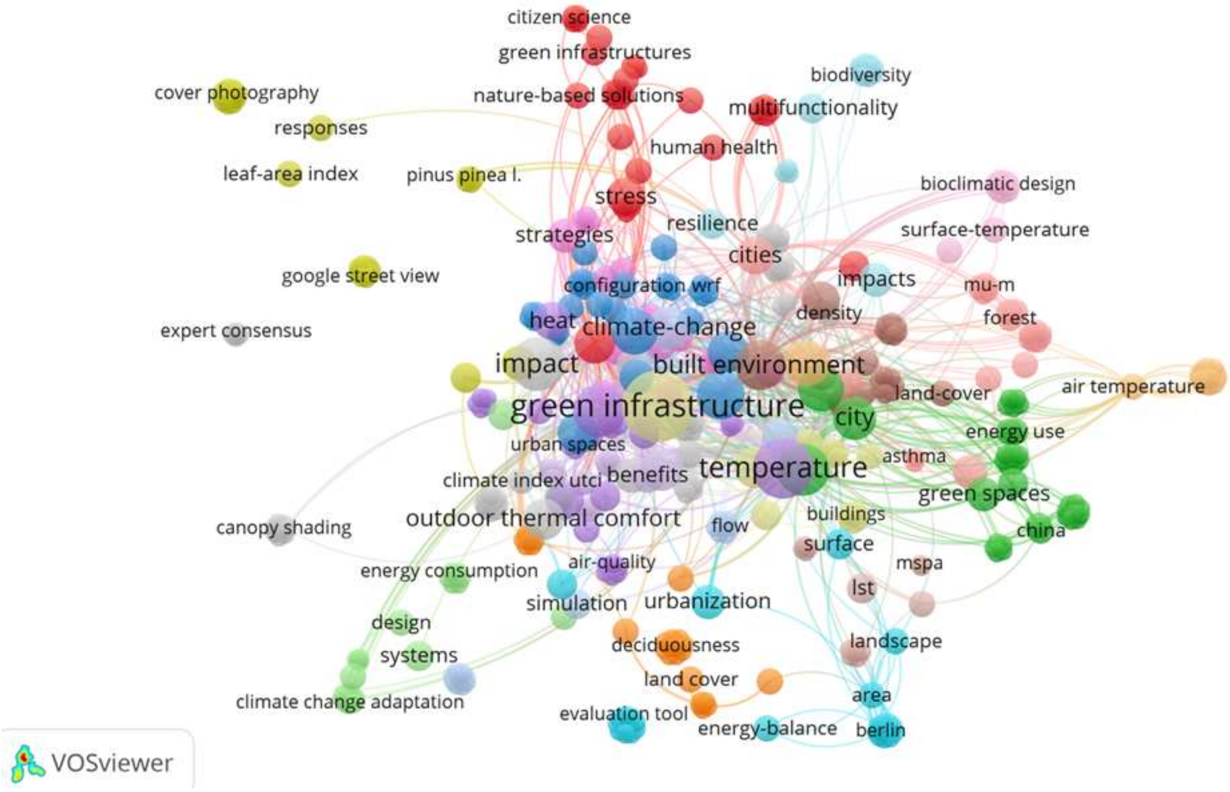

Figure 4. Co-occurring keyword map visualization using VOSviewer.

Several clusters are clearly oriented toward thermal processes and measurement approaches, with recurring terms including land surface temperature, surface temperature, air temperature, energy balance, and urban heat. These clusters underscore the dominant reliance on remote sensing, surface energy modeling, and climate simulations to quantify the cooling effects of green infrastructure. Closely connected keywords such as land cover, urbanization, density, and buildings highlight the recognition that GI performance is strongly conditioned by urban form, spatial configuration, and land-use patterns.

Methodological diversity is also evident across the network. Clusters containing terms such as simulation, evaluation tools, leaf area index, canopy shading, Google Street View, and citizen science point to increasing use of innovative data sources and mixed-method approaches. These methods enable more detailed characterization of vegetation structure, street-level thermal environments, and user perceptions, complementing traditional satellite-based analyses. Emerging conceptual framings are reflected in clusters associated with nature-based solutions, multifunctionality, biodiversity, and bioclimatic design.

Overall, the identification of 23 interrelated clusters with a high total link strength reveals a well-established yet evolving research field. The keyword network highlights both the consolidation of core themes, particularly the GI–LST relationship and the increasing integration of health, resilience, and methodological innovation.

Figure 5 presents the keyword density visualization generated using VOSviewer, offering a complementary perspective to the network map by highlighting the relative concentration and prominence of research themes within the literature on GI and temperature mitigation. The density map highlights areas of high research intensity through darker and more saturated regions, enabling clearer identification of dominant and peripheral research themes.

The bibliometric findings highlight a strong concentration of research on biophysical aspects of temperature reduction, while social, behavioral, and equity-related dimensions remain underexplored. This gap is consistent with the findings of the systematic review and suggests the need for more integrated, interdisciplinary approaches in future research.

