A Systematic Review and Trend Analysis of Urban Heat Island

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Structured Abstract

Purpose :

Urban heat island is a phenomenon where the temperature in the urban area is greater than its surrounding rural or non-urban areas and is considered a major factor contributing to global warming, heat-related deaths, and unexpected environmental fluctuations. There has been growth in the research on the UHI effect in recent decades, however, a methodical review of factors contributing to the UHI effect is rare.

Study design/methodology/approach :

This paper presents a systematic literature review (SLR) of 30 Scopus-indexed and recent (2014-2024) papers focusing on UHI. The findings will guide future research and aid UHI mitigation planning. This study uses VOS Viewer (Visualization of Similarities) to conduct the systematic literature review (SLR) to investigate the Urban Heat Island (UHI) phenomenon. It analyses the bibliometric networks and understands the research trends, knowledge gaps, effectiveness, and developing viewpoints in the field.

Findings :

Recent studies have shown its emphasis on the technology, methodology, and mitigation measures of the UHI effect rather than focusing on the factors contributing to the effect.

Originality/value:

The argumentative analysis of the literature has been presented that highlights (i) Rationale, (ii) Themes, (iii) Methods, (iv) Gaps, and (v) Variables that are studied in the context of UHI.

Research limitations/implications:

The study presents the gaps in UHI studies from an urban planning perspective and examines the interdependence of various systems in urban areas both globally and within India. The research concludes by evaluating potential interventions and the future scope for evidence-based policy formulation in the UHI field.

Keywords : *Systematic Literature Review; Urban Heat Island; VOS Viewer; Bibliometric Analysis; Climate Change; Urban Planning*

INTRODUCTION

The urban heat island effect (UHI) is a phenomenon occurring due to the rise of heat in urban areas, the result of human activities and development (Abbas Mohajerani, 2017). UHI phenomenon occurs when the temperature in urban areas is greater than its surrounding non-urban regions and it is thought to be a major contributor to climate change and heat-related mortalities (RIZWAN Ahmed Memon, 2008). Globally major cities are facing extreme effects of urban heat islands (UHIs), however, there are inadequate urban planning policies established. UHI has some notable consequences including impacts on water and air quality, energy consumption, and the health of the public (Elkhan Richard Sadik-Zada, 2022). The situation is significantly greater in cities with large populations and considerable economic processes (RIZWAN Ahmed Memon, 2008).

The Urban Heat Island (UHI) study has numerous important information gaps. Too much attention is paid to the origins, consequences, and efforts for reductions of urban heat, along with adaptation and readiness for it are not effectively managed. Urban heat mitigation and adaptation (UHMA) have continued to face challenges on a variety of fronts, ranging from the skewness in the distribution of research publications, authors, and affiliations; to biases and clustering concerning topics as well as affiliations among others; slower development in key disciplines, publications or star authors; knowledge

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isolation resulting from limited academic collaborations, restricted communication, the narrower focus of journals or lower methodological pluralism, etc (Bao-Jie He, 2023). None of the publications focuses on the mechanisms contributing to the UHI impact, rather, the emphasis of this research is on satellite technology, methodology, modeling methodologies, and mitigation strategies of the UHI effect therefore, a complete knowledge of the elements leading to the UHI impact is crucial to creating suitable policy mechanisms and planning for cities to alleviate the UHI effect (Kaveh Deilami, 2018).

By 2030, it's anticipated that over 60% of the global population will reside in urban areas, an increase from the current 55% living in cities. Each year, cities welcome 67 million new residents, with 90% of them coming from developing nations (IPCC, 2014). Because urban areas are already local hotspots, cities, and their inhabitants are extremely sensitive to weather and climatic extremes, especially heatwaves. At night, cities are frequently several degrees Celsius warmer than their surroundings (IPCC, 2014).

Globally, the UHI study lacks a comprehensive spatial planning perspective, particularly through the utilization of a Geographic Information System (GIS). A significant number of UHI studies have been conducted in China while only a few are focused on India, and the use of systems approach in analyzing UHI is very limited.

Unlike developed countries, developing countries like India, Pakistan, Nigeria, etc experience a more severe Urban Heat Island (UHI) effect. There is a growing severity of the UHI effect in many parts of India- Cities like Mumbai are experiencing temperature differences of up to 7°C between their urban centers and outskirts due to dense urbanization, concrete structures, and a lack of vegetation (Hindustan Times, 2023). This exacerbates the impact of heatwaves, with cities like Delhi, Gurugram, and Prayagraj seeing temperatures soar past 45°C, such extreme heat poses serious public health risks, especially for vulnerable populations, contributing to heat-related illnesses and deaths, and straining energy resources for cooling (Hindustan Times, 2022).

The research aims to determine patterns, knowledge gaps, and the general effectiveness of different studies carried out on this topic by examining bibliometric networks. This study focuses on various variables driving the UHI effect. These findings lay the groundwork for urban planners, practitioners, and researchers to develop evidence-based policies and pave the way for the future scope of the study (UHI).

METHODOLOGY

For this study on the Urban Heat Island (UHI) effect, as shown in *Figure 1*, a Systematic Literature Review (SLR) is conducted through a comprehensive bibliometric analysis using VOS (Visualization of Similarities) viewer which is a tool for constructing and visualizing bibliometric networks. The SLR examined peer-reviewed publications from 2014-2024, retrieved from Scopus as the primary database, and employed a structured search strategy to compile a robust dataset. Utilizing VOS viewer, bibliometric networks are constructed and visualized through graphical representation focusing on keyword co-occurrence and distribution of publications w.r.t. countries. This methodology helps in identifying research trends, key topics, and major contributions, while also highlighting less explored areas and significant research gaps. Through the use of clusters with rising publishing activity, emerging trends were found.

One of the challenges in this study was developing an effective search technique to locate relevant articles. As shown in *Table 1*, the criteria for the selection of publication for review is used to filter articles relevant to the topic. By using this technique, a total of 988 articles are identified as relevant to the UHI research topic. The search was conducted using a combination of keywords, specifically "urban planning," "urban heat island (UHI)," "spatial analysis," and "climate effect," to ensure a focus on research intersecting urban planning and UHI impacts. The selected documents were confined to journal articles within the social sciences, all of which were peer-reviewed to maintain a high standard of academic rigor. Articles published between 2014 and 2024 were considered, ensuring both recent and relevant contributions to the field.

