A systematic review and scientometric analysis of urban heat island research: Trends, gaps, and perspectives

Review Article

Received: 2025/11/10
Revised: 2026/02/23
Accepted: 2026/04/26

HOW TO CITE THIS ARTICLE
RezaeiRad H. Sheikhi S. Fallaah Barzegar S. A systematic review and scientometric analysis of urban heat island research: Trends, gaps, and perspectives. *Urban Economics and Planning* 7(9):50-75.

DOI: 10.22034/uep.2026.557763.1771

Hadi RezaeiRad[1*], Saba Sheikhi[2], Sahar Fallaah Barzegar[3]

1. Assistant Professor, Department of Urban Planning, Faculty of Art and Architecture, Bu-Ali Sina University, Hamedan, Iran
2. Ph.D. Graduated in Urban Planning, Faculty of Art and Architecture, Tarbiat Modares University, Tehran, Iran
3. B.Sc. student, Department of Urban Planning, Faculty of Art and Architecture, Bu-Ali Sina University, Hamedan, Iran

Abstract

The urban heat island (UHI) phenomenon is one of the major challenges arising from urbanization and climate change, adversely affecting public health, energy consumption, and urban resilience. This study presents a systematic review combined with a scientometric analysis to organize existing knowledge, map research trends, and identify the factors contributing to the intensification of urban heat islands. Data were collected using relevant search terms from the Web of Science, Scopus, and Google Scholar databases. VOSviewer software was used to analyze the knowledge structure and visualize co-occurrence, co-authorship, and co-citation networks. A qualitative sample review was conducted to extract spatial and functional indicators. The results indicated that the number of publications increased steadily between 1999 and 2025, with a marked acceleration observed after 2018. Countries such as China, the United States, and Australia accounted for the largest share of publications. Keyword cluster analysis revealed four major thematic domains: urban climate and health, temperature and remote sensing, urban design and form, and mitigation strategies. In total, 23 influential spatial–functional indicators were identified, among which vegetation cover, impervious surface density, and albedo were found to be the most significant. The findings provide practical recommendations for mitigating urban heat island effects at both local and regional scales, prioritizing urban interventions, and supporting policymakers and urban planners in developing more climate-responsive urban environments.

Keywords

Climate change
Co-Authorship Network
Co-Citation
Co-Occurrence
Urban Heat Island
VOSviewer

* Corresponding Author: h.rezaeirad@basu.ac.ir

1. Introduction

Climate change, one of the most significant challenges of the twenty-first century, has exerted widespread impacts on both natural and human systems, with the effects particularly evident in urban environments. Among the climate-related consequences of urbanization, the urban heat island (UHI) phenomenon is recognized as one of the most prominent and challenging issues (Santamouris et al., 2019). This phenomenon refers to the increase in urban temperatures relative to surrounding rural areas and, in conjunction with global warming, has intensified the frequency and severity of heatwaves while amplifying climate-related risks at the local scale (Ramani et al., 2023). Urban heat islands result from the interaction between natural factors, including climatic characteristics, atmospheric conditions, and land topography, and anthropogenic factors such as urban design, construction, and planning practices (Hernández-Herráez et al., 2025; Huang et al., 2025).

From a theoretical perspective, UHI is commonly explained through the urban surface energy balance framework, which emphasizes the interactions among net radiation, sensible heat flux, latent heat flux, heat storage within the urban fabric, and anthropogenic heat emissions. Within this framework, changes in the physical properties of urban surfaces, such as albedo, thermal capacity of materials, surface roughness, and vegetation cover, shift the energy balance toward higher surface temperatures. In addition, urban morphology models, which focus on indicators such as the height-to-width ratio, sky view factor (SVF), and building density, explain the role of urban physical structure in either mitigating or intensifying heat accumulation (Ning et al., 2024). In recent years, integrated microclimatic approaches combining numerical models, remote sensing data, and field measurements have provided a multiscale framework for analyzing the thermal dynamics of cities, enabling a more comprehensive understanding of the spatial heterogeneity of urban heat. These conceptual frameworks also constitute the basis of the thematic clusters identified in the present scientometric analysis.

The significance of addressing this issue can be understood from three main perspectives. First, it has a direct impact on public health and human well-being. Second, it plays a critical role in enhancing urban resilience against climate-related stresses. Third, it has substantial implications for energy efficiency and environmental sustainability. During heatwave events, the co-occurrence of the urban heat island effect with elevated temperatures exacerbates thermal stress and increases the risk of heat-related mortality (Wang & Zhang, 2025; Zhao et al., 2018). Furthermore, extensive evidence indicates that the urban heat island phenomenon has been identified and documented in more than 400 cities worldwide (Zhou et al., 2019; Santamouris, 2020).

Recent studies indicate that UHI research has increasingly moved toward the use of high-spatial-resolution data, multiscale analyses, and advanced machine learning and deep neural network algorithms. These approaches have enabled the modeling of nonlinear relationships among land surface indicators, urban morphology, and land surface temperature, thereby substantially improving the capacity to predict urban hotspots (Akintola & Neziri, 2025; Kong et al., 2025; Lynda et al., 2025). Moreover, the integration of socioeconomic data with physical environmental data within emerging thermal analysis frameworks has contributed to the development of concepts such as urban thermal justice and climate-responsive urban planning. These developments reflect a transition in UHI studies from predominantly descriptive analyses toward data-driven, model-driven, and policy-oriented frameworks in recent years.

Despite the remarkable growth of research on UHI, a review of previous studies reveals that a large proportion of the existing literature remains case-specific and geographically limited, providing neither a comprehensive picture of the knowledge structure nor a systematic understanding of conceptual evolution and scientific collaboration networks. Furthermore, most existing review studies have focused primarily on thermal modeling or climatic analyses, while relatively little attention has been devoted to identifying the connections between environmental indicators and global scientific patterns. These limitations, fragmented findings, and the absence of an integrated perspective have constrained the understanding of research trajectories and hindered the development of coherent evidence-based policy frameworks. In light of the aforementioned conceptual foundations and recent methodological advancements, the need for an integrated scientometric analysis has become increasingly evident.

The novelty of the present study lies in the integration of two complementary approaches: scientometric analysis and systematic qualitative review. This combined approach enables the development of a comprehensive map of UHI research and, beyond identifying patterns of knowledge production and scientific collaboration, facilitates the extraction and analysis of environmental factors contributing to the formation and intensification of this phenomenon. Accordingly, by utilizing data retrieved from the Web of Science, Scopus, and Google Scholar databases and analyzing them through VOSviewer software, this study examines temporal publication trends, identifies leading countries, determines major thematic clusters, and investigates the indicators influencing UHI intensity.

Within this framework, the study addresses the following research questions:

1. What are the most significant factors and indicators influencing the formation and intensification of the urban heat island (UHI) phenomenon according to the scientific literature?
2. Which countries, institutions, and researchers have played the most influential roles in knowledge production within this field?
3. How have scientific collaboration structures and dominant conceptual clusters evolved in UHI research, and what are the emerging trends in this field?

2. Literature review

The urban heat island (UHI) phenomenon was first introduced in the early nineteenth century by Luke Howard, who in 1818 observed and documented a noticeable temperature difference between central London and its surrounding areas (Gartland, 2008). Subsequently, Gordon Manley popularized the term "urban heat island" in meteorological studies in 1958 (Aflaki et al., 2017). Although the earliest observations date back to the nineteenth century, systematic research on this phenomenon began in the 1980s (Mofidi & Zare Mohazzabieh, 2013). Over recent decades, both the scope and depth of UHI research have expanded considerably, and the focus of studies has evolved from basic and field-based investigations toward the application of advanced technologies such as remote sensing, urban climate modeling, and data-driven analyses. Issues related to climate justice, sustainable design, and urban resilience have also gradually emerged as major research themes (Halder et al., 2021; Peroni & Pappalardo, 2024; Zhao et al., 2025). This evolution has not only enhanced the scientific understanding of the mechanisms underlying urban heat island formation but has also contributed to the development of practical strategies for mitigating its impacts and improving the quality of life in urban environments. Numerous studies at both international and national levels have examined various dimensions of the UHI phenomenon. These studies exhibit substantial diversity in terms of research approaches, spatial scales, methodologies, and objectives. To provide an overview of the findings reported in the literature, Table 1 presents a summary of the most significant national and international studies related to the UHI phenomenon.

Table 1. Review of national and international studies related to the urban heat island phenomenon

Article title/authors/year	Study area	Methodology	Objective	Key findings
Urban heat island effect: A systematic review of spatio-temporal factors, data, methods, and mitigation measures (Deilami et al., 2018)	Review study	Systematic literature review	To systematically review global studies and identify spatiotemporal factors, datasets, methods, and mitigation strategies related to the urban heat island (UHI) effect	Urban density, land use, vegetation cover, and climatic conditions were identified as the primary factors influencing UHI intensity. Assessment methods included remote sensing and field observations, while mitigation strategies emphasized green spaces, cool roofs and surfaces, and sustainable urban design.
Factors influencing urban heat island formation with emphasis on urban design characteristics and challenges (Pouramin et al., 2020)	Review study	Qualitative approach and systematic review	To conduct a systematic review and thematic analysis of scientific studies on Urban Heat Islands	Findings indicated that UHI formation is influenced by both climatic factors and urban structural characteristics, with the extent and quality of urban vegetation cover playing the most significant role.
Assessing urban heat islands and thermal comfort in Noida City using geospatial technology (Sharma et al., 2021)	Noida City, India	Land surface temperature modeling and thermal simulations	To assess urban heat islands and thermal comfort conditions in Noida using geospatial technologies	Areas characterized by higher impervious surface coverage and lower vegetation density experienced stronger UHI intensity and reduced thermal comfort. Enhancing vegetation cover and improving green-space management were found to mitigate UHI effects.

Article title/authors/year	Study area	Methodology	Objective	Key findings
Investigation of urban heat islands in Tehran using satellite imagery (Fadaei, 2020)	Tehran Metropolitan Area, Iran	Descriptive-analytical approach using satellite imagery and GIS	To analyze the spatial distribution of urban heat islands in Tehran, with particular emphasis on vegetation cover	Areas with limited vegetation and high building density exhibited the highest land surface temperatures and represented major UHI hotspots. An inverse relationship was observed between NDVI and land surface temperature.
Surface urban heat island assessment of a cold desert city: A case study over the Isfahan Metropolitan Area of Iran (Karimi et al., 2021)	Isfahan Metropolitan Area, Iran	Statistical modeling	To evaluate Surface Urban Heat Island Intensity (SUHII) using satellite-derived data	SUHII increased over time in Isfahan and exhibited the strongest negative correlations with vegetation cover and evapotranspiration. Areas characterized by low albedo and high building density recorded the highest surface temperatures.
Relationship between air temperature, mean radiant temperature, and albedo in mitigating urban heat islands (Haji Fathali et al., 2021)	Poonak Neighborhood, Qazvin, Iran	Quantitative analysis, field surveys, and modeling	To investigate the effects of air temperature, mean radiant temperature, and albedo on UHI intensity and identify mitigation strategies	Increased albedo and reduced mean radiant temperature significantly decreased UHI intensity. The use of high-reflectance materials and the expansion of green spaces were identified as the most effective mitigation measures.
Impacts of COVID-19 Lockdown on urban heat islands in urban, industrial, and green areas of Tehran (Nojavan & Tabib-Mahmoudi, 2022)	Industrial and green-space areas of Tehran, Iran	Quantitative analysis using land surface temperature data	To examine the effects of COVID-19 lockdown measures on UHI intensity in Tehran	Lockdown measures reduced surface temperatures in industrial zones and enhanced the cooling performance of green spaces. A significant inverse relationship was identified between vegetation cover and land surface temperature.
Correlation analysis of macro-scale natural and built environment factors with urban heat island intensity (Ghasemi et al., 2023)	Isfahan, Iran	Pearson correlation analysis and SPSS	To investigate the relationship between UHI intensity and macro-scale natural and built-environment factors using remote sensing data	Urban compactness was identified as the primary factor intensifying UHI effects. Air pollution showed a limited relationship with daytime land surface temperature, whereas vegetation cover had the strongest moderating effect on UHI intensity.
Temporal variations of urban heat islands and their relationship with air pollution using remote sensing in Kerman (Mazidi et al., 2023)	Kerman, Iran	Quantitative remote sensing analysis	To examine temporal changes in Urban Heat Islands and their relationship with air pollution	Increasing land surface temperature was associated with higher levels of air pollution. Areas characterized by sparse vegetation and barren land were more susceptible to UHI formation. Remote sensing proved to be an effective tool for monitoring and mitigating UHI impacts.
Urban heat island differentiation and influencing factors: A local climate zone perspective (Ning et al., 2024)	Local climate zones (LCZs) within the study area	Remote sensing, correlation analysis, and modeling	To investigate variations in UHI intensity and influencing factors from a Local Climate Zone perspective	Significant differences in UHI intensity were observed among LCZ types. Dense urban development and impervious surfaces increased UHI intensity, whereas vegetation and water bodies contributed to thermal mitigation.
Efficiency assessment for urban heat island mitigation measures in a city with an oceanic climate during the summer (Morales-González et al., 2024)	Valdivia, Chile	Quantitative microclimate-based modeling	To evaluate the effectiveness of UHI mitigation measures in improving thermal comfort and reducing energy consumption during summer	Increasing vegetation cover and applying high-reflectance materials effectively reduced land surface temperatures and improved thermal comfort conditions.
Adaptive analysis of the relationship between residential physical indicators and the distribution of urban heat islands in Tabriz (Badri-Asl et al., 2024)	Tabriz, Iran	Quantitative analysis using remote sensing and statistical techniques	To examine the role of urban physical indicators in reducing UHI intensity in Districts 2 and 8 of Tabriz	Residential physical characteristics significantly influenced the formation and intensity of UHI. Appropriate urban form and improved physical indicators contributed to reducing land surface temperatures and mitigating UHI effects.