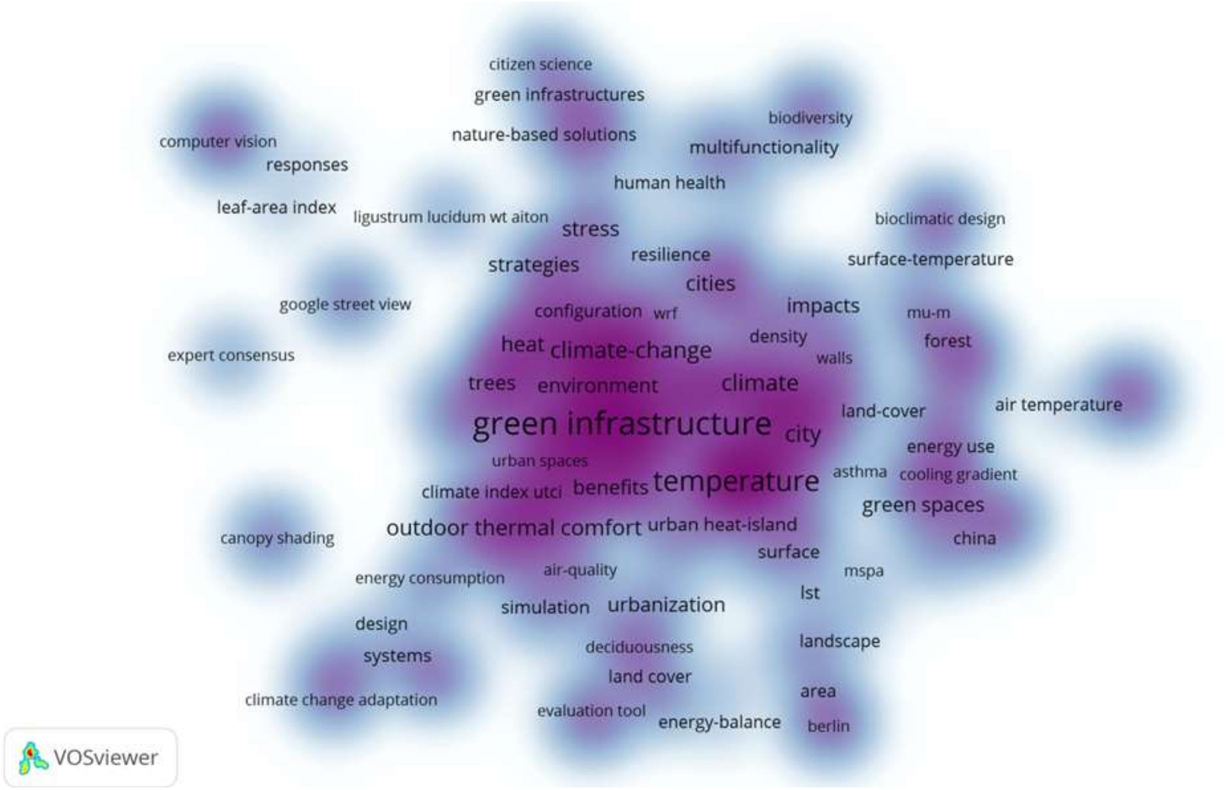

Figure 5. Keyword density visualization generated using VOSviewer, illustrating the thematic concentration and research intensity of co-occurring keywords in studies on green infrastructure and urban temperature mitigation.

Results reveal a research field that is highly concentrated around urban thermal regulation, yet gradually diversifying towards potential implications for thermal comfort outcomes, multifunctionality, and innovative data sources. This imbalance underscores the need for future studies to better integrate social, ecological, and methodological dimensions into GI effectiveness assessments, an objective directly addressed by the systematic synthesis undertaken in this review.

These clusters can be broadly interpreted into three dominant thematic domains:

(i) thermal processes and measurement approaches (e.g., LST, surface temperature, energy balance),

(ii) urban form and morphology (e.g., density, land use, urban structure), and

(iii) nature-based and design-oriented strategies (e.g., green infrastructure, ecosystem services, resilience).

Importantly, the analysis reveals comparatively weaker representation of keywords related to human thermal comfort, social vulnerability, and equity. This indicates a research gap in integrating biophysical temperature reduction with human-centered outcomes, which is further explored in the systematic synthesis.

3.3. Analysis of country distribution

Figure 6 illustrates the country-wise distribution of publications included in this systematic review, highlighting the geographical patterns of research activity on GI interventions for temperature reduction. The results reveal a clear concentration of scholarly output in a limited number of countries, reflecting uneven global engagement with this research theme.

China emerges as the leading contributor, accounting for the highest number of publications (n = 15). This dominance underscores the country's strong research focus on urban heat mitigation, rapid urbanization challenges, and the widespread application of remote sensing and spatial analysis techniques in GI–temperature studies. Australia follows with nine publications, reflecting sustained interest in climate-sensitive urban planning and heat resilience strategies in the context of extreme temperature exposure. Italy ranks third with seven studies, indicating a growing European emphasis on nature-based solutions and urban climate adaptation.

Germany and the United States contribute six publications each, demonstrating consistent research engagement in assessing the thermal and environmental performance of green spaces, urban forests, and other GI elements. England and India follow with five publications each, highlighting emerging but still moderate research activity, particularly in relation to urban sustainability and climate adaptation. Austria and Switzerland contribute three studies each, while Canada accounts for two publications, suggesting more limited but focused contributions. This geographical imbalance points to a need for broader cross-regional studies and greater inclusion of diverse climatic, socio-economic, and urban contexts. Importantly, the concentration of studies in specific regions may influence the reported effectiveness of GI, as cooling performance is highly dependent on local climate conditions, vegetation characteristics, and urban morphology.

As a result, findings derived predominantly from temperate and rapidly urbanizing regions may not be directly transferable to underrepresented regions such as Africa or parts of South America, where climatic conditions, urban forms, and resource constraints differ significantly. This highlights the need for caution when generalizing results and underscores the importance of context-specific evaluation of GI interventions.