Following a thorough review of the titles, abstracts, and conclusions of various journal articles extracted from this database 30 relevant articles relevant in the urban planning area were identified and selected for detailed content analysis. These articles were deemed most pertinent to the research focus and have undergone an in-depth examination in the next phase of the literature review. An argumentative analysis is done for writing the literature review to identify the gaps and establish the trend. In the literature review, the paper highlights (i) rationale, (ii) themes, (iii) methods, (iv) gaps, and (v) variables. The paper concludes by addressing the scope of future research and comprehensively analyzing the mentioned parameters in the context of UHI.

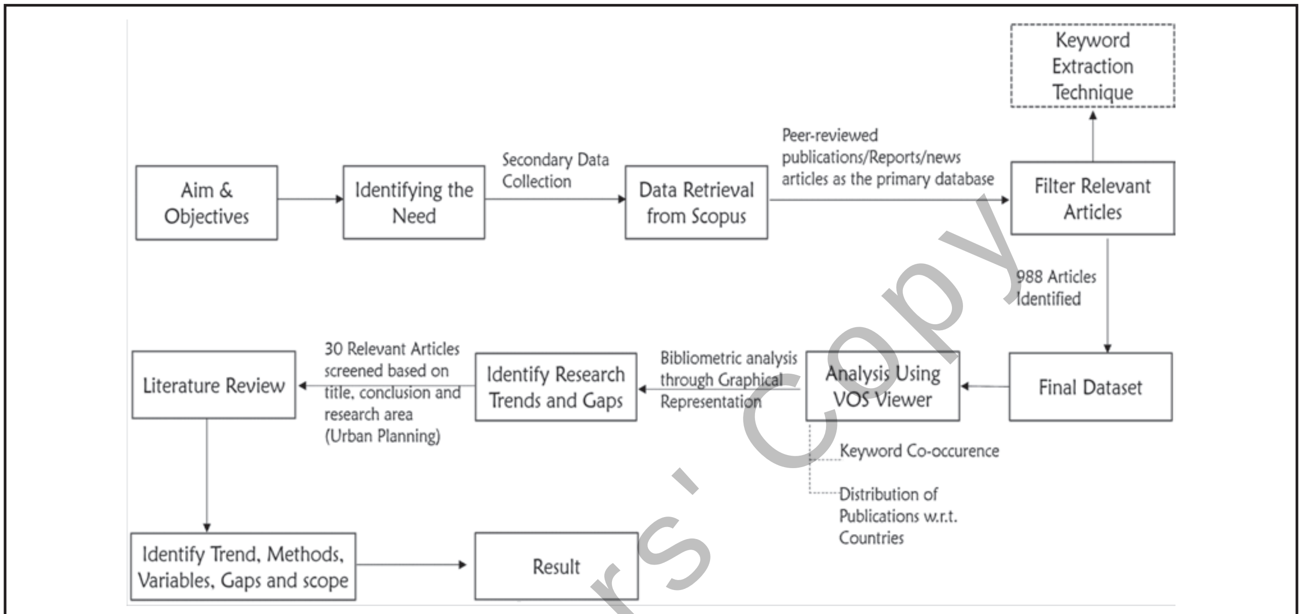

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Figure 1: SLR Methodology Flowchart

Table 1: Criteria Used for Selecting Publications for Review in this Study

Publisher	Elsevier
Database	Scopus
Keywords	"Urban planning" AND "urban heat island (UHI)" AND "spatial analysis" AND "climate effect"
Subject Area	Social science
Document Type	Journal articles
Peer-reviewed status	Only peer-reviewed documents
Language	English
Year	2014-2024

(Source: Compiled by Authors)

RESULTS AND ANALYSIS

Publications Trend Analysis

As shown in *Figure 2* , there has been a notable rise in studies about the Urban Heat Island (UHI) effect in the last decade. This suggests that scholars are becoming more interested in this topic. This growing interest highlights the importance of understanding and tackling how UHI affects environmental sustainability and human health. The number of studies on this topic grew from more than 30 in 2014 to around 150 in 2022 and almost 125 in 2024. This increase shows that more research is being conducted because the urban heat island effect affects urban planning and the health of the public. There has been a notable fall in 2024 but might see a spike in publications in the coming months (data collected till July). The increase in publications may point to a greater variety of research methods, geographic areas of focus, and interdisciplinary approaches, all of which will help us understand urban heat islands better. The chart shows that the amount of research is growing, which means there is a strong and expanding body of work that could offer useful information for organized reviews and guide future research.

A Comparative Analysis of Journal Publications

As shown in *Figure 3* , examining articles about the Urban Heat Island (UHI) effect from 2014 to 2024 in different journals reveals important patterns and points out areas where more research is needed. With a significant impact factor of 10.7, "Sustainable Cities and Society" journal leads with 208 publications highlighting its high relevance in urban sustainability research. "Climate and Buildings" and "Urban Climate" have impact factors of 6.7 and 7.4 respectively, demonstrating their high presence in climate and environmental research, each having 163 papers. With 155 articles and an impact factor of 3.9, "Sustainability Switzerland" comes in second with a considerable influence on sustainability research. With just 17 articles, "Applied Geography" has an impact factor of 4.0, which indicates that even with its modest production, it has a fair effect within geographical study. Between 2014 and 2018, the amount of research papers remained consistent. But starting in 2019, there was a noticeable rise, particularly in well-regarded journals like "Sustainable Cities and Society." This highlights the growing importance and necessity of the study. Yet, after 2021, there was a small drop in the number of papers in journals such as "Sustainability Switzerland" and "Building and Environment." This could suggest that research on Urban Heat Island (UHI) effects might be becoming less focused or that the topic is being explored thoroughly, leaving some areas less studied. To tackle UHI, it's important to have more research that combines different fields and is spread across various journals, considering the uneven distribution of papers in journals with different levels of influence.

Figure 4, shows that most research on urban heat islands focuses on social sciences (34.3%) and environmental sciences (22.5%). This research looks at how urban heat affects people's health, as well as its impact on society and the environment. Engineering (15.2%) and energy studies (12.9%) are also very important, probably because they help find ways to use technology and save energy.