Article title/authors/year	Study area	Methodology	Objective	Key findings
Assessment of urban heat island using remote sensing and geospatial applications: A case study in São Paulo, Brazil (Venkatraman et al., 2024)	São Paulo, Brazil	Quantitative and descriptive analysis using satellite data	To analyze the intensity and spatial distribution of UHI using remote sensing and geospatial technologies	Dense urban development and limited vegetation cover were identified as major drivers of increased land surface temperature and UHI intensity. Expansion of green infrastructure was found to be an effective mitigation strategy.
Analysis of the impact mechanisms and driving factors of urban spatial morphology on urban heat (Huang et al., 2025)	Central and peripheral areas of Tianjin, China	Remote sensing analysis using the XGBoost model	To identify the principal urban factors influencing land surface temperature and urban spatial structure	Three-dimensional urban characteristics, particularly building density and height, together with socioeconomic factors, were identified as the most influential drivers of urban heat. Their effects varied between central and peripheral urban areas.

A review of the studies presented in Table 1 indicates that the majority of research has focused on examining the relationships between urban physical and environmental variables, such as building density, vegetation cover, albedo, and land-use patterns and intensity of UHIs. Many of these studies have employed remote sensing data and spatial analysis techniques to identify thermal hotspots, consistently reporting a significant relationship between reduced vegetation cover and increased land surface temperature. In addition, international systematic reviews focusing on spatiotemporal factors have identified thermal mitigation strategies, including reflective surfaces, green roofs, and climate-responsive urban design, as some of the most effective approaches for addressing this phenomenon.

Domestic studies, particularly those conducted in recent years, have primarily concentrated on the spatial analysis of UHI in metropolitan areas such as Tehran, Isfahan, and Tabriz. These studies have emphasized the role of building density and urban compactness in intensifying the phenomenon while also highlighting the importance of urban design and the use of high-reflectance materials in reducing thermal impacts. Nevertheless, most of these investigations are case-specific and regionally focused, and comparative inter-climatic analyses as well as large-scale national studies remain relatively underexplored. Furthermore, although a substantial proportion of the literature relies on remote sensing techniques and modeling approaches, limited attention has been given to the conceptual integration of physical, environmental, and social indicators.

Overall, the review of previous studies demonstrates that while the role of physical indicators such as vegetation cover and albedo in mitigating UHI has been well established, more comprehensive analyses are required to better understand the interactive effects of natural, physical, and social factors across different urban scales. Moreover, from a scientific perspective, a methodological gap remains in integrating quantitative approaches, including scientometric and data-driven analyses, with qualitative assessments that emphasize conceptual and policy-oriented dimensions. Consequently, there is a need for a comprehensive study that not only systematically reviews the existing literature but also maps the knowledge structure of UHI research at the international level, thereby identifying knowledge gaps and emerging research trends. Accordingly, the following section examines the theoretical foundations of the study, including the conceptual framework and explanatory models of the UHI phenomenon, to provide the necessary theoretical basis for the analysis and interpretation of the findings.

3. Theoretical foundations

The urban heat island (UHI) phenomenon, one of the most widely recognized consequences of urbanization and climate change, has attracted scholarly attention for over two centuries. As illustrated in Table 2, the definition of UHI has evolved from early empirical descriptions to energy-based interpretations and, more recently, to conceptual frameworks such as the local climate zone (LCZ) approach. This conceptual evolution has provided the theoretical foundation for contemporary analyses of the factors influencing the intensity and spatial distribution of UHIs.

Table 2. Historical evolution of definitions and conceptualizations of the urban heat island phenomenon

Article title	Author(s)	Year	Definition of urban heat island (UHI)
The climate of London: Deduced from meteorological observations made in the metropolis and at various places around it	Howard	1818–1833	The first documented observations indicated that urban temperatures are higher than those of surrounding rural areas. The study focused on the influence of topography and land cover, although a formal scientific definition of UHI had not yet been established.
City size and urban heat island	Oke	1972	UHI was defined as a phenomenon in which urban air temperatures exceed those of surrounding rural environments, primarily due to surface modifications and human activities.
City size and urban heat island	Oke	1973	UHI was described as the temperature difference between urban and rural areas, with its intensity increasing according to city size and urban density.
The urban climate	Landsberg	1981	UHI was defined as the increase in urban temperatures relative to rural areas, resulting from building concentration, reduced evapotranspiration, and anthropogenic activities. This represented one of the first comprehensive and systematic definitions of the phenomenon.
The energetic basis of the urban heat island	Oke	1982	UHI was conceptualized as an energy-balance phenomenon caused by land-cover modification, heat storage within urban materials, reduced evapotranspiration, and anthropogenic heat emissions. This framework became the theoretical basis for many subsequent UHI studies.
Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island	Arnfield	2003	UHI was characterized as elevated urban temperatures relative to surrounding areas, driven by land-cover changes, urban structures, and human activities. The study also provided a comprehensive review of urban climate research.
The impact of urbanization and climate change on urban heat island intensity and cooling potential of green infrastructure	Chapman et al.	2017	UHI occurs when cities are warmer than adjacent rural areas. Urban density and vegetation loss intensify the phenomenon through mechanisms such as reduced evapotranspiration, increased anthropogenic heat, altered albedo, and urban canyon effects.
A systematic review and scientific critique of the urban heat island literature	Stewart	2021	UHI was defined as the air-temperature difference between urban and rural environments. The study highlighted limitations of conventional definitions and introduced the local climate zone (LCZ) framework as a standardized approach for UHI classification and comparison.
Contrasting trends and drivers of global surface and canopy urban heat islands	Du et al.	2023	The study distinguished between surface urban heat islands (SUHI), based on land surface temperature, and canopy urban heat islands (CUHI), based on near-surface air temperature. It demonstrated that these two forms exhibit different global trends and are influenced by distinct climatic and surface-related drivers.

To provide a coherent understanding of the theoretical evolution of the urban heat island (UHI) phenomenon, the conceptual development of this field can be explained through a staged and chronological framework. In the first stage, early studies, primarily based on empirical observations and field measurements, focused on identifying temperature differences between urban areas and their surrounding environments and were mainly concerned with describing the phenomenon. In the second stage, with the development of the urban surface energy balance (USEB) theory, physically based and model-oriented approaches emerged, to explain the mechanisms of energy transfer and storage within the urban fabric. The third stage was characterized by the expansion of urban morphology studies and the analysis of indicators such as building density, sky view factor (SVF), and land-use patterns, with particular attention given to the role of urban physical structure in either intensifying or mitigating urban heat. Finally, the fourth stage, which coincided with advances in remote sensing technologies, numerical modeling, and big data analytics, introduced integrated and multiscale approaches that incorporated not only physical dimensions but also social, economic, and thermal justice considerations into analytical frameworks. This staged classification provides a more comprehensive understanding of the theoretical evolution of the field and the relationships among different research approaches.

The theoretical evolution of the UHI phenomenon has not only deepened scientific understanding of the phenomenon but has also generated important practical implications for urban design and planning. Based on a systematic review of both national and international studies, the USEB framework has served as the foundation for developing the mitigation strategies, including increasing surface albedo, employing materials with appropriate thermal properties, modifying land-use patterns, expanding green spaces, and reducing anthropogenic heat emissions within urban environments. Morphological studies, emphasizing indicators such as urban density, height-to-width ratio, sky view factor (SVF), floor area ratio (FAR), shading, and building-height diversity, have contributed to improving urban layout patterns and enhancing natural ventilation. Socioeconomic indicators, including population density, human activities, nighttime light intensity, public infrastructure, and per capita income, have also been recognized as important determinants of urban thermal conditions. More recently, the integration of remote sensing data with microclimatic modeling has enabled the identification of urban hotspots and the prioritization of spatial interventions, thereby supporting the formulation of climate-responsive policies, the development of green infrastructure, and the promotion of thermal equity at the neighborhood scale. Consequently, the theoretical evolution of this field has been directly reflected in the development of practical strategies aimed at mitigating thermal impacts and enhancing urban resilience.

An examination of Table 3 reveals that vegetation-related indicators, particularly the normalized difference vegetation index (NDVI), together with surface albedo, exert the strongest negative (mitigating) effects on land surface temperature. In contrast, impervious surfaces and building density have consistently positive (intensifying) effects on urban warming. From a socioeconomic perspective, indicators such as population density and human activity, when combined with physical environmental factors, further contribute to the intensification of UHI. This three-dimensional classification forms the conceptual foundation of the present study. By employing scientometric analysis in conjunction with a systematic qualitative review, this research investigates the relationships among these indicators through knowledge networks and thematic research clusters to explain the interactions among natural, physical, and social determinants in the formation and evolution of the UHI phenomenon.

Table 3. Indicators influencing the urban heat island phenomenon based on a review of selected scientific studies

Indicator	Category	Effect on land surface temperature (LST)	Additional description
NDVI (normalized difference vegetation index)	Land surface	Temperature reduction	Higher vegetation cover contributes to greater cooling effects.
NDWI (normalized difference water index)	Land surface	Temperature reduction	Its effect is often influenced by interactions with other indicators, particularly NDVI.
Albedo (surface reflectance)	Land surface	Temperature reduction	High-reflectance surfaces reduce heat absorption by reflecting incoming solar radiation.
Impervious surface area	Land surface	Temperature increase	Impervious materials such as asphalt and concrete intensify heat accumulation.
LST (land surface temperature)	Dependent variable	Primary indicator	Represents temperature differences between urban and non-urban areas.
Building height	Urban form	Temperature reduction	Building height influences heat storage and airflow patterns within urban environments.
Building density	Urban form	Temperature increase	Higher density reduces ventilation and enhances heat accumulation.
Sky view factor (SVF)	Urban form	Temperature reduction	Lower SVF values are generally associated with greater heat retention.