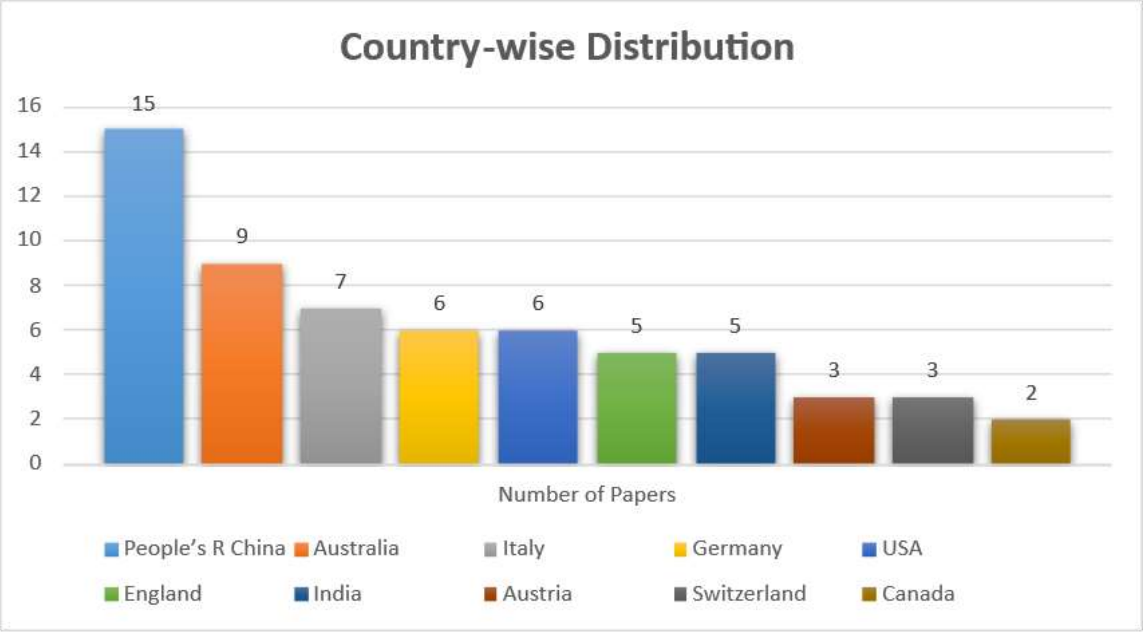

Figure 6. Geographical distribution of publications. Source: WOS

The country distribution indicates that research on GI and land surface temperature reduction is predominantly concentrated in Asia, Europe, and Australia, with comparatively fewer contributions from North America and limited representation from the Global South beyond China and India. This geographical imbalance points to a need for broader cross-regional studies and greater inclusion of diverse climatic, socio-economic, and urban contexts. Addressing this gap is essential for improving the generalizability of evidence and informing context-sensitive green infrastructure planning at a global scale.

3.4. Content Analysis

This section presents the results of the content analysis of 61 selected studies that examined the comparative performance of land surface temperature (LST) and green infrastructure (GI) in built environments, as summarized in Table 2. The synthesis was conducted using a qualitative coding approach, in which recurring patterns and relationships across studies were identified and grouped according to GI type, urban morphology, and climatic context. This approach enabled systematic comparison while accommodating methodological heterogeneity across the reviewed studies.

The synthesis was structured to directly address the research objectives outlined in the introduction, particularly by consolidating empirical evidence on LST reduction associated with GI interventions and categorizing findings based on urban morphology, vegetation type, and climate zone. This facilitates a more context-specific understanding of cooling effectiveness.

The aim of this synthesis is to extract recurring patterns, conceptual orientations, and practical insights across multiple dimensions of evaluation. Such a structured approach not only supports understanding of the current state of knowledge but also helps identify methodological inconsistencies and research gaps that may hinder evidence-based planning and policy development. By organizing the review in this manner, the analysis provides a more nuanced understanding of the practical advantages, trade-offs, and contextual applicability of LST in addressing challenges related to urban sustainability and infrastructure resilience.

The “key inferences” reported in Table 2 were derived through a structured synthesis of each study’s primary findings. Rather than subjective interpretation, these inferences summarize the main conclusions presented by the original authors, with emphasis on the relationship between GI characteristics and LST reduction. To minimize subjectivity, consistent coding criteria were applied across all studies during the data extraction and synthesis process.

Table 2. Content analysis of 61 selected studies that examined the comparative performance of LST and GI in Built environments

S. No.	Author(s)	Year	GI Type	Urban Morphology	LST Measurement Method	Key Inferences
1	(Oraiopoulos et al., 2026)	2026	Urban green infrastructure	Informal settlements	Remote sensing + field data	GI significantly reduces surface heat stress and improves habitability in dense informal settlements.
2	(Berger et al., 2026)	2026	Native vegetation	Residential urban areas	Field experiments	Native plant-based GI enhances thermal regulation under urban heat stress conditions.
3	(Helmreich et al., 2025)	2025	Infiltration swales (blue–green GI)	Urban neighborhoods	ENVI-met simulation	Blue–green GI provides measurable surface cooling while improving stormwater management.
4	(S. Yang & La Roche, 2025)	2025	Tree canopies, green roofs	Dense urban blocks	ENVI-met	Tree canopies outperform green roofs in reducing daytime LST in compact urban areas.
5	(Lazovic et al., 2025)	2025	Roadside greenery	Traffic corridors	Numerical simulation	Roadside GI mitigates LST and contributes to improved thermal conditions along high-traffic streets.
6	(Hogeweij et al., 2025)	2025	Urban parks	High-density city center	Landsat LST	Urban parks function as thermal sinks with cooling effects extending into surrounding areas.
7	(J. Liu et al., 2025)	2025	Green roofs	High-rise urban districts	Remote sensing	Green roofs reduce roof-level LST but show limited neighborhood-scale cooling.
8	(Esperon-Rodriguez et al., 2025)	2025	Street trees	Street canyon morphology	CFD + ENVI-met	Tree height and spacing strongly influence cooling performance in street canyons.
9	(Roversi & Longo, 2025)	2025	Blue–green corridors	Riverfront urban areas	Satellite imagery	Combined vegetation–water systems generate stronger LST reductions than vegetation alone.
10	(Bachofen et al., 2025)	2025	Pocket parks	Mixed-use urban zones	Landsat	Small green spaces significantly reduce localized surface heat hotspots.
11	(Ramadan et al., 2025)	2025	Urban forests	Metropolitan scale	MODIS	Large urban forests lower regional LST more effectively than fragmented green spaces.