However, there are some missing parts in the research. Even though the Urban Heat Island (UHI) effect has a big impact on things like property, energy costs, and money, there isn't much research from people who study business and economics. There's not much research in computer science (3.4%) and farming (1.2%), which means we need more studies that use things like machine learning, data analysis, and ways to grow food in cities that are good for the environment. There's hardly any research from people who study art and history (0.2%), which means research is required to understand how culture and history are connected to UHI. To tackle the tough problems around UHI, more research in these areas is needed that haven't been studied earlier and brings together ideas from farming, computer science, and economics.

Additionally, the way articles are published in the journals we looked at shows that there aren't enough studies from an urban planning perspective. Even though there are many studies about the Urban Heat Island (UHI) effect in different areas, this gap suggests that city planning strategies haven't been well integrated into UHI research. This could be important for making better and more effective plans to reduce the UHI effect.

As shown in *Figure 5* , the term "urban heat island" is centrally placed and denotes close linkages to topics such as "climate change", "land surface temperature", "urban planning," and "thermal comfort. There are notable clusters centered on temperature and climate, urban planning and mitigation, environmental methods, and remote sensing. Even though it exists, the picture suggests that urban planning isn't as important as it should be, indicating a lack of focus on research about the Urban Heat Island (UHI) effect. More emphasis should be placed on urban planning, particularly when designing neighborhoods that can withstand the impacts of UHI by implementing thorough zoning, land use planning, and eco-friendly urban design.

As shown in *Figure 6*, the graphic points out a noticeable absence of connections between the keywords “GIS” and terms like “spatial analysis” and “urban planning”. Despite Geographic Information System (GIS) being valuable in providing spatial insights for UHI research, is not being fully integrated into urban planning and analysis aspects of UHI studies. Therefore, more research is needed that combines different fields of study like nature, city design, technology, and how people live. Right now, there aren't many connections between these different areas.

The studies often mention "remote sensing," which is a way to gather information from far away. But newer tools like artificial intelligence, huge sets of data, and the Internet of Things aren't discussed as much, even though they could help keep track of and reduce the heat in cities. Further research in the new areas and the use of GIS as a tool for mapping and analyzing things, together with methods for studying places and planning cities. This would help us come up with better and more effective ways to deal with the rising heat problem in cities by providing spatial analysis to further make strategies and policy recommendations.

Analysis of Publications Distribution by Countries

The number of articles published by various countries in the UHI research field, keeping the criteria of a minimum of 20 articles per country is highlighted in *Figure 7*. The research is dominated by China and the United States, followed by the United Kingdom, Japan, and others. This network also shows strong international collaborations between China, the U.S., and European Nations. However, out of 988 articles, only 66 articles are published by India. Looking at India's rapid urbanization which is the most populated country, faces escalating urban heat challenges, whereas only nine papers focus on the urban planning domain concerning UHI. However, the lack of research carried out in the UHI (urban planning) domain in India is concerning. This highlights an urgent need for increased focus on UHI studies. Expanding research in this area is vital for informing better urban planning, policies, and technologies to address the growing challenges posed by UHI.

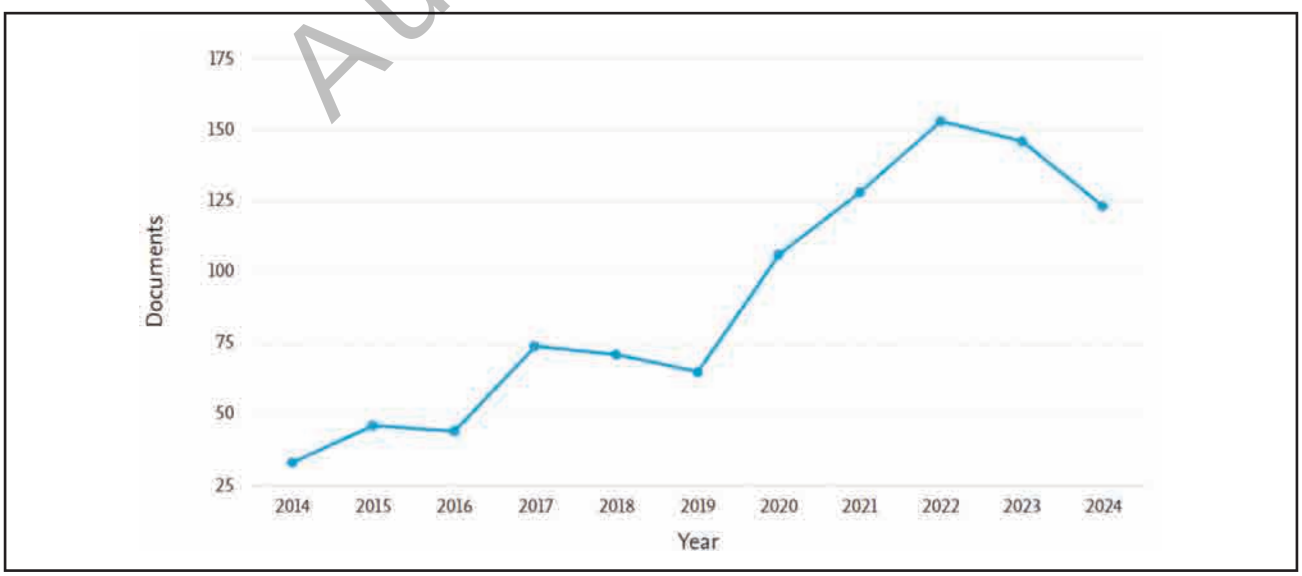

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Figure 2: Trend of Publications on Urban Heat Island Effect (2014-2024)

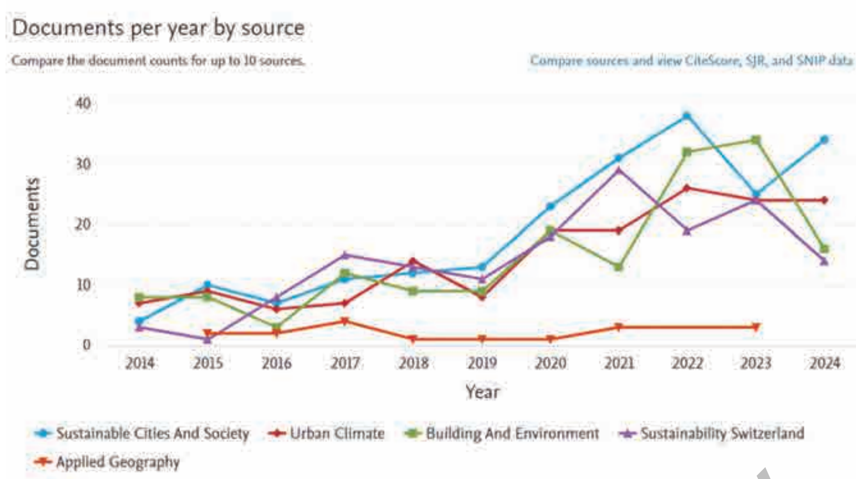

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Figure 3: Publications on Urban Heat Island Effect per Year