Indicator	Category	Effect on land surface temperature (LST)	Additional description
Floor area ratio (FAR)	Urban form	Temperature increase	Higher development intensity is typically associated with elevated urban temperatures.
Population density	Socioeconomic	Temperature increase	Greater population concentrations intensify anthropogenic heat generation.
Land use type	Land surface	Variable	Effects vary according to land-use characteristics (e.g., vegetation, water bodies, or built-up areas).
Green space ratio	Land surface	Temperature reduction	Higher proportions of green space contribute to urban cooling.
Transportation index	Socioeconomic	Temperature increase	Transportation activities generate additional heat, increasing surface temperatures.
Nighttime light index	Socioeconomic	Temperature increase	Serves as a proxy for urbanization intensity and human activities.
Per capita income	Socioeconomic	Variable	The relationship varies depending on urban development patterns and local conditions.
Public infrastructure score	Socioeconomic	Temperature increase	Extensive infrastructure development is often associated with increased heat accumulation.
Building height diversity	Urban form	Variable	Its influence depends on interactions with indicators such as NDVI and SVF.
Public green space	Land surface	Temperature reduction	Provides localized cooling effects, although its influence may vary in magnitude.
Shadowing	Urban form	Temperature reduction	Increased shading reduces solar heat gain, whereas insufficient shading contributes to warming.
Anthropogenic heat	Socioeconomic	Temperature increase	Human activities, including transportation, industry, and energy consumption generate heat.
Wind speed	Land surface / climatic factor	Temperature reduction	Enhanced airflow facilitates heat dissipation and improves thermal conditions.
Cloud cover	Land surface / climatic factor	Temperature reduction	Influences incoming solar radiation and surface temperature dynamics.
NDBI (normalized difference built-up index)	Land surface	Temperature increase	Represents urban density and built-up surfaces that contribute to heat accumulation.

Based on the systematic review of previous studies and the analysis of the extracted knowledge clusters, a process-oriented framework can be proposed to explain the mechanisms underlying the formation and intensification of UHIs. Within this framework, climate change and urbanization processes act as macro-level drivers that, through their influence on urban physical structure and land-surface characteristics, initiate transformations in the urban energy balance system. The interactions among urban morphology, land-surface properties, and socioeconomic factors affect patterns of radiation absorption and reflection, heat storage, evapotranspiration, airflow dynamics, and anthropogenic heat emissions. At the process level, these interactions result in increased land surface temperatures and urban air temperatures, thereby intensifying the UHI effect.

The intensification of UHI, in turn, leads to a range of consequences, including reduced thermal comfort, increased energy consumption, and heightened public health risks. Conversely, climate-responsive urban design and planning strategies, the development of green infrastructure, and improvements in the reflective properties of urban surfaces can function as feedback mechanisms that contribute to moderating the urban energy system. Accordingly, the conceptual framework of the present study explains the interactive relationships among urban structure, land-surface characteristics, and energy-related processes within the context of broader macro-level drivers. This framework provides the theoretical foundation for the scientometric analysis and the organization of the thematic research clusters examined in this study (Figure 1).

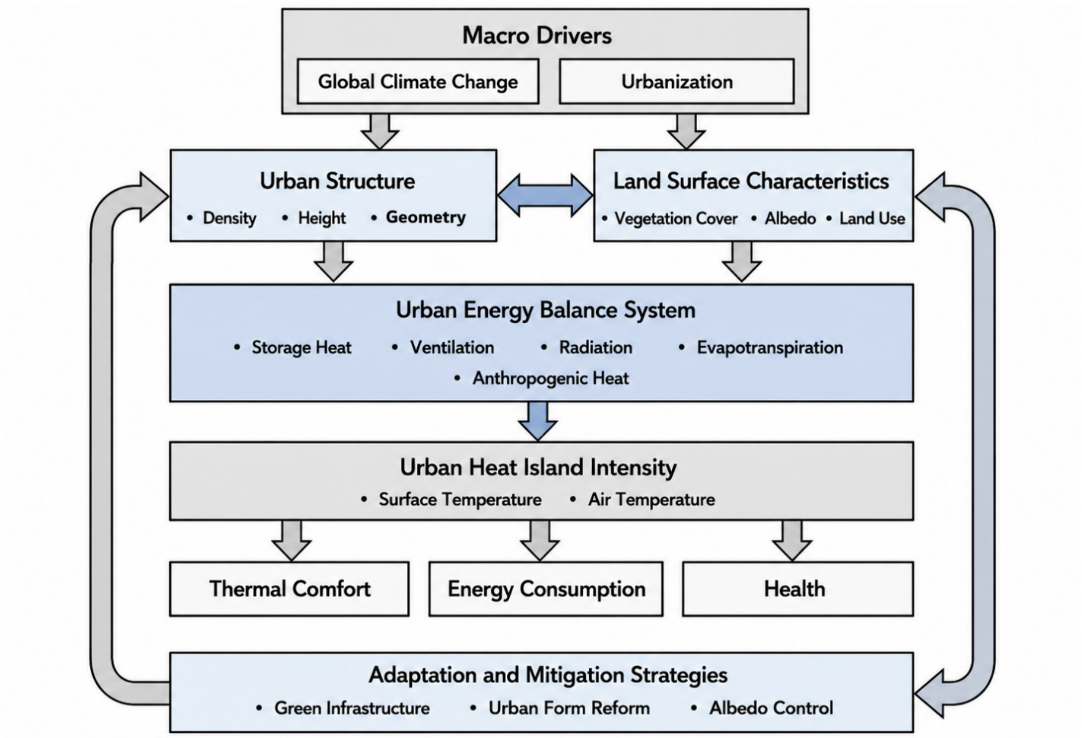

Figure 1. Process-oriented conceptual framework of the study for explaining factors influencing urban heat island intensity

4. Methodology

This study was designed based on a systematic literature review approach combined with scientometric analysis methods. The primary objective is to identify research trends, conceptual themes, and knowledge structures related to the urban heat island (UHI) phenomenon within the global scientific literature and to provide insights into future research directions. The study adopts an applied mixed-methods design (qualitative–quantitative). In the first stage, a systematic content analysis was conducted to extract key indicators and theoretical themes. In the second stage, scientometric techniques were employed to analyze the knowledge structure and scientific collaboration networks within the field.

4.1. Research procedure

Stage 1: Systematic review of the scientific literature

In the first stage, the theoretical and empirical literature related to UHI was systematically reviewed to identify the conceptual framework and the key influencing indicators. The systematic review was conducted in accordance with the PRISMA 2020 guidelines and consisted of three screening phases: title screening, abstract screening, and full-text review. To ensure transparency and reproducibility, the systematic review protocol was developed based on the SPAR-4-SLR framework, which is described in Table 4.

Table 4. Conceptual design and search strategy of the study for the systematic review of urban heat island research

Research design components	Description
Databases	Web of Science Core Collection, Scopus, and Google Scholar
Keywords and search strategy	(“Urban heat island” or “UHI”) and (“urban climate” or “surface temperature”) and (“mitigation” or “green infrastructure” or “urban design”)
Time period	1999–2025
Document types	Research articles, review articles, and conference papers

Research design components	Description
Language	English
Inclusion criteria	Studies containing empirical data, modeling approaches, or analytical investigations related to UHD, published in reputable indexed journals.
Exclusion criteria	Studies lacking direct relevance to urban environments or urban climate, studies without full-text availability, and non-peer-reviewed reports or publications.

The screening process was conducted independently by two researchers, and any disagreements were resolved through consensus. Based on the predefined inclusion and exclusion criteria, a three-stage screening procedure (title, abstract, and full-text review) was performed. From an initial pool of 1,245 records, a total of 292 articles were ultimately selected for the final synthesis. Of these, 180 articles were included in the qualitative analysis, while 112 articles were incorporated into the scientometric analysis (Figure 2).

Stage 2: Qualitative synthesis of the literature

Following the screening process based on the PRISMA guidelines and the identification of eligible studies, 180 articles were included in the qualitative synthesis stage. The purpose of the qualitative synthesis was to systematically extract the indicators, variables, and theoretical themes associated with factors influencing UHI intensity. At this stage, a thematic content analysis approach was employed to identify and categorize recurring conceptual patterns within the literature. The inclusion and exclusion criteria were established before the analysis and included: direct relevance to the UHI phenomenon; provision of empirical data, modeling approaches, or analytical investigations; a focus on physical, environmental, or socioeconomic indicators; and publication in peer-reviewed journals. Studies lacking a specific focus on urban environments, purely theoretical studies without a clearly defined analytical framework, and publications without accessible full-text versions were excluded from the synthesis process.

Each article was treated as a unit of analysis, and information regarding the indicators employed, variables examined, and principal findings related to UHI intensity was systematically extracted.

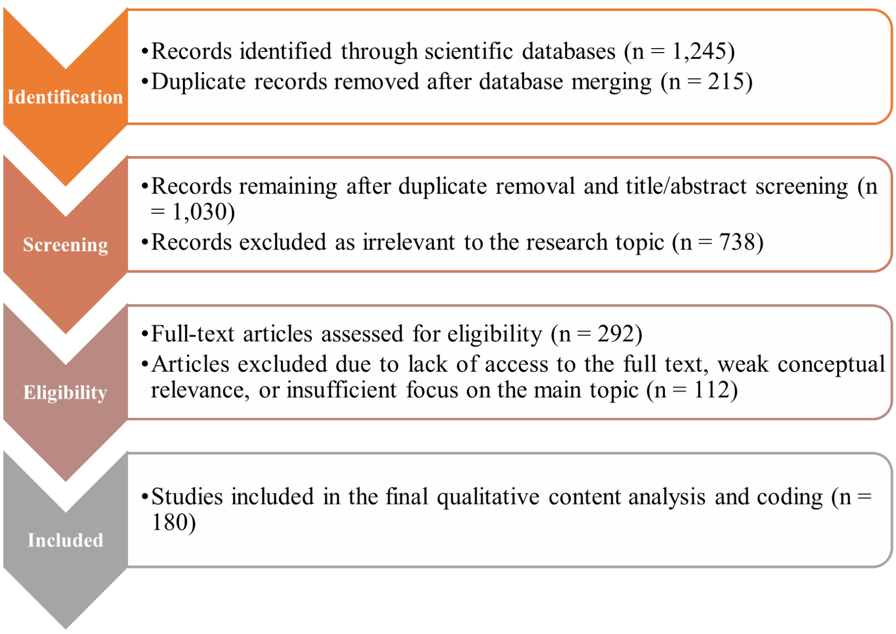

Figure 2. PRISMA 2020 flow diagram for the study screening and selection process

Stage 3: Coding process and indicator extraction

To enhance accuracy and reproducibility, the coding process was conducted in two stages. In the first stage, open coding was independently performed by two researchers, and all concepts, indicators, and variables associated with UHI intensity were extracted. This stage was primarily inductive in nature, aiming to identify the broad spectrum of factors discussed in the literature. Subsequently, axial coding was conducted using an integrated inductive–deductive approach. During this stage, the extracted indicators were classified according to the study's theoretical framework into three principal dimensions:

1. Land surface characteristics (e.g., vegetation cover, albedo, and impervious surfaces);
2. Urban morphology and physical structure (e.g., density, building height, and urban geometry);
3. Socio-economic factors and anthropogenic heat.

Disagreements between coders were resolved through discussion and consensus to ensure analytical consistency. Ultimately, the most frequently reported indicators and dominant themes were identified, serving as the basis for developing the study's conceptual framework.

Stage 4: Scientometric analysis

In the fourth stage, a scientometric analysis was conducted to map the knowledge structure and scientific collaboration networks within the UHI research. Scientometrics is a branch of science studies that employs quantitative methods to analyze patterns of scientific knowledge production, dissemination, and citation, thereby facilitating the understanding of knowledge structures, research trends, and existing gaps (Hood & Wilson, 2001).

In this study, scientometric analysis was performed using VOSviewer software (Version 1.6.20) and data retrieved from the Web of Science Core Collection, Scopus, and Google Scholar databases. The Web of Science database was selected as one of the primary scientometric data sources due to its extensive coverage of peer-reviewed international journals, standardized citation structure, and widespread application in bibliometric studies. Owing to the consistency of its citation data and its capability to accurately extract co-citation relationships, bibliographic coupling, and scientific collaboration networks, Web of Science is considered one of the most reliable sources for network-based scientometric analyses. The concurrent use of Scopus and Google Scholar was intended to enhance the comprehensiveness of document retrieval and minimize the risk of excluding relevant studies. Nevertheless, all datasets used in the network analyses were standardized and normalized following data cleaning procedures to ensure analytical consistency. VOSviewer enables the visualization of co-authorship networks, keyword co-occurrence networks, and co-citation relationships (Van Eck & Waltman, 2010). The scientometric analysis comprised six main components:

1. Keyword co-occurrence analysis to identify conceptual structures;
2. Overlay visualization analysis to detect emerging topics and temporal trends;
3. Density visualization analysis to illustrate the intensity of conceptual relationships;
4. Country co-authorship analysis to map international scientific collaboration networks;
5. Bibliographic coupling analysis of organizations to identify leading institutions; and
6. Author co-citation analysis to determine influential scholars within the field.