12	(Cuce et al., 2025)	2025	Vertical greenery systems	High-rise districts	Field measurements	Vertical GI reduces façade temperatures but has limited city-scale influence.
13	(Karimi et al., 2025)	2025	Green belts	Urban fringe	Remote sensing	Continuous green belts outperform fragmented GI in reducing surface temperatures.
14	(P. Chen & Hanlon, 2025)	2025	Grassland GI	Low-density suburbs	Landsat	Grass-based GI provides moderate cooling but is less effective than tree cover.
15	(H.-R. Yang et al., 2025)	2025	Wetlands	Peri-urban areas	Satellite imagery	Urban wetlands exhibit strong daytime LST reduction due to evapotranspiration.
16	(Seidu et al., 2025)	2025	Urban trees	Residential neighborhoods	Field + satellite	Increased tree canopy cover correlates with lower surface temperatures.
17	(Pattnaik et al., 2025)	2025	Green roofs	Compact urban form	ENVI-met	Roof greening effectiveness depends on building height and roof coverage ratio.
18	(Al-Zghoul & Al-Homoud, 2025)	2025	Linear greenways	Transport corridors	Remote sensing	Linear GI reduces thermal fragmentation across urban landscapes.
19	(Bera & Nag, 2025)	2025	Mixed GI systems	Dense urban fabric	Landsat + modeling	Integrated GI networks outperform isolated interventions in LST mitigation.
20	(Ni et al., 2025)	2025	Urban parks	Compact city	Remote sensing	Park size and shape strongly influence cooling intensity and reach.
21	(Del Rosario et al., 2025)	2025	Street greenery	High-density streets	Field measurements	Shaded streets show significantly lower surface temperatures during peak heat.
22	(Yazdi et al., 2024)	2024	Blue–green infrastructure	Flood-prone urban areas	ENVI-met	Blue–green GI provides dual benefits of cooling and climate resilience.
23	(M. Chen et al., 2024)	2024	Green walls	High-rise buildings	Thermal imaging	Green walls lower wall surface temperatures but have localized effects.
24	(Y. Chen et al., 2024)	2024	Urban vegetation	City-wide	Landsat time series	Expansion of urban greenery correlates with long-term LST decline.
25	(Frosini et al., 2024)	2024	Green roofs	Commercial districts	Remote sensing	Commercial roof greening reduces extreme surface heat accumulation.
26	(Chu et al., 2024)	2024	Urban trees	Residential blocks	Field sensors	Tree shade significantly reduces ground and pavement temperatures.
27	(Jimenez & de Adana, 2024)	2024	Urban parks	Mixed-density areas	MODIS	Larger parks exhibit stronger and more stable cooling effects.
28	(Guan & Zhang, 2024)	2024	Vegetated courtyards	Compact housing	ENVI-met	Internal green courtyards improve microclimate in dense housing complexes.
29	(H. Liu et al., 2024)	2024	Blue–green networks	Metropolitan regions	Remote sensing	Network connectivity enhances regional LST mitigation.

30	(Azmeer et al., 2024b)	2024	Urban agriculture	Peri-urban zones	Landsat	Urban farming areas show measurable surface cooling benefits.
31	(Ibric et al., 2024)	2024	Street trees	Urban road networks	Field + GIS	Tree-lined streets reduce surface heat accumulation during summer.
32	(Zakrzewska et al., 2023)	2023	Green roofs	Residential buildings	Thermal monitoring	Roof vegetation moderates diurnal surface temperature extremes.
33	(Fong et al., 2023)	2023	Urban greenery	Informal settlements	Remote sensing	Even small-scale GI interventions reduce extreme LST in vulnerable areas.
34	(Pragati et al., 2023)	2023	Urban parks	City center	Landsat	Park cooling intensity decreases with distance from park edges.
35	(La Rosa & Li, 2023)	2023	Green corridors	Compact cities	ENVI-met	Corridors facilitate spatial diffusion of cooling effects.
36	(Sobrinho et al., 2023)	2023	Blue infrastructure	Waterfront districts	Satellite imagery	Water bodies enhance adjacent green cooling effects.
37	(Pritipadmaja et al., 2023)	2023	Urban trees	Suburban areas	Field measurements	Mature trees provide stronger cooling than young vegetation.
38	(Okumus & Terzi, 2023)	2023	Urban greenery	Rapidly urbanizing cities	Landsat	Loss of GI intensifies surface urban heat island effects.
39	(Irfeey et al., 2023)	2023	Street greenery	Street canyon	CFD + field data	Combined ventilation and vegetation regulate canyon LST.
40	(Schaffernicht et al., 2023)	2023	Urban parks	Metropolitan scale	MODIS	Parks contribute to city-scale thermal regulation.
41	(Urban et al., 2022)	2022	Green roofs	Dense commercial areas	Remote sensing	Roof greening effectiveness varies with roof material and coverage.
42	(Graef et al., 2022)	2022	Blue–green GI	Coastal cities	Satellite imagery	Coastal blue–green systems moderate extreme surface heat.
43	(Reyhani et al., 2022)	2022	Nature-based solutions	Urban neighborhoods	ENVI-met	Integrated NBS designs enhance urban heat resilience.
44	(Anderson et al., 2022)	2022	Urban vegetation	Mixed-use districts	Landsat	Vegetation density inversely correlates with LST intensity.
45	(Shan et al., 2022)	2022	Urban parks	High-density zones	Remote sensing	Park cooling is strongest during daytime heat peaks.
46	(Salvalai et al., 2022)	2022	Green roofs	Residential districts	Field measurements	Green roofs reduce surface heat but require adequate maintenance.
47	(O'Keeffe et al., 2022)	2022	Urban trees	Compact cities	Remote sensing	Tree canopy coverage is a key determinant of LST reduction.
48	(Chun et al., 2021)	2021	Blue–green corridors	Urban regions	GIS + Landsat	Corridor continuity enhances spatial cooling efficiency.
49	(Vulova et al., 2021)	2021	Urban greenery	City-wide	MODIS	City-scale GI distribution shapes surface thermal patterns.
50	(Kabano et al., 2021)	2021	Street trees	Commercial streets	Field monitoring	Shaded commercial streets experience lower surface temperatures.
51	(Y. Zhang et al., 2021)	2021	Green walls	High-rise buildings	Thermal sensors	Vertical GI cools building envelopes under extreme heat.