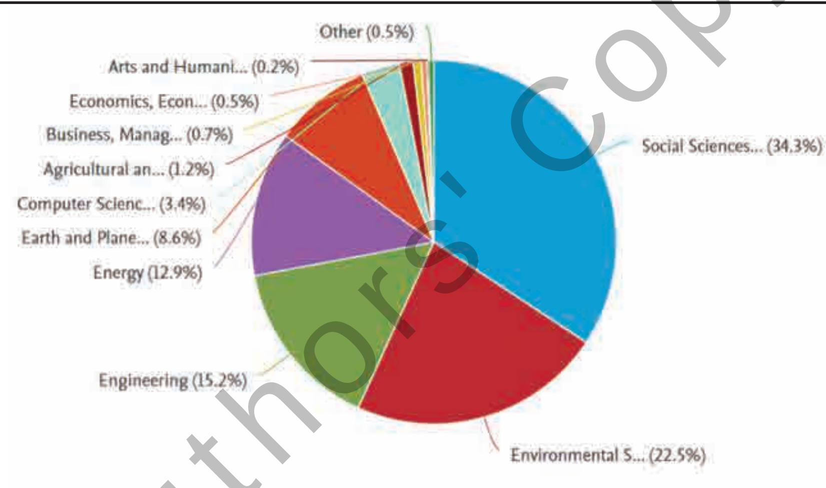

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Figure 4: Distribution of UHI Research Publications in Subject Areas

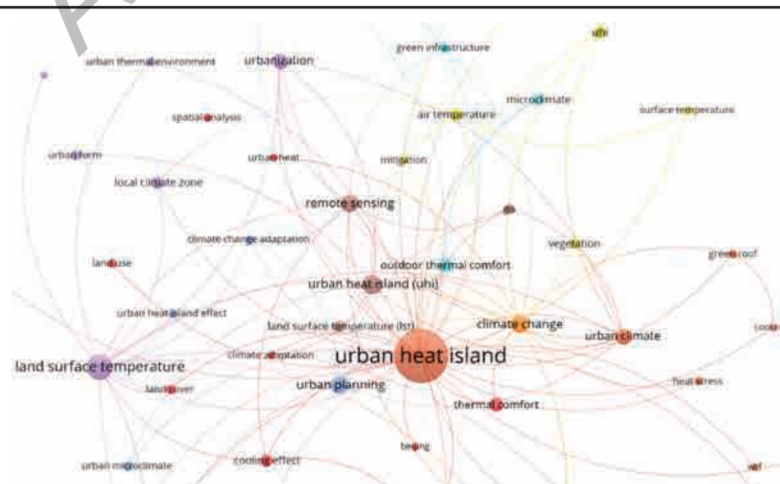

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Figure 5: Keyword Co-occurrence Network for Urban Heat Island Effect Studies

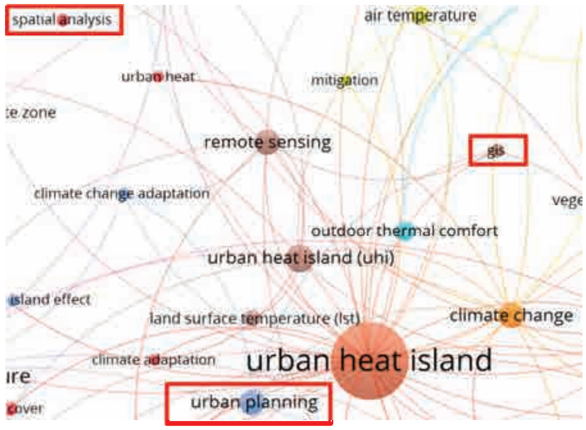

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Figure 6: Keyword Co-occurrence Network Illustrating Key Terms

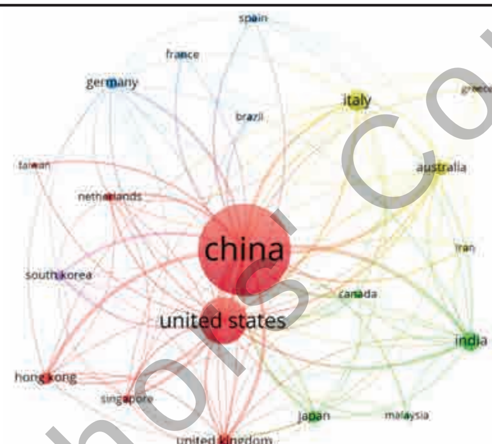

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Figure 7: Global Distribution of Publications in UHI Research

REVIEW OF KEY RESEARCH

The literature review covers 30 articles understanding the intricacies of the UHI in the urban planning field, emphasizing the need to address this phenomenon. The review highlights the focus of these articles, the pressing need identified by the researchers, and the gaps in the current understanding of the UHI dynamics. This study also investigates the methodologies used and the factors that influence the intensity of the UHI, providing scope for future studies.

Rationale for the Study Based on Research Perspective

Global warming is increasing the demand for cooling, which is leading to intensified UHI effects, higher energy consumption, and greater health risks (Assenova, Vitanova, & Antonova, 2024) (Peron, Maria, Spinazzè, & Mazzali, 2015) (Zhao, Lee, Smith, & Oleson, 2014). Though extensive research has been carried out on UHI, much of it remains fragmented, lacking a comprehensive and holistic approach to mitigate UHI impacts and promote sustainable urban development (Assenova, Vitanova, & Antonova, 2024). These issues require evaluating and implementing strategies at the local level, in contrast to the majority of the studies that focus on larger areas (Peron, Maria, Spinazzè, & Mazzali, 2015) (Zhao, Lee, Smith, & Oleson, 2014)

Urban grid forms have considerable influence on the reduction of UHI, as the modification of urban layouts can improve thermal behavior, reduce electricity demand as well as enhance liveability, offering a tangible mitigation strategy for these issues (Sosa, Correa, & Cantón, 2017). Studies have highlighted the significant role of human activities as the driving mechanism of the UHI and remains the primary driver in increasing urban temperatures, emphasizing the need to quantify and mitigate them (Min, Lin, Duan, Jin, & Zhang, 2019) (Halder, Bandyopadhyay, & Banik, 2021).