The search strategy included the terms 'heat island" in the topic field, "urban heat island" in the title field, and "urban design" across all searchable fields. These keywords were selected based on a preliminary review of the literature and the identification of the most frequently used and conceptually central terms in UHI research. The combination of terms related to "urban heat island" as the core conceptual focus, together with complementary terms associated with urban climate and urban design, was intended to simultaneously capture climatological, physical, and strategic dimensions of the literature. This approach facilitated the retrieval of studies specifically related to urban environments while minimizing the inclusion of research conducted in non-urban contexts. Nevertheless, restricting the search to these terms may have resulted in the exclusion of studies employing alternative terminology or different conceptual frameworks, which represents an inherent limitation of any systematic search strategy.

The literature search was conducted on 17 May 2025, yielding a total of 604 scientific documents, including 498 research articles, 74 conference papers, and 33 review articles. The most recent publication dates from 2025, whereas the earliest publication dates from 1999. The collected dataset included information related to authors, countries, institutions, keywords, and citations. Since the data retrieval process was completed on 17 May 2025, the findings reflect the state of the indexed literature available up to that date. Publications released in recent years, particularly during 2024 and 2025, may not yet have accumulated sufficient citations and therefore may appear less prominently in co-citation analyses and network linkage assessments. This issue may introduce a temporal bias into citation-based analyses. Furthermore, indexing processes within scientific databases are inherently subject to delays, meaning that some recently published documents may not yet have been fully indexed at the time of data collection. Consequently, the scientometric findings of this study should be interpreted within the specified temporal framework, acknowledging that the structure of scientific networks may evolve as databases are updated in the future.

4.2. Analysis Parameters and Software Settings

To ensure the transparency and reproducibility of the scientometric analysis, the key parameters employed in VOSviewer are presented in Table 5. These parameters include the type of analysis, data inclusion thresholds, normalization methods, and clustering algorithms. The selected thresholds were determined based on standard practices in bibliometric network analysis (Van Eck & Waltman, 2010), to maintain network coherence and minimize data noise. All datasets were extracted from the selected databases and subsequently standardized and normalized before analysis. The resulting knowledge maps were generated using fixed analytical settings to ensure methodological consistency and reproducibility.

In the final stage, the findings of the systematic review were integrated with the scientometric results. This integrative approach enabled the identification of the most frequently reported indicators across the three principal dimensions of land surface characteristics, urban morphology, and socio-economic factors, while simultaneously revealing emerging research trends and existing knowledge gaps within the field. The combination of systematic review findings with scientometric evidence provided a more comprehensive understanding of the conceptual evolution, intellectual structure, and policy-oriented dimensions of UHI research.

Table 5. Configuration parameters and normalization methods applied in the VOSviewer-based scientometric analyses

Analysis type	Network inclusion threshold	Normalization method	Clustering algorithm
Keyword co-occurrence analysis	≥ 14 keyword occurrences	Association strength	LinLog / modularity-based clustering
Country co-authorship analysis	≥ 5 collaborative links	Fractional counting	Modularity optimization (resolution = 1.00)
Organizational bibliographic coupling analysis	≥ 4 shared citations	Fractional counting	Vos clustering (resolution = 1.00)
Author co-citation analysis	≥ 4 citations	Fractional counting	Modularity-based clustering
Overlay and density visualization analyses	Based on occurrence frequency and publication year	Association strength	No clustering applied (scalable visual representation)

5. Findings

Visualization is recognized as an effective tool for analyzing, interpreting, and communicating information in scientometric studies. The purpose of this section is to elucidate the conceptual relationships, knowledge structures, and scientific collaboration networks within the UHI research. To facilitate a clearer understanding of the analytical procedures and network visualizations presented in this study, the key scientometric concepts and visualization metrics are introduced in Table 6.

Table 6. Definitions of key analytical concepts and visualization elements used in VOSviewer

Term	Definition
Item (node)	Items represent the entities under investigation in a scientometric study, such as authors, keywords, countries, organizations, or publications.
Link	A link represents the connection or relationship between two items within a network.
Link strength	A positive numerical value indicating the intensity of the relationship between two items. Higher values represent stronger connections.
Network	A network consists of a set of interconnected items and the links established among them.

Term	Definition
Cluster	A group of closely related items within a network. Clusters are identified through clustering algorithms and are typically distinguished by different labels or colors.
Network visualization	A graphical representation of the relationships among items and their links within a network.
Overlay visualization	A visualization technique similar to network visualization, but with item colors assigned according to an additional attribute, such as publication year or citation impact.
Density visualization	A visualization method used to highlight the most important and densely connected regions of a network, facilitating the interpretation of its overall structure.
Co-occurrence	The simultaneous appearance of two or more items within the same document. In keyword analysis, co-occurrence is used to identify major themes, research topics, and emerging trends within a field of study.
Co-citation	Co-citation occurs when two documents are cited together in a third document. A higher frequency of co-citation generally indicates a stronger intellectual or thematic relationship between the cited documents.
Bibliographic coupling	Bibliographic coupling occurs when two documents cite one or more common references. The greater the number of shared references, the stronger the bibliographic coupling between the documents. This concept can be considered the inverse of co-citation analysis.
Co-authorship	Co-authorship refers to collaboration among researchers in producing scientific publications, which reflects patterns of scientific cooperation within a research field.
All keywords	In co-occurrence analysis, this category includes author keywords, indexed keywords, and terms automatically extracted from bibliographic databases, including titles, abstracts, and metadata.

5.1. Analysis of the co-occurrence of two items in network visualization

Keyword co-occurrence analysis was employed to identify conceptual relationships among frequently occurring keywords. This method enables the exploration of hidden structures within a research field, the identification of prominent keywords, and the examination of their interconnections. The analysis was conducted using VOSviewer software and visualized through a network map. In this network, nodes represent keywords and are displayed as labeled circles. The size of each node is determined by its weight; larger nodes indicate higher significance or frequency. The lines connecting nodes represent the co-occurrence relationships of keywords across different documents. The thickness of the connecting lines reflects the strength of the relationship (Total Link Strength) between keywords, while the spatial proximity of nodes indicates the degree of conceptual relatedness. The shorter the distance between two nodes, the stronger their relationship and the more frequently they appear together within the same document. Furthermore, keywords are grouped into clusters distinguished by different colors, with each cluster representing a specific conceptual domain within the literature under investigation.

Among the 2,699 items identified from the articles retrieved from the selected databases, 60 items met the minimum threshold of 14 occurrences. The co-occurrence of keywords reflects stronger conceptual associations among them and may reveal emerging research directions within the field. After a screening process to remove duplicate and irrelevant terms, a total of 52 keywords were retained for the final analysis. The keyword “urban heat island” ranked first with a total link strength of 874 and a co-occurrence frequency of 48. The keywords “impact” and “city” ranked second and third, with total link strengths of 602 and 428, respectively, and co-occurrence frequencies of 50 for both terms. The keyword “remote sensing” ranked last in the network, with a total link strength of 54 and a co-occurrence frequency of 30. Figure 3 presents the overall network visualization.

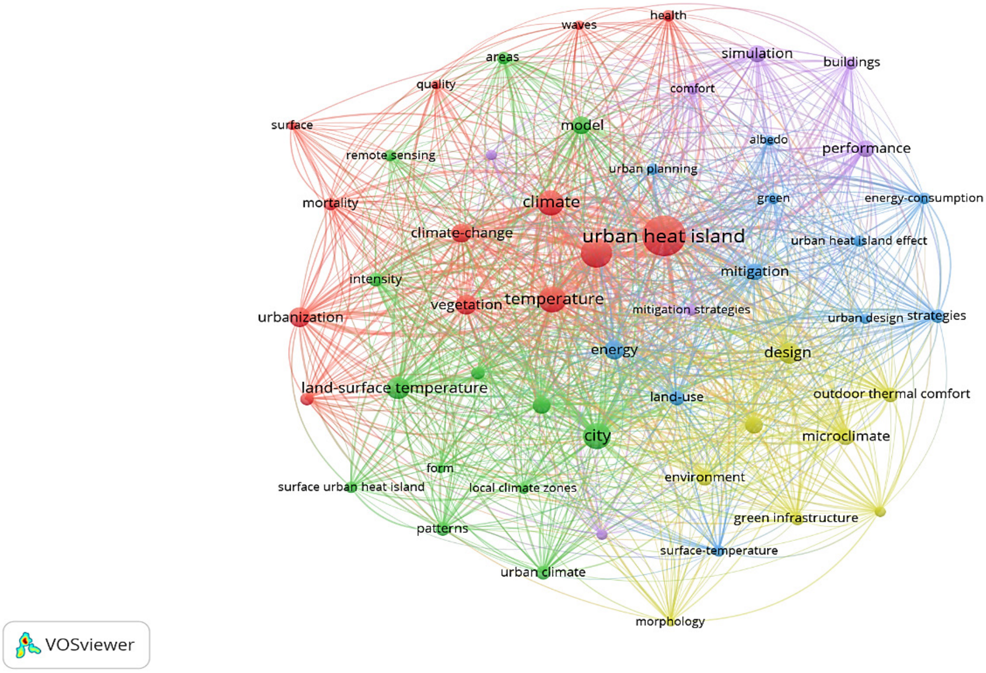

Figure 3. Co-occurrence analysis of two items based on urban heat island keywords in network visualization

The 52 items were divided into five clusters, with each color representing a distinct cluster. The items within each cluster exhibit greater similarity to one another than to those in other clusters, and these items are connected through links. Cluster 1, containing the largest number of items, consists of 13 items and is represented in red. Cluster 2 also contains 13 items and is represented in green. Cluster 3 consists of 11 items and is represented in blue. Cluster 4 contains eight items and is represented in yellow, while Cluster 5 consists of seven items and is represented in purple.

Cluster 1: The first cluster consists of 13 keywords (approximately 25% of the total number of keywords), including climate, climate change, urban cover, urban health, impact, mortality, quality, surface cover, temperature, urban heat island, urbanization, vegetation, and waves. Urban heat island ranked first with a total link strength of 874 and a co-occurrence frequency of 48, whereas surface recorded the lowest value, with a total link strength of 59 and a co-occurrence frequency of 27.

Cluster 2: The second cluster also consists of 13 keywords (approximately 25% of the total number of keywords), including air temperature, areas, city, city form, intensity, land surface temperature, local climate zone, model, patterns, remote sensing, surface urban heat island, urban climate, and urban heat islands. The city ranked first with a total link strength of 428 and a co-occurrence frequency of 50, while remote sensing recorded the lowest value, with a total link strength of 54 and a co-occurrence frequency of 30.

Cluster 3: The third cluster comprises 11 keywords (approximately 21.15% of the total number of keywords), including albedo, energy, energy consumption, green space, land use, mitigation, strategies, surface temperature, surface design, urban heat island effect, and urban planning. The albedo recorded the lowest numerical value, with a total link strength of 63 and a co-occurrence frequency of 30.

Cluster 4: The fourth cluster consists of 8 keywords (approximately 15.38% of the total number of keywords), namely design, environment, geometry, green infrastructure, microclimate, urban morphology, outdoor thermal comfort, and thermal comfort. The urban morphology recorded the lowest value, with a total link strength of 71 and a co-occurrence frequency of 33.

Cluster 5: The fifth cluster encompasses seven keywords (approximately 13.46% of the total number of keywords), including anthropogenic heat, buildings, thermal comfort, mitigation strategy, performance, and thermal environment. The thermal environment recorded the lowest value, with a total link strength of 77 and a co-occurrence frequency of 30. Table 7 presents the statistical details of the keywords extracted from the co-occurrence analysis.