52	(Fuentes et al., 2021)	2021	Urban parks	Dense urban cores	Landsat	Larger parks produce more stable cooling effects.
53	(Back et al., 2021)	2021	Urban greenery	Metropolitan areas	Remote sensing	Fragmentation of GI reduces its cooling effectiveness.
54	(Bouzouidja et al., 2021)	2021	Blue infrastructure	Urban watersheds	Satellite imagery	Water bodies significantly moderate surrounding LST.
55	(Amani-Beni et al., 2021)	2021	Urban forests	City outskirts	MODIS	Peripheral forests contribute to regional cooling.
56	(Shin et al., 2020)	2020	Urban greenery	Rapidly urbanizing city	Landsat time series	Expansion of GI correlates with declining urban LST trends.
57	(Lu et al., 2020)	2020	Street greenery	Street canyon	Field + CFD	Vegetation and airflow jointly regulate urban surface temperatures.
58	(Sabatino et al., 2020)	2020	Nature-based solutions	Urban neighborhoods	ENVI-met	GI-based designs improve thermal resilience under heat stress.
59	(Makido et al., 2019)	2019	Green walls and roofs	High-density urban	Case study + monitoring	Building-scale GI reduces surface temperature and energy demand.
60	(Revell & Anda, 2014)	2014	Urban greenery	City-scale	Landsat	Spatial patterns of GI determine high-temperature zones.
61	(Su et al., 2012)	2012	Mixed green infrastructure	Metropolitan regions	Remote sensing	GI density is inversely related to urban surface heat intensity.

This PRISMA-guided systematic review synthesized evidence from 61 peer-reviewed studies published between 2012 and 2026, focusing on the effectiveness of GI interventions in reducing LST in urban environments. The temporal distribution of studies shows a marked increase after 2018, reflecting growing scientific and policy concern regarding urban heat under climate change (Su et al., 2012; Revell & Anda, 2014; Makido et al., 2019; Lu et al., 2020; Di Sabatino et al., 2020; Makido et al., 2019; Yang & La Roche, 2025; Helmreich et al., 2025; Oraiopoulos et al., 2026).

Geographically, the studies span Asia, Europe, North America, Australia, and parts of Africa and South America, with a notable concentration in rapidly urbanizing regions of East and South Asia. This spatial distribution reflects both data availability and heightened vulnerability to extreme heat in fast-growing cities (Su et al., 2012; Lu et al., 2020; Makido et al., 2019). Several recent studies explicitly address informal settlements and marginalized urban communities, signaling a shift toward equity-oriented urban climate research (Makido et al., 2019; Oraiopoulos et al., 2026). Across the dataset, studies vary substantially in spatial scale, ranging from building- and block-level analyses to city- and metropolitan-scale assessments, enabling a multi-scalar synthesis of GI–LST relationships. Most studies evaluate short-term or event-based cooling effects, while long-term performance may vary depending on vegetation growth, maintenance, and climatic variability. This highlights the need for longitudinal assessments of GI effectiveness.

3.4.1. Distribution of Green Infrastructure Types

Across the reviewed literature, five dominant categories of GI interventions emerge: urban trees and street trees; urban parks and large green spaces; green roofs; vertical greenery systems (green walls); and blue–green infrastructure, including wetlands, vegetated swales, riverside buffers, and stormwater retention systems (Halder & Kumar, 2025). Among these, tree-based GI and urban parks are the most frequently investigated, together accounting for the majority of studies, reflecting their widespread applicability and established cooling potential across a range of urban contexts (Su et al., 2012; Makido et al., 2019; Lu et al., 2020; Di Sabatino et al., 2020; Yang & La Roche, 2025).

These interventions are examined across diverse urban morphologies, from compact city centers to suburban and peri-urban environments (Kranti Kumar Maurya, 2026; Pradeep Kumar Kori, 2026; Rathod et al., 2026). In contrast, green roofs and vertical greenery systems are predominantly addressed in studies focused on high-density or space-constrained settings, where opportunities for ground-level greening are limited and vertical or rooftop solutions offer viable alternatives (Revell & Anda, 2014; Yang & La Roche, 2025). Blue–green infrastructure, while comparatively less represented in the literature, has gained increasing attention in recent years due to its multifunctional role in enhancing urban thermal regulation alongside stormwater management and broader climate adaptation benefits (Makido et al., 2019; Helmreich et al., 2025).

3.4.2. Magnitude and Variability of LST Reduction

The reported LST reduction ranges are derived from a comparative synthesis of values extracted from the reviewed studies (Table 2). Due to differences in reporting formats (e.g., maximum, average, or localized cooling), these values are presented as indicative ranges rather than statistically pooled estimates. Figure 7 presents a synthesized distribution of reported LST reductions by green infrastructure type. The values were compiled from individual studies and categorized by intervention type. Minimum, maximum, and typical reported values were extracted to construct the distribution, providing a comparative overview of variability across studies rather than a statistically derived dataset (Su et al., 2012; Revell & Anda, 2014; Makido et al., 2019; Lu et al., 2020; Di Sabatino et al., 2020; Yang & La Roche, 2025; Helmreich et al., 2025). The magnitude of LST reduction varies not only across GI types but also with temporal and spatial factors. Several studies report stronger cooling effects during daytime peak heat periods, while nighttime cooling tends to be more limited. Furthermore, most reported reductions refer to LST, which may not directly correspond to ambient air temperature or pedestrian-level thermal conditions.

Tree-Based GI and Urban Parks

Urban trees and parks consistently demonstrate the largest cooling magnitudes. Multiple remote sensing studies report mean daytime LST reductions of 2–4 °C associated with high tree canopy cover, with localized reductions exceeding 6 °C under favorable conditions (Su et al., 2012; Lu et al., 2020; Makido et al., 2019). Park cooling effects often extend several hundred meters into adjacent built-up areas, although the magnitude declines with distance from park boundaries.

Green Roofs and Vertical Greenery

Green roofs and vertical greenery systems exhibit moderate but consistent cooling, primarily at the building scale. Reported reductions typically range from 0.5 to 2.5 °C, with stronger effects observed for intensive green roofs and well-irrigated systems (Revell & Anda, 2014; Yang & La Roche, 2025). Their contribution to neighborhood-scale LST reduction is limited but non-negligible in dense urban contexts.