Urban size being a key indicator of urbanization plays a significant role in UHI intensity and yet there is very little knowledge about how urban size influences UHI and its spatial-temporal variations across regions (Li X. , Zhou, Asrar, Imhoff, & Li, 2017). It is essential to view towns and cities as a continuum, rather than isolated units to better understand UHI's inner annual dynamics and its determinants within large urban agglomerations (Sun, Gao, Li, Wang, & Liu, 2019). Emphasis should be given to the need to move beyond large metropolitan areas to study how factors like urban size influence the UHI effect (Heinl, Hammerle, Tappeiner, & Leitinger, 2015). Though previous studies on the rural-urban gradient within single cities have shown a positive correlation between UHI and development intensity, the research has been limited to a few large cities, leaving a knowledge gap on UHI's response to urbanization across broader regions (Li & Zhou, 2019). However, (Borbora & Das, 2014) emphasizes the need to direct more attention to smaller urban centers as urbanization continues to expand beyond large metropolises.

Spatiotemporal variations in Surface Urban Heat Island Intensity (SUHII) are one of the major contributors to the UHI, illustrating the need to understand its interplay between various systems like natural, social, and economic, despite their significance these remain underexplored (Wang, Huang, Fu, & Atkinson, 2015). The contribution of spatiotemporal factors to the UHI effect has been significant and to mitigate the phenomenon there is a need to develop a thorough understanding of their causal mechanism (Deilami, Kamruzzaman, & Hayes, 2018). Therefore, for designing effective mitigation strategies, understanding the relationship between the Surface Heat Island (SUHI) and urban size is critical (Li X. , Zhou, Asrar, Imhoff, & Li, 2017) (Guo, et al., 2019). Despite the significant impacts of spatiotemporal patterns of land use/land cover changes (LUCC) on UHI distribution and intensity, their relationship hasn't been studied majorly, prompting a need for a mixed method of investigation (Yang, et al., 2017).

It is also significant to examine how rural land cover patterns affect UHI mitigation (Yang, et al., 2024). LULC changes cause a significant rise in the surface temperatures in urban areas, highlighting the need to study their relationship (S, F, & M, 2022) (Suwaidi & Elessawy, 2021) (Pal & Ziaul, 2016). Globally due to rapid urbanization, there has been a transformation of natural, vegetated surfaces into built-up, impervious areas – characterized by the use of bitumen, asphalt, bricks, and concrete for construction, roads, and parking lots, which play a pivotal role in intensifying UHI (Mathew, Khandelwal, & Kaul, 2016). Land Surface Temperature (LST) serves as a critical parameter and with urbanization, it is crucial to address this challenge (Mathew, Sreekumar, Khandelwal, Kaul, & Kumar, 2016). LST is significantly affected by urban building materials, but the other main factors that are largely responsible for the spatial and temporal patterns of UHI are the plant cover and the elevation (Mathew, Khandelwal, & Kaul, 2017). The increasing land surface temperature, mainly caused by the transformation of natural landscapes into impermeable surfaces, is one of the most significant challenges urban areas are currently facing (Singh, Kikon, & Verma, 2017) (Wang, Zhang, Tsou, & Li, 2017) (Morris, et al., 2015).

Identifying Research Gaps for Future Investigation

Earlier research on UHI primarily focused on a few cities or a limited number of factors, such as vegetation, neglecting the interactions of multiple variables like city size, form, and anthropogenic factors (Wang, Huang, Fu, & Atkinson, 2015). There is a noticeable gap in comprehensive reviews that analyze different aspects of UHI research, including methodologies, data, and its impact on other urban dimensions (Assenova, Vitanova, & Antonova, 2024). While most studies concentrate on how specific factors influence UHI, fewer investigate the opposite - how UHI impacts the urban environment, including air quality, wind comfort, and rainfall (Assenova, Vitanova, & Antonova, 2024). Furthermore, the temporal scope of these studies is often limited, with many examining the same periods (Assenova, Vitanova, & Antonova, 2024). Prior research has demonstrated that data from remote sensing

is useful for calculating land surface characteristics and extracting surface information. However, to gain a complete understanding of Urban Heat Island (UHI) formation, it is crucial to integrate this data with information that reflects human activities (Min, Lin, Duan, Jin, & Zhang, 2019). This is important because similar surface coverage can result in different land surface temperatures (LST) due to varying human influences (Min, Lin, Duan, Jin, & Zhang, 2019). While a number of studies have examined the effects of urban heat islands (UHI) in major cities, there is a lack of understanding regarding UHI variations in smaller communities (Sun, Gao, Li, Wang, & Liu, 2019). Previous UHI research has overlooked small to medium-sized cities and the surrounding rural landscape, despite its significant influence, revealing that urban-rural vegetation differences (NDVI) drive UHI intensity more than urban-size (Heinl, Hammerle, Tappeiner, & Leitinger, 2015) (Zhao, Lee, Smith, & Oleson, 2014). In metropolitan areas, land surface temperatures (LST) tend to rise consistently as one gets closer to the city center, yet there has been little exploration of these effects in urban agglomerations of varying sizes (Sun, Gao, Li, Wang, & Liu, 2019).

Despite the increase in UHI research, comprehensive reviews remain rare due to synonymous terms and the limited classification methods used, constrained by the complexity and cost of analyzing multiple images, therefore, broader analytical approaches are needed to better understand the spatiotemporal factors affecting UHI (Deilami, Kamruzzaman, & Hayes, 2018). Because the spatial resolutions of the images from remote sensing vary, the relationship between observed LST and surface cover is often masked, making it crucial to select the appropriate analytic unit (Guo, et al., 2019). Spatial statistical methods are essential for exploring the relationship between driving factors and surface temperature in UHI studies (Guo, et al., 2019). Land use and land cover (LU/LC) predictions are not 100% accurate.