Table 7. Keywords extracted from the co-occurrence analysis in urban heat island Studies

ID	Cluster	Keyword	Total link strength	Total links	Occurrences
1	1	Air temperature	237	47	43
3	1	Anthropogenic heat	94	35	16
4	1	Area	126	33	25
6	1	City	498	51	97
10	1	Land cover	140	37	25
12	1	Energy	256	47	50
15	1	Urban structure	81	33	15
21	1	Intensity	152	43	27
22	1	Land surface temperature	339	45	68
24	1	Local climate zone	90	35	17
28	1	Model	208	48	47
32	1	Patterns	123	35	26
35	1	Remote sensing	66	31	20
39	1	Surface urban heat island	102	31	21
40	1	Surface temperature	102	33	19
46	1	Urban heat island	995	38	244
51	1	Vegetation cover	304	49	57
7	2	Climate	460	50	95
8	2	Climate change	253	45	50
19	2	Health	113	37	19
20	2	Impact	658	51	128
30	2	Mortality	122	37	24
34	2	Quality	84	29	15
38	2	Surface	71	28	14
41	2	Temperature	452	48	99
48	2	Urban heat islands	94	49	23
50	2	Urbanization	302	46	61
52	2	Waves	79	31	15
11	3	Design	316	49	67
14	3	Environment	166	45	30
16	3	Geometry	95	35	17
18	3	Green infrastructure	111	40	24
25	3	Microclimate	227	45	44
29	3	Urban morphology	79	34	15
31	3	Outdoor thermal comfort	172	43	32
42	3	Thermal comfort	222	43	42
44	3	Urban climate	106	37	26
2	4	Albedo	71	31	17
13	4	Energy consumption	120	39	21

ID	Cluster	Keyword	Total link strength	Total links	Occurrences
17	4	Green space	112	40	19
23	4	Land use	159	43	32
26	4	Mitigation	227	49	44
37	4	Strategies	148	43	27
45	4	Urban design	88	37	17
47	4	Urban heat island effect	91	37	19
49	4	Urban planning	82	34	19
5	5	Building	112	39	23
9	5	Comfort	96	36	22
27	5	Mitigation strategies	103	37	17
33	5	Performance	192	34	41
36	5	Simulation	196	45	44
43	5	Thermal environment	94	41	18

Figure 4 illustrates the conceptual clusters of frequently occurring keywords in studies related to UHI. Each color represents a distinct semantic cluster, indicating a high level of keyword co-occurrence within the scientific literature. The results show that the keyword "urban heat island" has the highest total link strength (995) and occupies the central position in the network, functioning as the core theme of the research field. Keywords such as "impact," "climate," and "temperature" are also among the most prominent conceptual connections associated with it. In contrast, keywords related to "green infrastructure," "urban design," and "mitigation strategies," despite exhibiting lower link strengths, reflect emerging research trends and indicate a gradual shift in the literature from merely analyzing the phenomenon toward policy-oriented approaches and sustainable urban design strategies.

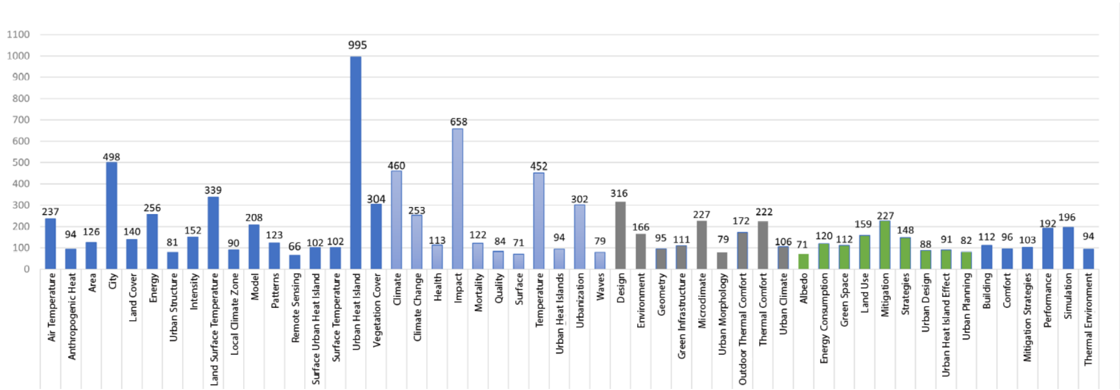

Figure 4. Clustering of keywords based on co-occurrence analysis in urban heat island studies

The keyword co-occurrence network analysis revealed that the conceptual structure of the UHI literature is organized into five distinct clusters. The first cluster, which constitutes the largest and densest part of the network, is centered on concepts such as urban heat island, urbanization, vegetation cover, climate, and mortality. The high concentration of link strength within this cluster suggests that the core body of knowledge in this field remains grounded in climatic concepts and health-related consequences. This finding reflects the expansion of research from the physical dimensions of the phenomenon toward its social implications and climate-related risks. The second cluster is primarily focused on concepts such as land surface temperature (LST), air temperature, and local climate zone (LCZ), which emphasize the measuring, monitoring, and modeling of urban heat island intensity. The third cluster includes keywords such as design, energy, land use, and urban planning, highlighting the growing emphasis of the literature on human-scale considerations and the role of urban design and planning in thermal regulation. The fourth and fifth clusters focus respectively on microclimate, thermal comfort, and urban morphology, as well as mitigation strategies, performance, and buildings. This structure suggests that recent studies have moved beyond merely understanding and characterizing the phenomenon, increasingly focusing on the development of design solutions and performance-based assessments. Overall, the distribution of clusters indicates a conceptual transition within the literature. While early studies primarily focused on thermal monitoring and measurement, research has progressively evolved to analyze the impacts, climate-responsive design approaches, and mitigation strategies. This evolution reflects the gradual maturation of the field and its shift from descriptive investigations toward intervention-oriented and solution-driven research.

5.2. Analysis of the co-occurrence of two items in overlay visualization

In the overlay visualization, keyword co-occurrence analysis was conducted by considering the average publication year of the articles associated with each keyword. As shown in Figure 5, in this type of visualization, keywords are color-coded not only according to their co-occurrence relationships but also based on the timing of their occurrence. Older keywords are displayed in cooler colors (blue to green), whereas newer keywords are represented by warmer colors (yellow to orange).

In this regard, examining the co-occurrence of the two keywords urban heat island and climate change indicates that these keywords are not only located within a common conceptual cluster, but have also received attention from researchers of UHI during relatively similar time periods. Compared with emerging keywords, their temporal focus was established earlier and became stabilized sooner.

The yellow-colored keywords (green space, urban structure/morphology, local climate zone, surface, etc.) and the green-colored keywords (performance, green infrastructure, cover, thermal comfort, etc.) indicate that these topics have attracted increasing attention in the UHI study in recent years and have the potential to become influential research themes. Keywords displayed in yellow are generally associated with publications published after 2021 and have received considerable attention from researchers in recent years. As such, they provide opportunities for identifying emerging topics and can contribute to advancing research in this field.

The size of the circles represents the weight of the items, indicating the extent to which a particular item appears together with other items in scientific publications. The distance between items reflects the strength of their relationships, and a shorter distance indicates a stronger connection between items. Therefore, as the distance between two items decreases, the relationship between them becomes stronger.

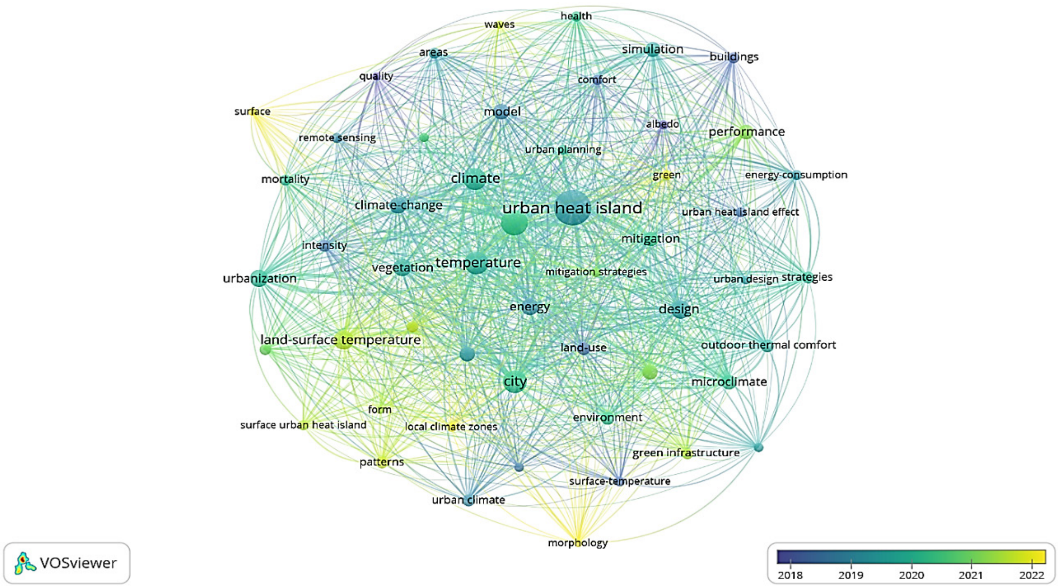

Figure 5. Keyword co-occurrence analysis of urban heat island research in the overlay visualization

The temporal evolution of keywords suggests that the initial focus of research has been primarily on fundamental concepts such as urban heat island, temperature, climate, and climate change, which were predominantly at the center of scholarly attention before 2019. This phase can be regarded as the period of conceptual establishment and phenomenon measurement. In contrast, the emergence of keywords such as green infrastructure, urban morphology, thermal comfort, performance, and local climate zone within the warmer color spectrum reflects a shift in research emphasis from understanding and characterizing the phenomenon toward design-oriented interventions and climate adaptation strategies.

This transformation indicates a change in the orientation of the literature, moving from descriptive and measurement-based studies toward more applied, policy-oriented, and climate-responsive research. The overlay network analysis demonstrates that, in recent years, the urban heat island literature has increasingly focused on physical planning and urban design solutions as key instruments for mitigating thermal impacts. This trend is consistent with the process-oriented conceptual framework developed in the present study.

5.3. Analysis of the co-occurrence of two items in density visualization

Density visualization is a visual tool for displaying the intensity of repetition and the relative importance of keywords. As shown in Figure 6, this visualization displays different regions of the map in colors ranging from blue to yellow according to the density of keywords and the number of links between items. Yellow-colored areas indicate points with the highest frequency and relational weight. As the number of items associated with the point of interest increases, the distance decreases, and as the weight of items in the neighborhood of the point increases, the color of that item becomes closer to yellow, and vice versa. When two terms are located in adjacent regions with high density in this visualization, such spatial proximity may indicate their conceptual co-occurrence in scientific texts. Keywords that appear within a dense cluster and at a close distance from one another are more likely to have been used simultaneously in scientific articles and to possess stronger semantic relationships. The yellow-colored region encompasses the keywords urban heat island, city, impact, temperature, climate, and others. In this visualization, items with smaller font sizes or lower density have received less attention from researchers, reflecting their degree of importance in the literature.

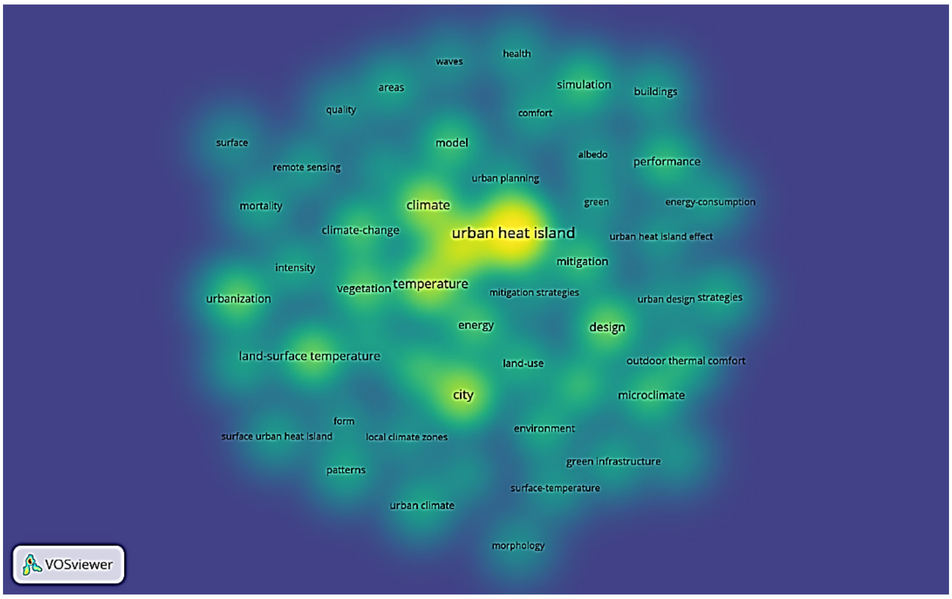

Figure 6. Co-occurrence analysis of urban heat island keywords in density visualization

The density analysis indicates that the dense core of the network is primarily centered on the concepts of urban heat island, city, temperature, climate, and impact. The high concentration of these keywords within the yellow region suggests that they have become established as the dominant and foundational concepts in the literature. This finding suggests that the majority of scientific output continues to focus on measuring, describing, and analyzing the intensity of the phenomenon.