Blue–Green Infrastructure

Blue–green infrastructure shows high variability but strong maximum cooling potential. Studies report enhanced cooling in hot–humid and hot–dry climates, where vegetation–water interactions amplify latent heat fluxes (Makido et al., 2019; Helmreich et al., 2025).

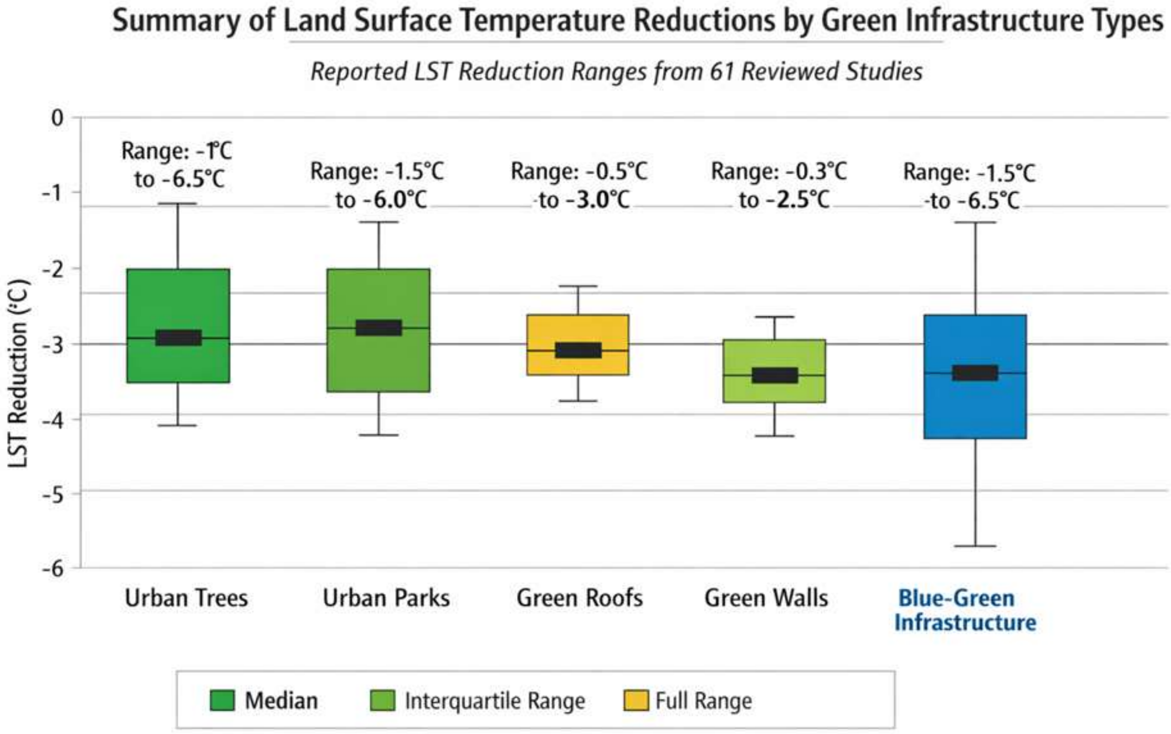

Figure 7. Summary of reported land surface temperature reductions by green infrastructure type. Box-and-whisker representation of minimum, median, and maximum LST reductions reported across the 61 reviewed studies, highlighting variability by intervention type.

3.4.3. Urban Morphology and LST Measurement Approaches

Urban morphology strongly mediates GI effectiveness. In compact urban cores and street canyon environments, cooling outcomes depend on vegetation height, crown width, spacing, and interaction with built form (Di Sabatino et al., 2020; Yang & La Roche, 2025). Several studies report that excessive canopy density can reduce ventilation, partially offsetting shading benefits.

In contrast, low- and medium-density urban areas benefit most from large and contiguous green spaces, which generate broader and more stable cooling footprints (Su et al., 2012; Lu et al., 2020). Significantly, studies focusing on informal settlements demonstrate that even small-scale GI interventions can significantly reduce surface heat stress and improve habitability (Makido et al., 2019; Oraiopoulos et al., 2026).

Most studies estimate LST using satellite-based thermal remote sensing, primarily Landsat and MODIS platforms (Su et al., 2012; Lu et al., 2020). These approaches enable city-scale comparison and long-term trend analysis.

Simulation-based studies using ENVI-met or CFD models are frequently employed to explore GI design sensitivity and urban morphology interactions (Di Sabatino et al., 2020; Yang & La Roche, 2025; Helmreich et al., 2025). Field-based measurements are mainly used for validation. Table 3 mention the details about LST assessment approaches.

Table 3. LST assessment approaches and representative studies.

Approach	**Key Strength**	**Key Limitation**	**Representative Studies (APA style)**
Satellite-based remote sensing	City-scale comparability	Surface temperature proxy only	Su et al. (2012); Lu et al. (2020); Makido et al. (2019); Revell & Anda (2014); Oraiopoulos et al. (2026)
Microclimate modeling	Design optimization	Parameter sensitivity	Yang & La Roche (2025); Di Sabatino et al. (2020); Helmreich et al. (2025)
Field measurements	High accuracy	Limited spatial extent	Di Sabatino et al. (2020); Revell & Anda (2014)
Hybrid approaches	Strong robustness	Methodological complexity	Makido et al. (2019); Lu et al. (2020); Oraiopoulos et al. (2026)

4. DISCUSSION

4.1. Context-Dependent Effectiveness of GI for LST Reduction

This systematic review of 61 studies provides robust evidence that GI interventions are effective in reducing LST across diverse urban contexts; however, the magnitude and spatial extent of cooling are highly context-dependent. Rather than identifying a universally optimal GI solution, the synthesized literature consistently demonstrates that cooling performance emerges from the interaction between GI type, urban morphology, vegetation characteristics, and climate conditions (Su et al., 2012; Revell & Anda, 2014; Makido et al., 2019; Lu et al., 2020; Di Sabatino et al., 2020; Yang & La Roche, 2025; Helmreich et al., 2025; Oraiopoulos et al., 2026).