The relationship between LST, elevation, and vegetation is not always consistent (Mathew, Sreekumar, Khandelwal, Kaul, & Kumar, 2016). A notable knowledge gap in UHI research is the absence of seasonal analysis, which is crucial given the seasonal variations in LST-vegetation index (NDVI, EVI) relationships (Mathew, Khandelwal, & Kaul, 2017). Existing UHI mitigation research focuses predominantly on intra-urban solutions, neglecting the potential of neighboring rural land cover (NRLC) to alleviate urban heat, resulting in significant knowledge gaps regarding its quantified impact, optimal locations, and patterns (Yang, et al., 2024).

Rapid urbanization and changes in land use are not well understood in terms of their impact on urban heat islands (UHI) and ecological degradation (Singh, Kikon, & Verma, 2017). Previous studies lacked a comprehensive approach using remote sensing to evaluate the effects of land surface temperature (LST), vegetation cover, and urban development on UHI in Indian cities (Singh, Kikon, & Verma, 2017). Understanding the correlation between urban morphology and cooling energy consumption remains limited, particularly in arid environments, where balancing urban design with energy efficiency poses a significant challenge (Sosa, Correa, & Cantón, 2017). There is difficulty in accurately measuring the correlation between land-use changes (impervious surfaces, vegetation, and water) and the SUHI effect over time (Wang, Zhang, Tsou, & Li, 2017) (Yang, et al., 2017).

Research on SUHI's response to urbanization is mostly city-specific, using indicators like impervious surface area and population density. However, these models face data and computational limitations when applied to larger, multi-metropolitan regions, and temporal dynamics of SUHI response to urban expansion remain understudied (Li X. , Zhou, Asrar, Imhoff, & Li, 2017). A significant gap existed in prognostic studies using computational tools to analyze the temporal and spatial variation of UHI, the influence of surface materials, and how different urban fabrics contribute to UHI (Morris, et al., 2015). Many earlier studies suffer from multicollinearity issues, reducing the reliability of their conclusions about UHI formation. The city's complex urban fabric, with its mix of informal housing, high-rise buildings, and varied urban forms, presents a challenge in isolating the impact of each factor on UHI intensity

(Okumus & Terzi, 2021).

Methods Used to Study UHI

The methods listed in *Table 2*, are classified based on their specific focus and approach in research studies, especially in the fields of environmental science and urban planning. They are organized according to various factors, including the type of research (such as experimental, computational, or survey-based), the focus area (like data collection, analysis, or model development), the application (whether in the field or laboratory), and whether the methods are quantitative or qualitative. This organized classification helps clarify research findings and showcases the different techniques used in the field, making it easier to understand how various methodologies enhance the overall body of knowledge.

Most of the studies reviewed (38%) concentrate on analyzing Land Surface Temperature (LST) and Urban Heat Island (UHI) effects through satellite data sources like Landsat and MODIS. Techniques related to remote sensing and image classification, which include both supervised and unsupervised methods, make up 8% of the studies. Statistical and spatial analysis methods, such as Pearson correlation and spatial autocorrelation, represent 10%. Simulation and modeling techniques, which include ENVI-met simulations, weather research and forecasting (WRF) models, and Urban Climate Models (UCM), account for 18% of the literature examined. Lastly, 10% of the studies incorporate climate data derived from meteorological station records and in-situ measurements. These percentages illustrate the significance of each methodological approach in the existing research landscape.

Variables Contributing to UHI

Table 3 categorizes factors relevant to urban studies into five main classes: "Land Use and Land Cover (LULC)", "Physical Characteristics", "Environmental Characteristics", "Population and Human Factors", and "Remote Sensing Indices". Most of the variables highlighted in the literature primarily concentrate on "Land Use and Land Cover" (such as built-up areas and vegetation cover), "Physical Characteristics" (including impervious surfaces and urban size), and "Environmental Characteristics" (like land surface temperature and air temperature). These variables are frequently expressed in percentages, especially for built-up areas, vegetation, and impervious surfaces, as they serve as essential indicators in urban analysis.

The methodology for categorization involves thematically grouping these variables to illustrate their significance in urban studies. By organizing them into broad classes, the table connects variables with key urban research themes, supported by a review of existing studies. This approach provides a thorough framework that encompasses the physical, environmental, and human dimensions of urban environments.

Way Forward Stated in the Reviewed Literature

Based on the literature review the focus should be on increasing green spaces, minimizing hard surfaces, and integrating vegetation into urban design to help lower surface temperatures. Researchers suggest enhancing remote sensing methods, such as combining satellite imagery and creating new algorithms to improve the accuracy of land cover and land surface temperature (LST) measurements. Future research should investigate UHI impacts at various scales, during different seasons and times of day, while also taking into account factors like wind patterns, humidity, evapotranspiration, groundwater quality, and smart city technologies. Urban planners are urged to consider factors such as impervious surface area (%ISA), LST, and elevation in their development plans. Key strategies for mitigating UHI include using reflective materials, increasing vegetative surfaces, expanding green cover, and reducing building density. To create more precise models, cross-regional studies, extended data collection periods, and high-resolution satellite data are crucial. Urban policies should integrate these findings to promote sustainable development and lessen UHI impacts on cities that are expanding quickly.Conclusion