In contrast, keywords related to green infrastructure, urban morphology, thermal comfort, and mitigation strategies are located in areas of moderate density. This pattern suggests that although these research domains are growing, they have not yet become part of the central knowledge core to the same extent as the classical concepts associated with thermal measurement and assessment. In other words, the density structure of the network reflects an asymmetrical conceptual concentration in which descriptive studies remain dominant, while intervention-oriented studies are gradually strengthening their position.

This finding is also consistent with the results of the temporal overlay analysis, indicating a gradual transition within the field from a primary focus on measuring the phenomenon toward climate-responsive design and heat-mitigation strategies.

5.4. Co-authorship analysis based on countries

Co-authorship analysis suggests that researchers or countries have collaborated on multiple scientific publications, and these collaborations are connected within a scientific cooperation network. In the present study, co-authorship analysis was conducted based on countries as the unit of analysis. In this network, each node represents a country, and the lines between them indicate research relationships and collaborative efforts among countries in the production of joint scientific publications. The larger the size of a node, the greater the number of publications produced by that country and the stronger its network connections. Likewise, the thickness of the links and the proximity between nodes indicate a higher degree of collaboration among countries.

Co-authorship analysis helps researchers understand existing patterns of collaboration, identify potential partners, and improve scientific cooperation among authors from diverse countries. Out of 66 countries identified in the dataset, 26 countries met the initial threshold criteria. After data screening, a total of 25 countries with a minimum of five links were included in the network visualization. These 25 items were grouped into five clusters, each represented by a distinct color. Countries belonging to the same cluster exhibit greater similarity and stronger collaborative relationships compared with countries located in different clusters.

According to Figure 7, Cluster 1 (shown in red) and Cluster 2 (shown in green) each contain six countries, representing the largest clusters in the network. Cluster 1 consists of Chile, Egypt, Germany, Greece, Italy, and Spain. Cluster 2 includes Australia, India, Iran, Malaysia, and Mexico. Cluster 3, represented in blue, contains five countries: Canada, France, Morocco, Singapore, and Switzerland. Cluster 4, shown in yellow, includes four countries: China, South Korea, Taiwan, and the United States. Finally, Cluster 5, represented in purple, consists of the United Kingdom, Japan, the Netherlands, and Turkey.

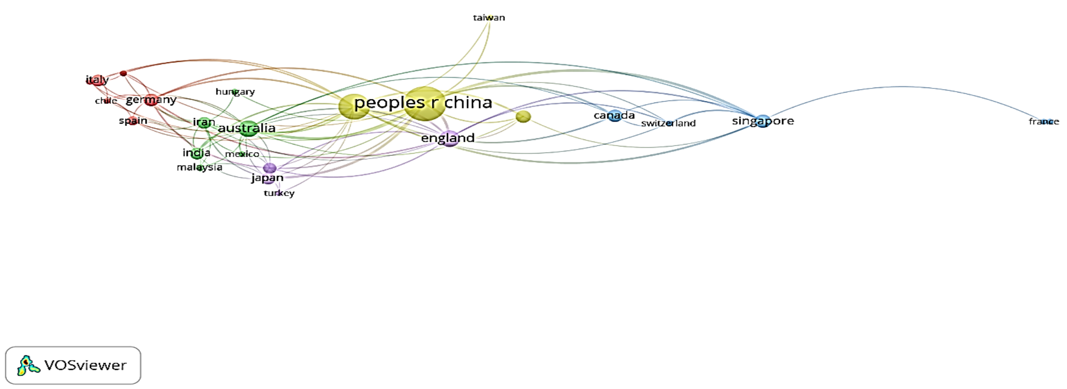

Figure 7. Co-authorship analysis by country in urban heat island studies using network visualization

The co-authorship network analysis of countries reveals that the structure of knowledge production in UHI is characterized by a clustered and regionally-oriented nature. The pattern of cluster formation suggests that a considerable proportion of collaborations are organized within geographical and regional connections. In some clusters, a concentration of European countries can be observed, whereas in others, Asian countries or major global economies are grouped. However, in certain cases, the clusters also include countries from different regions, reflecting the expansion of transregional and international linkages in knowledge production.

The presence of countries such as China and the United States within a dense cluster characterized by strong linkages highlights their central role in the scientific collaboration network and their position as major hubs of knowledge production in this field. In contrast, some countries are located within multinational clusters with more dependent linkages, which may indicate a greater reliance on international collaborations to enhance their scientific output.

Overall, although the expansion of global scientific collaboration in this field is evident, the network structure remains, to some extent, influenced by geographical proximity, shared climatic conditions, and similar urban challenges. The concentration of collaborations among industrialized countries and leading emerging economies also points to a form of spatial inequality in the distribution of knowledge-production capacity related to UHI research.

5.5. Bibliographic coupling analysis based on organizations

In this section, bibliographic coupling analysis was conducted based on organizations. This type of analysis identifies institutions whose scientific outputs rely on common sources and references. When two organizations cite similar references in their research publications, it can be inferred that these institutions are active in closely related conceptual domains.

As shown in Figure 8, organizations were used as the unit of analysis in this study. The minimum citation threshold for each organization was set at four citations. Among the 674 organizations identified, 54 organizations met this minimum citation threshold. In the network visualization, the connection between two items represents the number of references they share. A shorter distance between two items indicates a stronger relationship between them. Link strength refers to the number of shared references. The weighted size of each item is determined by its total link strength; therefore, the larger the item, the greater its link strength.

According to Figure 9, the Chinese Academy of Sciences ranked first with the highest total link strength, recording 10,211 citations. Peking University and Chongqing University ranked second and third, respectively, with link strengths of 6,827 and 5,856. In contrast, the University of Manchester recorded the lowest link strength, with a value of 144.

The bibliographic coupling map is divided into five clusters. The first cluster, shown in red, contains 25 items; the second cluster, shown in green, contains 14 items; the third cluster, shown in blue, contains 12 items; the fourth cluster, shown in yellow, contains two items; and the final cluster, shown in purple, contains one item. Figures 8 and 9 illustrate these relationships.

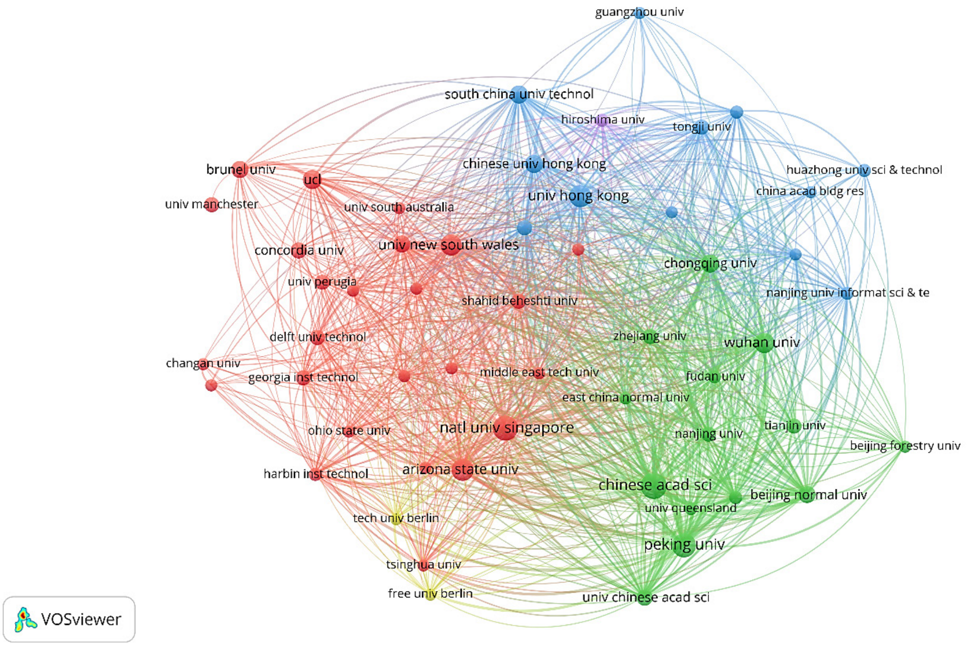

Figure 8. Bibliographic coupling analysis based on organizations in global urban heat island studies using network visualization

RezaeiRad H. et al.
December 2026
Volume 7, Issue 9

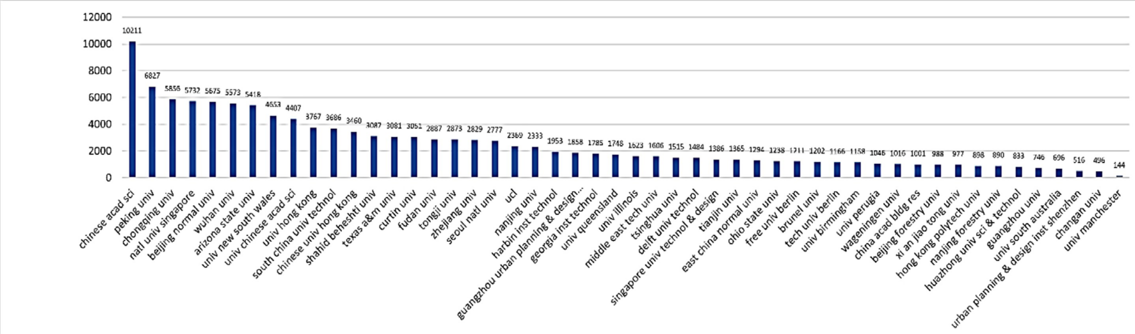

Figure 9. Total link strength of bibliographic coupling items based on organizations in urban heat island studies

Results of the bibliographic coupling analysis indicate that the citation structure of the UHI literature exhibits a considerable degree of institutional concentration. The prominence of organizations such as the Chinese Academy of Sciences, Peking University, and Chongqing University reflects the significant role of Chinese scientific institutions in shaping the theoretical and empirical foundations of this field. The high link strength concentrated within these organizations suggests that a substantial portion of scientific publications relies on a relatively common set of reference sources, indicating the formation of a dominant knowledge core. In contrast, organizations with lower link strengths are positioned within smaller clusters, reflecting a relative diversity of approaches and the dispersion of certain research streams. The division of the network into five clusters further demonstrates the existence of institutional blocks characterized by similar conceptual orientations; organizations within the same cluster are likely to focus on common topics or methodological approaches. Overall, the bibliographic coupling structure reveals that, although the UHI literature is geographically widespread, it remains citation-wise relatively concentrated and dependent on a limited number of major scientific hubs. This concentration may play a decisive role in shaping research directions and determining thematic priorities within the field.

5.6. Co-citation analysis based on author co-citation in network visualization

In this section, author co-citation analysis was conducted to identify researchers whose works have been cited simultaneously in different scientific publications. When two authors are repeatedly co-cited across various studies, it can be inferred that there is a thematic or intellectual relationship between them. This type of analysis contributes to identifying intellectual clusters, research streams, and the most influential scholars within a specific field, playing an important role in mapping the scientific structure of that domain.

As illustrated in Figure 10, each node represents an author. Among the 11,095 authors identified in the UHI research domain, 54 authors met the minimum threshold of 40 scientific documents. After data screening, 51 authors were ultimately selected for analysis, while three authors were excluded due to name ambiguity and duplication issues.

According to Figure 10, each color represents a group of authors who share similar research interests and often work within comparable thematic areas. The larger the circle, the greater the number of citations received by that author. Smaller circles indicate lower citation counts and generally represent less-established or early-career researchers.