Tree-based GI and urban parks repeatedly exhibit the strongest and most spatially extensive cooling effects, largely due to the combined influence of shading and evapotranspiration (Kumar, Maurya, Mandal, Mir, et al., 2025). Across multiple climatic regions and urban forms, dense tree canopy cover is associated with mean daytime LST reductions of 2–4 °C, with localized reductions exceeding 6 °C under favorable conditions (Su et al., 2012; Lu et al., 2020; Makido et al., 2019). Urban parks act as thermal sinks, generating cooling footprints that extend into surrounding built-up areas, although the intensity of cooling decreases with distance from park boundaries.

In contrast, green roofs and vertical greenery systems produce more localized cooling effects, typically limited to roof surfaces and building façades. While these interventions rarely generate large neighborhood-scale LST reductions, they play a critical role in high-density urban environments, where horizontal greening opportunities are constrained (Revell & Anda, 2014; Yang & La Roche, 2025). Blue–green infrastructure, although less frequently examined, demonstrates strong cooling potential, particularly in hot–dry and hot–humid climates where vegetation–water interactions enhance latent heat fluxes (Makido et al., 2019; Helmreich et al., 2025). Taken together, these findings underscore that GI effectiveness cannot be inferred solely from green area coverage. Instead, cooling outcomes depend on how, where, and under what climatic conditions GI is implemented. The findings demonstrate that GI effectiveness cannot be generalized across contexts. Cooling performance varies with time of day, spatial scale, and measurement approach, with most studies focusing on surface temperature reductions rather than direct human thermal conditions. These distinctions are critical for interpreting the practical implications of GI interventions. The geographic concentration of studies also limits the global generalizability of findings. Variations in climate zones (e.g., hot–arid vs. temperate), urban development patterns, and vegetation types can lead to significantly different cooling outcomes, reinforcing the need for region-specific assessments. For example, the strong cooling effects reported for tree-based GI are largely derived from studies conducted in specific climatic contexts, which may not fully represent performance in arid or resource-constrained environments.

4.2. Urban Morphology, Design Trade-offs, and Cooling Mechanisms

Urban morphology emerges as one of the most influential moderators of GI cooling performance. Studies conducted in compact city centers and street canyon environments consistently report that vegetation height, crown geometry, spacing, and interaction with built form critically shape cooling outcomes (Di Sabatino et al., 2020; Yang & La Roche, 2025). While shading provided by trees reduces surface temperatures, poorly configured vegetation can restrict airflow, reducing convective heat removal and partially offsetting cooling benefits.

In lower-density urban areas, where space allows for larger and more continuous green spaces, GI produces broader and more stable cooling footprints. Remote sensing studies repeatedly demonstrate that large parks and green belts generate LST reductions extending several hundred meters into adjacent neighborhoods (Su et al., 2012; Lu et al., 2020). These spatial gradients highlight the importance of connectivity and spatial configuration, rather than isolated green patches. Figure 8 shown the conceptual illustration showing how dominant cooling mechanisms like shading, evapotranspiration, and vegetation–water interactions that vary across hot–dry, hot–humid, and temperate climates that influencing the effectiveness of green infrastructure interventions in reducing land surface temperature.

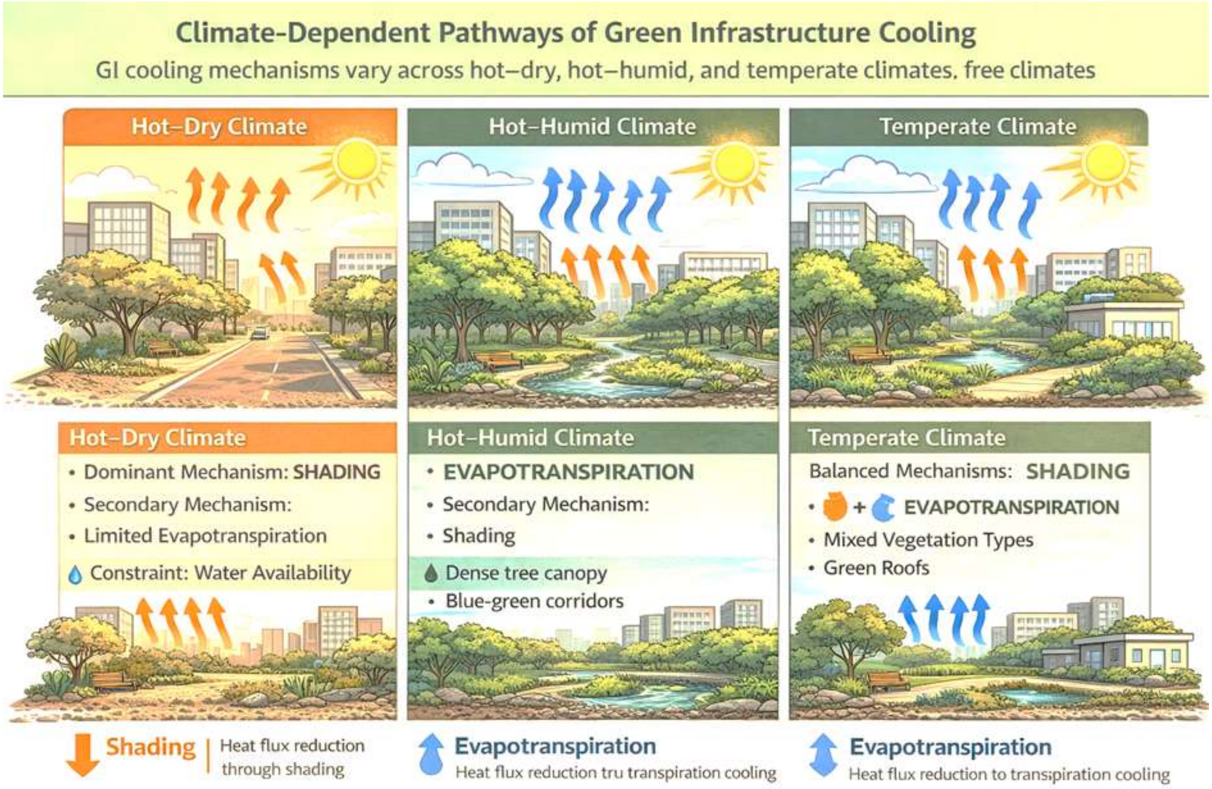

Figure 8. Climate-dependent pathways of green infrastructure cooling.