Table 2: Categorization of Literature Based on Methods

Category	Methods used	Reviewed literature
Land Surface Temperature (LST)	Landsat satellite data (OLI, TM), MODIS data, Mono -window algorithms, regression models, correlation analysis, NDVI, NDBI, and UHI metrics	(Min, Lin, Duan, Jin, & Zhang, 2019), (Sun, Gao, Li, Wang, & Liu, 2019) , (Guo, et al., 2019), (Mathew, Sreekumar, Khandelwal, Kaul, & Kumar, 2016), (Mathew, Khandelwal, & Kaul, 2017), (Yang, et al., 2024), (Singh, Kikon, & Verma, 2017), (Zhao, Lee, Smith, & Oleson, 2014), (Wang, Zhang, Tsou, & Li, 2017), (Yang, et al., 2017), (Pal & Ziaul, 2016)
Remote Sensing and Image Classification Techniques	Image classification (supervised, unsupervised), machine learning models (SVM, ANN), NDVI, NDBI, LU/LC classification, CA - ANN models for future predictions, satellite thermal infrared data	(Halder, Bandyopadhyay, & Banik, 2021), (Heinl, Hammerle, Tappeiner, & Leitinger, 2015)
Statistical and Spatial Analysis	Pearson correlation, spatial autocorrelation, spatial regression models (GWR, OLS), SHAP, ALE, spectral mixture analysis, statistical tools for parameter extraction	(Sosa, Correa, & Cantón, 2017) , (Li X. , Zhou, Asrar, Imhoff, & Li, 2017) , (Deilami, Kamruzzaman, & Hayes, 2018)
Simulation and Modeling Approaches	ENVI-met simulations, WRF model, UCM, climate models, energy consumption prediction (e.g., P REDISE software), urban canopy models, RRM machine learning models.	(Mushtaha, et al., 2021) , (Peron, Maria, Spinazzè, & Mazzali, 2015) , (Suwaidi & Elessawy, 2021) , (Morris, et al., 2015), (Okumus & Terzi, 2021)
Climate Data Integration and Comparative Studies	Meteorological station data, in situ measurements, microclimatic data collection, regression tree models, comparison across climate zones, and climate decomposition models.	(Sheng, Lu, & Huang, 2015), (Borbora & Das, 2014), (Yang, Li, Luo, & Chan, 2016)
Vegetation and Urbanization Impact on UHI	Vegetation indices (NDVI, EVI), percent impervious surface area (%ISA), urbanization patterns analysis, vegetation's role in UHI mitigation.	(Li & Zhou, 2019), (Mathew, Khandelwal, & Kaul, 2016)
Machine Learning and Predictive Modeling	Artificial Neural Networks (ANN), Cellular Automata (CA), Random Regression Model (RRM), supervised machine learning techniques	(S, F, & M, 2022), (Okumus & Terzi, 2021)

(Source: Compiled by Authors)

Table 3: Variables Influencing UHI Intensity

Themes	Variables	Reviewed Literature
Land Use and Land Cover (LULC)	Vegetation area, Built-up area, Water bodies, Agricultural land, Open spaces	(Assenova, Vitanova, & Antonova, 2024), (Min, Lin, Duan, Jin, & Zhang, 2019), (Deilami, Kamruzzaman, & Hayes, 2018), (Halder, Bandyopadhyay, & Banik, 2021), (Heinl, Hammerle, Tappeiner, & Leitinger, 2015), (Wang, Huang, Fu, & Atkinson, 2015), (Yang, et al., 2024), (Yang, et al., 2017), (Morris, et al., 2015)
Physical Characteristics	Urban size, Building materials, Impervious surface areas, Vegetation cover, Percent impervious surface, Elevation, Proximity to r oads, Slope, Urban albedo	(Assenova, Vitanova, & Antonova, 2024), (Sun, Gao, Li, Wang, & Liu, 2019), (Deilami, Kamruzzaman, & Hayes, 2018), (Heinl, Hammerle, Tappeiner, & Leitinger, 2015), (Li & Zhou, 2019), (Mathew, Khandelwal, & Kaul, 2017), (Peron, Maria, Spinazzè, & Mazzali, 2015)
Environmental Characteristics	Land Surface Temperature (LST), Air temperature, Relative humidity, Diurnal Temperature Range (DTR)	(Assenova, Vitanova, & Antonova, 2024), (Mathew, Khandelwal, & Kaul, 2016), (Sosa, Correa, & Cantón, 2017), (Borbora & Das, 2014), (Li X. , Zhou, Asrar, Imhoff, & Li, 2017)
Population and Human Factors	Population density, Health/human comfort, Heat storage, Energy consumption, Urban cluster size, Urban thermal field variance index (UTFVI)	(Assenova, Vitanova, & Antonova, 2024), (Min, Lin, Duan, Jin, & Zhang, 2019), (Deilami, Kamruzzaman, & Hayes, 2018), (Mathew, Khandelwal, & Kaul, 2017), (Wang, Huang, Fu, & Atkinson, 2015)
Remote Sensing Indices	NDVI, NDBI, MNDWI, NDBSI (Normalized Difference Bare Soil Inde x), Sky view factor, Artificial Neural Network (ANN), Cellular Automata (CA)	(Min, Lin, Duan, Jin, & Zhang, 2019), (Guo, et al., 2019), (Mathew, Sreekumar, Khandelwal, Kaul, & Kumar, 2016), (Mathew, Khandelwal, & Kaul, 2017), (Sheng, Lu, & Huang, 2015), (Singh, Kikon, & Verma, 2017), (Wang, Zhang, Tsou, & Li, 2017), (S, F, & M, 2022), (Suwaidi & Elessawy, 2021), (Okumus & Terzi, 2021)
Climate and Meteorological Data	Precipitation, Convection efficiency, Albedo, Air movement, Urban heat island intensity (UHI), Heat storage	(Zhao, Lee, Smith, & Oleson, 2014), (Yang, Li, Luo, & Chan, 2016)

The Urban Heat Island (UHI) effect is examined in detail in this research, with a focus on how important it is in accelerating global warming, impacting public health, and shaping urban development. Significant information gaps and developing trends are identified by the study through the analysis of many criteria, including vegetation cover, developed areas, population density, proportion of waterbodies, and impervious surfaces. The use of VOS Viewer for bibliometric analysis highlights the necessity for integrated urban planning and evidence-based policies to mitigate UHI effects. The research underscores the importance of a holistic approach, combining advanced technology, innovative methodologies, and interdisciplinary collaboration to effectively address the challenges posed by UHI, especially in rapidly urbanizing regions like India. This comprehensive approach is essential for developing sustainable urban environments that can withstand the adverse impacts of UHI. Collectively, these studies highlight the pressing need for comprehensive UHI research that integrates spatial, temporal, environmental, and social dimensions in urban planning to effectively tackle the complex issues that UHI has brought forth.

References

Abbas Mohajerani, J. B.-B. (2017). The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. Journal of Environmental Management, 522-538.

Assenova, I., Vitanova, L., & Antonova, D. P. (2024). Urban heat islands from multiple perspectives: Trends across disciplines and interrelationships . Urban Cimate.

Bao-Jie He, W. W. (2023). Progress, knowledge gap and future directions of urban heat mitigation and adaptation research through a bibliometric review of history and evolution. Energy and Buildings.