The author co-citation analysis shows that Oke ranks first with 504 citations and a total link strength of 4,912, making him the most influential author in the network. Santamouris and Akbari rank second and third in terms of citation counts, with 429 and 179 citations, respectively. In terms of total link strength, Santamouris and Zhou occupy the second and third positions with 4,674 and 2,175, respectively.

The 51 items were grouped into three clusters. The first cluster, displayed in red, contains 23 items and represents the largest cluster. The second cluster, shown in green, includes 15 items, while the third cluster, displayed in blue, consists of 13 items. Figures 10 and 11 present the graphical representation of this analysis.

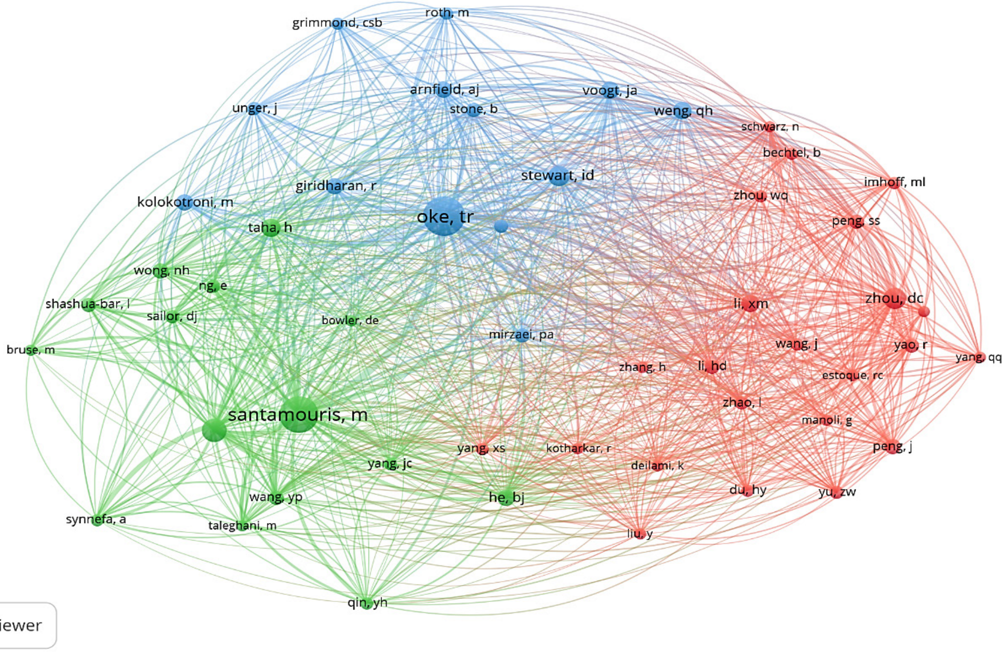

Figure 10. Author co-citation analysis based on author citation relationships in urban health studies using network visualization

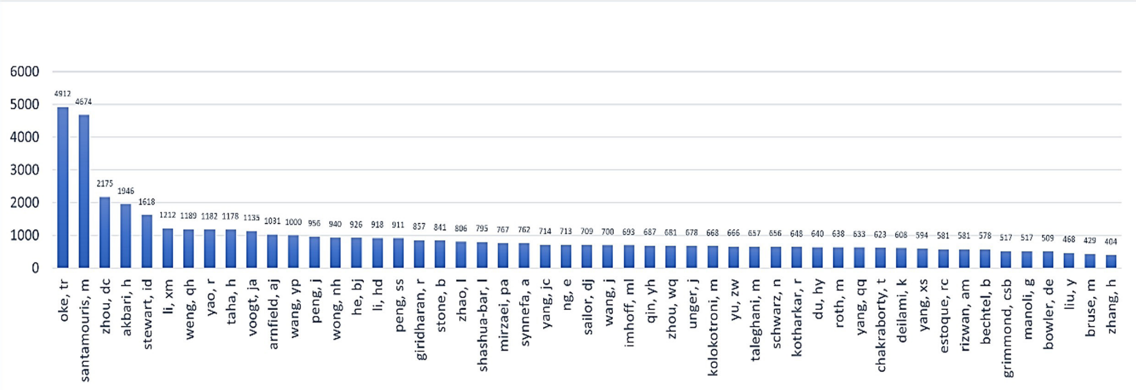

Figure 11. Total link strength of co-citation items based on author citations in urban heat island studies

The author co-citation analysis reveals that the intellectual structure of the UHI field has been shaped around a group of foundational scholars. The central position of Tim R. Oke within the co-citation network, together with his highest citation count and total link strength, confirms his pivotal role in establishing the early theoretical frameworks of urban climatology. His works serve as common reference points for numerous subsequent studies and constitute the theoretical backbone of the literature.

In other clusters, researchers such as Mat Santamouris and Hashem Akbari represent the stream of research focused on energy issues and heat mitigation strategies in built environments. Meanwhile, the presence of authors such as Weiqi Zhou reflects a strong emphasis on remote sensing applications and quantitative analyses at the urban scale. This clustering pattern indicates the emergence of three major intellectual streams within the literature: 1) theoretical and urban climatology foundations, 2) energy-oriented and mitigation-based design approaches, and 3) data-driven and remote sensing studies. Overall, the co-citation structure reveals that the UHI field possesses a well-established theoretical core, gradually complemented by applied and technology-oriented research streams over time. This pattern reflects the progressive maturation of knowledge in the field, evolving from a stage of theory development toward one of practical application and intervention.

5.7. Synthesis and integration of scientometric findings on urban heat islands

The findings obtained from the scientometric analysis of Urban Heat Island (UHI) research indicate a remarkable growth in scientific attention to this phenomenon in recent years. This section integrates the results from the six main analyses, including keyword co-occurrence, co-authorship, co-citation, and organizational, national, and conceptual analyses, to provide a comprehensive picture of the knowledge structure and research orientations within this field.

Based on the systematic review of 604 scientific documents, a total of 23 indicators influencing UHI were identified and classified into three main dimensions: land surface indicators, urban morphology indicators, and socio-economic indicators. Among these, indicators such as land surface temperature (LST), normalized difference vegetation index (NDVI), normalized difference built-up index (NDBI), Albedo, and land use type were the most frequently reported.

In the keyword co-occurrence analysis, the terms "urban heat island," "impact," and "city" emerged as the most frequently occurring keywords and constituted the conceptual core of the network. In contrast, terms such as "urban morphology," "local climate zone," and "green infrastructure" have emerged as recent and growing research topics, reflecting a shift in research focus from impact assessment toward adaptation strategies and heat mitigation approaches. The overlay visualization further indicates that keywords related to urban design, thermal comfort, and green infrastructure have primarily appeared after 2021; whereas, terms such as albedo, intensity, and surface temperature were more prevalent in earlier studies. This transition reflects a broader shift in research approaches from purely physical analyses to interdisciplinary studies integrating climate science and urban design.

The country co-authorship network analysis revealed that China, the United States, and Australia account for the highest levels of scientific collaboration, whereas countries such as France, Bulgaria, and Morocco exhibit comparatively lower levels of participation. Iranian researchers have primarily collaborated with India, Australia, Malaysia, and Mexico, indicating the emergence of new scientific networks among developing countries.

The results of the bibliographic coupling analysis based on organizations showed that institutions such as the Chinese Academy of Sciences, Peking University, and Chongqing University possess the highest levels of link strength and shared citations and are recognized as major centers of knowledge production in this field. Furthermore, the author co-citation analysis demonstrated that scholars such as Tim R. Oke, Mat Santamouris, and Hashem Akbari have been among the most influential figures in shaping the theoretical and methodological foundations of UHI studies. Although the core body of knowledge in this field has largely been built upon the seminal works of these scholars, recent years have witnessed the emergence of new researchers who are expanding the knowledge frontier through the application of remote sensing technologies and thermal modeling techniques.

Overall, the integration of the six scientometric analyses reveals that the knowledge structure of UHI research includes three major layers: an empirical core based on thermal measurement and modeling, an intermediate layer focused on climatic and health-related consequences, and an emerging intervention-oriented layer centered on urban design and green infrastructure. This multilayered structure reflects the gradual maturation of the field and its evolution from a primary focus on measuring the phenomenon toward interdisciplinary analyses and mitigation-oriented strategies. The convergence of findings from keyword co-occurrence, co-citation, and bibliographic coupling analyses further suggests that the conceptual transformation of the field has occurred not only at the level of terminology but also within citation structures and scientific collaboration networks.

6. Discussion and conclusion

The present study was conducted to analyze the structure of knowledge production, patterns of scientific collaboration, and the conceptual organization of the global literature on UHI. The application of a scientometric approach, together with analyses of keyword co-occurrence, author co-citation, country co-authorship, and bibliographic coupling, enabled us to map the theoretical frameworks, research streams, and knowledge linkages within this field in a systematic manner.

The results of the keyword co-occurrence network revealed that concepts such as urban heat island, impact, climate, and land surface temperature possess the highest frequency and link strength and are recognized as the stable conceptual core of the literature. The concentration and density of conceptual linkages surrounding these keywords indicate that a substantial portion of the studies has been organized around the measurement, analysis, and interpretation of thermal patterns within the context of urban climate.

In contrast, the emergence and growing prominence of concepts such as green infrastructure, mitigation strategies, thermal performance, and urban resilience in recent years, which are located in relatively distinct clusters yet remain connected to the central core, demonstrate an expansion of the thematic scope of research from the level of phenomenon analysis to the level of intervention and policymaking. This shift in the network configuration of concepts suggests that the literature has evolved from an exclusive focus on identifying and measuring the intensity of urban heat islands toward the evaluation of mitigation measures and climate adaptation strategies.

An examination of the conceptual clusters further indicates that land surface- and urban morphology-related indicators, including vegetation cover, the proportion of impervious surfaces, albedo, and building density, have been at the center of research attention. The high frequency of keywords and the strength of the links between these variables and land surface temperature concepts demonstrate their prominent position within existing analytical frameworks. This conclusion is based on the analysis of the conceptual structure of the literature rather than direct causal inference from empirical data; nevertheless, the network-based emphasis on these variables suggests that they have been widely regarded as key factors in explaining variations in urban thermal conditions.

At the level of scientific collaboration, the country co-authorship network analysis revealed that knowledge production in this field exhibits a clustered and, to some extent, region-oriented structure. The highest concentration of collaborations was observed among countries such as China, the United States, and Australia, which possess greater link strength and higher volumes of scientific output. At the same time, the presence of countries such as Iran, India, and Malaysia in active network clusters indicates the gradual expansion of scientific participation in developing regions. The arrangement of clusters suggests that although international collaboration is increasing, the network structure remains shaped by geographical connections, climatic similarities, and regional research networks. This pattern may indicate a form of spatial concentration in knowledge production and a relative inequality in access to advanced research resources.

Recent developments in UHI studies indicate a gradual transition from descriptive approaches based on simple statistical analyses toward data-driven, model-based, and network-oriented approaches. The expanding use of multi-temporal satellite imagery, urban energy models, and machine-learning algorithms has enabled the investigation of thermal dynamics at shorter temporal scales and with finer spatial resolution. Although the present study is scientometric in nature and does not involve direct empirical modeling, the patterns extracted from co-occurrence and co-citation networks suggest that the focus of the literature over the past two decades has increasingly shifted toward quantitative, data-driven, and applied analyses. This change in the conceptual structure of the field reflects the relative maturity of analytical methods and the growing sophistication of the tools employed in urban studies.

From the perspective of research gaps, network analyses revealed that despite the extensive focus on remote sensing and land surface temperature analyses, the social, economic, and behavioral dimensions of the UHI phenomenon occupy a less prominent position within the conceptual structure of the field. The relatively weak linkages between concepts such as thermal justice, social vulnerability, and spatial inequality and the core network indicate considerable potential for the future development of interdisciplinary approaches. Furthermore, the mismatch of analytical scales, from large-scale studies based on medium-resolution satellite data to the requirements of neighborhood-scale urban design, remains one of the major methodological challenges in the literature. The dominant reliance on remote-sensing data, although enabling extensive spatial coverage, creates limitations in representing microclimatic heterogeneity, which may affect the translation of findings into urban design policies.