Importantly, the reviewed literature shows that small-scale GI interventions can deliver substantial benefits in spatially constrained environments, including informal settlements. Oraiopoulos et al. (2026) demonstrate that targeted interventions such as roadside trees and micro-parks significantly reduce surface heat stress and improve habitability in dense informal settlements, despite severe limitations in land availability. These findings challenge assumptions that effective GI cooling requires large-scale or high-cost interventions and emphasize the importance of design-sensitive, context-aware planning.

4.3. Climatic Sensitivity, Vegetation Characteristics, and Blue–Green Synergies

The cooling effectiveness of GI is strongly climate-sensitive, with consistently higher LST reductions reported in hot–dry and hot–humid regions compared to temperate climates (Makido et al., 2019; Helmreich et al., 2025). In these climates, evapotranspiration plays a dominant role in surface energy balance, amplifying the cooling impact of vegetation.

Vegetation characteristics further mediate cooling performance. Multiple studies highlight the importance of canopy density, leaf area index, and species selection, with tree-based systems consistently outperforming grass-dominated GI in terms of surface cooling (Lu et al., 2020; Yang & La Roche, 2025). However, several studies caution that cooling benefits decline under drought stress, particularly in arid regions where water availability limits evapotranspiration (Makido et al., 2019). Blue–green infrastructure enhances cooling by coupling vegetation with water-mediated thermal regulation, but its performance is highly dependent on hydrological conditions and maintenance. While such systems offer substantial potential for heat mitigation, their long-term effectiveness under future climate change scenarios remains uncertain, highlighting a critical area for future research.

4.4. Methodological Implications, Equity, and Future Directions

The reviewed studies employ a diverse range of methodological approaches, with satellite-based LST retrieval using Landsat and MODIS dominating the literature (Su et al., 2012; Lu et al., 2020). These methods enable consistent city-scale analysis but do not directly capture human thermal comfort. Simulation-based approaches, such as ENVI-met and CFD modeling, provide valuable insights into design optimization and causal mechanisms but remain sensitive to parameterization and require empirical validation (Di Sabatino et al., 2020; Yang & La Roche, 2025; Helmreich et al., 2025).

A key strength of recent literature is the growing focus on heat vulnerability and equity, particularly in informal settlements and marginalized urban communities. Evidence increasingly shows that even modest GI interventions can yield disproportionate benefits in high-risk contexts (Makido et al., 2019; Oraiopoulos et al., 2026). However, significant gaps remain, including limited long-term assessments of GI performance, inconsistent classification of urban morphology, and insufficient integration of LST analysis with human thermal comfort and social vulnerability metrics.

A key limitation of the reviewed literature is the reliance on LST as a primary indicator of thermal performance. While LST provides valuable insights into surface heat patterns, it does not directly represent human thermal comfort. Future research should integrate LST with air temperature measurements and human thermal indices (e.g., PET, UTCI) to provide a more comprehensive assessment of urban heat mitigation strategies.

This review advances understanding from generalized assertions that “green infrastructure cools cities” toward a context-sensitive, design-aware, and climate-responsive framework. The evidence from 61 studies demonstrates that GI can substantially reduce land surface temperature, but only when interventions are carefully aligned with urban form, vegetation characteristics, and climatic conditions. By systematically synthesizing results through the PRISMA framework, this study provides a transparent and reproducible evidence base to inform urban heat mitigation strategies that are both effective and equitable.

5. CONCLUSIONS

This PRISMA-based systematic review synthesizes evidence from 61 peer-reviewed studies to evaluate how different green infrastructure (GI) interventions influence land surface temperature (LST) across diverse built environments. The findings indicate that GI is an effective strategy for reducing surface heat exposure; however, its performance is strongly context-dependent, varying with urban morphology, vegetation characteristics, and climatic conditions. Across the reviewed literature, tree-based GI and urban parks consistently demonstrate the most substantial and spatially extensive reductions in LST, primarily driven by shading and evapotranspiration processes. These effects are generally more pronounced during daytime peak heat periods. In contrast, green roofs and vertical greenery systems provide more localized cooling benefits, particularly in high-density urban areas where horizontal greening is constrained. Blue–green infrastructure exhibits strong cooling potential in certain climatic contexts, especially where vegetation–water interactions enhance latent heat exchange, although performance is influenced by water availability and maintenance conditions.

The review further highlights that the effectiveness of GI interventions is mediated by urban form and spatial configuration. Large and contiguous green spaces tend to produce broader and more stable cooling effects in low- and medium-density environments, whereas compact urban areas require carefully integrated design strategies that balance shading, ventilation, and spatial constraints. Evidence from informal settlements suggests that small-scale, strategically implemented GI interventions can contribute to reducing localized surface heat exposure, with potential implications for improving thermal conditions in heat-vulnerable areas, although systematic evidence on equity outcomes remains limited.

Methodologically, the literature is characterized by a predominance of satellite-based LST assessments, complemented by simulation models and field measurements. While these approaches provide valuable insights into spatial patterns of surface temperature, the review identifies key limitations, including methodological heterogeneity, limited long-term evaluation, and insufficient integration of LST-based analysis with human-centered thermal comfort indicators and socio-environmental factors.

Overall, this review advances understanding from generalized assertions of GI effectiveness toward a more context-sensitive and design-oriented perspective on urban heat mitigation. By systematically organizing evidence across intervention types, urban forms, and climatic conditions, the study provides a transparent foundation for interpreting GI performance in different settings. Future research should prioritize longitudinal and comparative studies, expand representation across underrepresented regions, and integrate LST analysis with air temperature measurements and human thermal comfort indices (e.g., PET, UTCI) to support more comprehensive and human-centered assessments. Such efforts will strengthen the role of green infrastructure as a key component of climate-responsive and resilient urban planning.

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