Borbora, J., & Das, A. K. (2014). Summertime Urban Heat Island study for Guwahati City, India. Sustainable Cities and Society.

Deilami, K., Kamruzzaman, M., & Hayes, J. F. (2018). Correlation or Causality between Land Cover Patterns and the Urban Heat Island Effect? Evidence from Brisbane, Australia. Remote Sensing.

Elkhan Richard Sadik-Zada, A. G. (2022). Vulnerability to the urban heat islands effect in the Global North and the Global South: assessment of the drivers and mitigation strategies. Global Urban Heat Island Mitigation, 29-45.

Guo, A., Yang, J., Xiao, X., Xia, J., Jin, C., & Li, X. (2019). Influences of urban spatial form on urban heat island effects at the community level in China. Sustainable Cities and Society.

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.

Heinl, M., Hammerle, A., Tappeiner, U., & Leitinger, G. (2015). Determinants of urban–rural land surface temperature differences – A landscape scale perspective. Landscape and Urban Planning, 33-42.

Hindustan Times. (2022, April).

Hindustan Times. (2023, April).

IPCC. (2014). Climate Change 2014. IPCC.

Kaveh Deilami, M. K. (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, 30-42.

Li, X., & Zhou, W. (2019). Spatial patterns and driving factors of surface urban heat island intensity: A comparative study for two agriculture-dominated regions in China and the USA. Sustainable Cities and Society.

Li, X., Zhou, Y., Asrar, G. R., Imhoff, M., & Li, X. (2017). The surface urban heat island response to urban expansion: A panel analysis for the conterminous United States. Science of the Total Environment.

M. Santamouris, C. C. (2015). On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings—A review. Energy and Buildings, 119-124.

Mathew, A., Khandelwal, S., & Kaul, N. (2016). Spatial and Temporal Variations of Urban Heat Island Effect and the effect of Percentage Impervious Surface Area and Elevation on Land Surface Temperature: Study of Chandigarh City, India. Sustainable Cities and Society.

Mathew, A., Khandelwal, S., & Kaul, N. (2017). Investigating spatial and seasonal variations of urban heat island effect over Jaipur city and its relationship with vegetation, urbanization and elevation parameters. Sustainable Cities and Society.

Mathew, A., Sreekumar, S., Khandelwal, S., Kaul, N., & Kumar, R. (2016). Prediction of Surface Temperatures for the Assessment of Urban Heat Island Effect over Ahmedabad City Using Linear Time Series Model. Energy and Buildings.

Min, M., Lin, C., Duan, X., Jin, Z., & Zhang, L. (2019). Spatial distribution and driving force analysis of urban heat island effect based on raster data: A case study of the Nanjing metropolitan area, China. Sustainable Cities and Society.

Morris, K. I., Salleh, S. A., Chan, A., Ooi, M. C., Abakr, Y. A., Oozeer, M. Y., & Duda, M. (2015). Computational study of urban heat island of Putrajaya, Malaysia. Sustainable Cities and Society.

Mushtaha, E., Abdelrahi, M., Shareef, S., Alsyouf, I., Albannay, S., Mori, T., & Kayed, A. (2021). A study of the impact of major Urban Heat Island factors in a hot climate courtyard: The case of the University of Sharjah, UAE. Sustainable Cities and Society.

Okumus, D. E., & Terzi, F. (2021). Evaluating the role of urban fabric on surface urban heat island: The case of Istanbul. Sustainable Cities and Society.

Pal, S., & Ziaul, S. (2016). Detection of land use and land cover change and land surface temperature in English Bazar urban centre. The Egyptian Journal of Remote Sensing and Space Sciences.

Peron, F., Maria, M. D., Spinazzè, F., & Mazzali, U. (2015). An analysis of the urban heat island of Venice mainland. Sustainable Cities and Society.

RIZWAN Ahmed Memon, D. L. (2008). A review on the generation, determination and mitigation of Urban Heat

Island. Journal of Environmental Sciences, 120-128.

S, S., F, Z., & M, E.-M. (2022). Automated Mapping of Urban Heat Island to Predict Land Surface Temperature and Land Use/Cover Change Using Machine Learning Algorithms: Mansoura City . International Journal of Geoinformatics.

Sheng, L., Lu, D., & Huang, J. (2015). Impacts of land-cover types on an urban heat island in Hangzhou, China. International Journal of Remote Sensing.

Singh, P., Kikon, N., & Verma, P. (2017). Impact of land use change and urbanization on urban heat island in Lucknow city, Central India. A remote sensing based estimate. Sustainable Cities and Society.

Sosa, M. B., Correa, E. N., & Cantón, M. A. (2017). Urban grid forms as a strategy for reducing heat island effects in arid cities. Sustainable Cities and Society.

Sun, Y., Gao, C., Li, J., Wang, R., & Liu, J. (2019). Evaluating urban heat island intensity and its associated determinants of towns and cities continuum in the Yangtze River Delta Urban Agglomerations. Sustainable Cities and Society.

Suwaidi, M. A., & Elessawy, F. M. (2021). Urban Heat Island Effect Detection in the Al 'Ain Region in 2000 and 2019. The Arab World Geographer.

Wang, H., Zhang, Y., Tsou, J. Y., & Li, Y. (2017). Surface Urban Heat Island Analysis of Shanghai (China) Based on the Change of Land Use and Land Cover. sustainability.

Wang, J., Huang, B., Fu, D., & Atkinson, P. M. (2015). Spatiotemporal Variation in Surface Urban Heat Island Intensity and Associated Determinants across Major Chinese

Cities. Remote Sensing.

Yang, C., He, X., Yan, F., Yu, L., Bu, K., Yang, J., . . . Zhang, S. (2017). Mapping the Influence of Land Use/Land Cover Changes on the Urban Heat Island Effect—A Case Study of Changchun, China. sustainability.

Yang, M., Ren, C., Wang, H., Wang, J., Kumar, ., Haghighat, F., . . Feng, Z. (2024). Mitigating urban heat island through neighboring rural land cover. Springer Nature.

Yang, X., Li, Y., Luo, Z., & Chan, P. W. (2016). The urban cool island phenomenon in a high-rise high-density city and its mechanisms. International Journal of Climatology.

Zhao, L., Lee, X., Smith, R. B., & Oleson, K. (2014). Strong contributions of local background climate to urban heat islands. nature cities.