In recent years, the use of machine learning methods and deep neural networks to analyze nonlinear relationships among land surface variables, urban morphology, and surface temperature has expanded considerably. However, an examination of citation patterns indicates that challenges such as model overfitting, dependence on the quality of input data, and limitations in the interpretability of results remain subjects of discussion within the literature. Therefore, the development of integrated frameworks that combine satellite data, field measurements, and socio-economic indicators in a unified manner may represent one of the most promising directions for future research.

From an applied perspective, the findings of this study, based on an analysis of the knowledge structure of the global literature, can be utilized at three levels: first, at the diagnostic level, through the identification of dominant conceptual themes and highly recurring variables that have shaped the analytical frameworks of existing studies; second, at the research-planning level, through the identification of thematic gaps and opportunities for the development of interdisciplinary approaches; third, at the policy level, through aligning urban planning programs with prevailing scientific trends, particularly in the areas of green infrastructure, land-use management, and climate adaptation. Nevertheless, we should emphasize that this study provides a map of the knowledge structure rather than a direct empirical evaluation of the effectiveness of intervention strategies.

In the context of international collaboration, the transfer of advanced technologies in remote sensing, microclimatic modeling, and big-data analytics can play a decisive role in strengthening the capacities of developing countries. However, the localization of these technologies requires their adaptation to the climatic conditions, physical structure, and social characteristics of each city. Establishing collaborative research networks and developing local databases can facilitate the transfer of knowledge from the global level to regional applications, providing a foundation for designing strategies tailored to specific climatic contexts.

Finally, an analysis of the 25-year evolution of the literature reveals that the UHI research has progressed from an initial focus on the climatological explanation of the phenomenon toward analytical, data-driven, and policy-oriented approaches. The growing prominence of concepts such as green infrastructure, thermal resilience, and climate justice in recent years reflects the expansion of the field's conceptual horizons and its gradual integration with broader discussions of sustainable urban development. By mapping the network structure of existing knowledge, the study's results provide a framework for guiding future research and identifying pathways for scientific advancement in addressing the challenges of urban warming.

Authors' Contributions

The authors contributed equally to this article.

Acknowledgments

This article received no financial or institutional support.

Conflict of Interest

The authors declared no conflict of interest.

References

Aflaki, A., Mirnezhad, M., Ghaffarianhoseini, A., Ghaffarianhoseini, A., Omrany, H., Wang, Z. H., & Akbari, H. (2017). Urban heat island mitigation strategies: A state-of-the-art review on Kuala Lumpur, Singapore, and Hong Kong. *Cities*, 62, 131-145. https://doi.org/10.1016/j.cities.2016.09.003

Akintola, M., & Neziri, G. (2025). An open-source deep learning framework for scalable urban heat island detection using geospatial data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 48, 11-16. https://doi.org/10.5194/isprs-archives-XLVIII-4-W13-2025-11-2025

Arnfield, A. J. (2003). Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, 23(1), 1-26. https://doi.org/10.1002/joc.859

Badri Asl S., Pourmohammadi M. R., & Roustaei S. (2024). A comparative study of the relationship between physical indicators of residential areas and the distribution of urban heat islands in Tabriz. *Urban Planning Knowledge*, 8(2): 97–113. https://doi.org/10.22124/upk.2023.23422.1822 [In Persian]

Chapman, S., Watson, J. E., Salazar, A., Thatcher, M., & McAlpine, C. A. (2017). The impact of urbanization and climate change on urban temperatures: A systematic review. *Landscape Ecology*, 32(10), 1921-1935. https://doi.org/10.1007/s10980-017-0561-4

Deilami, K., Kamruzzaman, M., & Liu, Y. (2018). Urban heat island effect: A systematic review of spatio-temporal factors, data, methods, and mitigation measures. *International Journal of Applied Earth Observation and Geoinformation*, 67, 30-42. https://doi.org/10.1016/j.jag.2017.12.009

Du, H., Zhan, W., Voogt, J., Bechtel, B., Chakraborty, T. C., Liu, Z., ... & Miao, S. (2023). Contrasting trends and drivers of global surface and canopy urban heat islands. *Geophysical Research Letters*, 50(15), e2023GL104661. https://doi.org/10.1029/2023GL104661

Fadaei H. (2021). Investigation of Tehran's urban heat islands using satellite imagery. *Geographical Information Scientific-Research Quarterly*, 29(116): 119–130. https://doi.org/10.22131/sepehr.2021.242864 [In Persian]

Gartland, L. (2008). *Heat islands: Understanding and mitigation of heat in urban areas*. London, Erthscan. https://doi.org/10.4324/9781849771559

Ghasemi E., Nazemi Z., Mokhtarzadeh S., & Soleimani M. (2024). Correlation analysis of macro-scale natural and artificial environmental factors with the intensity of urban heat islands. *Urban Studies Quarterly*, 13(49): 17-32. https://doi.org/10.22034/urbs.2023.62764 [In Persian]

Haji Fathali M., Feyzi M., & Dehghan A. (2022). The relationship between air temperatures, mean radiant temperature, and albedo in reducing urban heat islands. *Geography (Journal of the Iranian Geographical Association)*, 19(71): 173–191. https://dor.isc.ac/dor/http://dor.net/dor/20.1001.1.27833739.1400.19.71.9.6 [In Persian]

Halder, B., Bandyopadhyay, J., & Banik, P. (2021). Monitoring the effect of urban development on urban heat island based on remote sensing and geo-spatial approach in Kolkata and adjacent areas, India. *Sustainable Cities and Society*, 74, 103186. https://doi.org/10.1016/j.scs.2021.103186

Hernández-Herráez, G., Martínez-Lastras, S., Lagüela, S., Martín-Jiménez, J. A., & Del Pozo, S. (2025). Morphological and environmental drivers of urban heat islands: A geospatial model of nighttime land surface temperature in Iberian cities. *Applied Sciences*, 15(11), 6093. https://doi.org/10.3390/app15116093

Howard, L. (1833). *The climate of London: Deduced from meteorological observations made in the metropolis and at various places around it* (Vol. 3). Harvey and Darton, J. and A. Arch, Longman, Hatchard, S. Highley [and] R. Hunter. https://doi.org/10.1017/cbo9781139135467.020

Huang, C., Liu, K., Ma, T., Xue, H., Wang, P., & Li, L. (2025). Analysis of the impact mechanisms and driving factors of urban spatial morphology on urban heat islands. *Scientific Reports*, 15(1), 18589. https://doi.org/10.1038/s41598-025-04025-0

Karimi, A., Mohammad, P., Gachkar, S., Gachkar, D., García-Martínez, A., Moreno-Rangel, D., & Brown, R. D. (2021). Surface urban heat island assessment of a cold desert city: A case study over the Isfahan Metropolitan Area of Iran. *Atmosphere*, 12(10), 1368. https://doi.org/10.3390/atmos12101368

Kong, G., Peng, J., & Corcoran, J. (2025). Modelling urban heat island effects: A global analysis of 216 cities using machine learning techniques. *Computational Urban Science*, 5(1), 18. https://doi.org/10.1007/s43762-025-00178-w

Landsberg, H. E. (1981). The urban climate (Vol. 28). Academic Press.

Lynda, D., Logeswari, G., Tamilarasi, K., & Rakesh, S. (2025). Hybrid Bayesian deep learning model for predicting urban heat island intensity in African cities. *Scientific Reports*, 15(1), 31280. https://doi.org/10.1038/s41598-025-13492-4

Mazidi A., Rousta, I., & Mohammadi Ravari F. (2023). Temporal changes of urban heat islands and their relationship with air pollution using remote sensing. *Climate Change Research Journal*, 4(13): 103–120. https://doi.org/10.30488/ccr.2023.404996.1151 [In Persian]

Mofidi S. M., & Zare Mohazzabieh A. (2013). Urban sidewalk surface materials for reducing the effects of heat islands. *Tarah Quarterly*, 8: 118–122. https://www.magiran.com/p1186885 [In Persian]

Morales-González, J. I., Verichev, K., & Carpio, M. (2024). Efficiency assessment for the urban heat island mitigation measures in a city with an oceanic climate during the summer period: Case of Valdivia, Chile. *Urban Climate*, 55, 101897. https://doi.org/10.1016/j.uclim.2024.101897

Ning, S., Zhou, Y., Wang, M., Li, B., Li, P., Zhang, L., & Luo, Y. (2024). Urban heat Island differentiation and influencing factors: A local climate zone perspective. *Sustainability*, 16(20), 9103. https://doi.org/10.3390/su16209103

Nojavan M., & Tabib-Mahmoudi F. (2022). Investigation of the effect of the COVID-19 lockdown on heat islands in urban, industrial, and green areas of Tehran. *Spatial Analysis of Environmental Hazards*, 9(3): 57–74. http://jsaeh.khu.ac.ir/article-1-3326-fa.html [In Persian]

Oke, T. R. (1972, January). City size and urban heat island. In Bulletin of the American Meteorological Society (Vol. 53, No. 7, p. 713). 45 BEACON ST, BOSTON, MA 02108-3693: AMER METEOROLOGICAL SOC.

Oke, T. R. (1973). City size and the urban heat island. *Atmospheric Environment (1967)*, 7(8), 769-779. https://doi.org/10.1016/0004-6981(73)90140-6

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly journal of the Royal Meteorological Society*, 108(455), 1-24. https://doi.org/10.1002/qj.49710845502

Peroni, F., & Pappalardo, S. E. (2024). Climate justice in future cities: Geographical perspectives for inclusive urban resilience and adaptation. *Landscape and Urban Planning*, 244, 104998. https://doi.org/10.1016/j.landurbplan.2023.104998

Pouramin K., Khatami S. M., & Shamsoddini A. (2020). Factors affecting the formation of urban heat islands with emphasis on urban design characteristics and challenges. *Urban Design Discourse Journal*, 1(1): 69–83. https://udd.modares.ac.ir/article_23160.html [In Persian]

Santamouris, M. (2020). Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability, and health impact. Synergies with the global climate change. *Energy and Buildings*, 207, 109482. https://doi.org/10.1016/j.enbuild.2019.109482

Santamouris, M., Ding, L., & Osmond, P. (2019). Urban heat island mitigation. In *Decarbonising the Built Environment: Charting the Transition* (pp. 337-355). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-13-7940-6_18

Sharma, R., Pradhan, L., Kumari, M., & Bhattacharya, P. (2021). Assessing urban heat islands and thermal comfort in Noida City using geospatial technology. *Urban Climate*, 35, 100751. https://doi.org/10.1016/j.uclim.2020.100751

Stewart, I. D., Krayenhoff, E. S., Voogt, J. A., Lachapelle, J. A., Allen, M. A., & Broadbent, A. M. (2021). Time evolution of the surface urban heat island. *Earth's Future*, 9(10), e2021EF002178. https://doi.org/10.1029/2021EF002178

Van Eck, N., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84(2), 523-538. https://doi.org/10.1007/s11192-009-0146-3

Venkatraman, S., Kandasamy, V., Rajalakshmi, J., Sabarunisha Begum, S., & Sujatha, M. (2024). Assessment of urban heat island using remote sensing and geospatial application: A case study in São Paulo city, Brazil, South America. *Journal of South American Earth Sciences*, 134, 104763. https://doi.org/10.1016/j.jsames.2023.104763

Wang, S., & Zhan, W. (2025). Urban heat islands increase or reduce mortality in different cities. *Nature Climate Change*, 15(5), 473-474. https://doi.org/10.1038/s41558-025-02310-4

Zhao, L., Oppenheimer, M., Zhu, Q., Baldwin, J. W., Ebi, K. L., Bou-Zeid, E., ... & Liu, X. (2018). Interactions between urban heat islands and heat waves. *Environmental research letters*, 13(3), 034003. https://doi.org/10.1088/1748-9326/aa9f73

Zhao, L., Fan, X., & Hong, T. (2025). Urban heat island effect: Remote sensing monitoring and assessment—methods, applications, and future directions. *Atmosphere*, 16(7), 791. https://doi.org/10.3390/atmos16070791

Zhou, D., Zhao, S., Liu, S., Zhang, L., & Zhu, C. (2014). Surface urban heat island in China's 32 major cities: Spatial patterns and drivers. *Remote sensing of environment*, 152, 51-61. https://doi.org/10.1016/j.rse.2014.05.017