

Research Progress and Hotspot Analysis of Urban Heat Island in Recent 20 Years Based on CiteSpace

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ABSTRACT

In this paper, 1850 literatures published in CNKI from 2001 to 2021 are selected as the research objects, and the progress and hot trends of urban heat island research in China in recent two decades are analyzed by using scientometrics and CiteSpace. The results show that; 1) Urban heat island research in China can be roughly divided into three stages, and the number of current literatures remains stable; 2) There are many research institutions but few publications, which are relatively independent and lack of trans-regional, trans-institutional and trans-field collaborative academic community; 3) The research focuses on the causes, research methods, temporal and spatial characteristics and influencing factors of urban heat island; 4) The research trend front focuses on the evaluation index of thermal environment, sponge city, landscape pattern and spatio-temporal pattern, and analyzes and prospects them. Through the analysis and sorting of the above contents, it is expected to provide beneficial enlightenment for the innovation and practical development of urban heat island theory in China.

KEYWORDS

Urban Heat Island; Citespace; Research Hotspots; Research Trends.

1. INTRODUCTION

Urban Heat Island (UHI) is a climatic phenomenon in which the temperature in urban areas is significantly higher than that in surrounding rural areas. This phenomenon was first documented in 1833 by British climatologist Luke Howard, who observed higher temperatures in the center of London compared to its suburbs and named this climatic characteristic the "heat island effect" [1]. Subsequently, it was not until 1958 that Manley formally proposed the concept of urban heat island [2].

With the acceleration of urbanization and global climate warming, the urban heat island effect has become increasingly severe. This phenomenon significantly impacts the urban environment and residents' health. Over the past few decades, the urban heat island has garnered widespread attention from scholars and received substantial focus from governments, emerging as one of the contemporary research hotspots. Systematic studies on the urban heat island effect not only provide a theoretical basis for the sustainable development of urban environments but also hold critical practical significance in safeguarding residents' quality of life and physical and mental health.

This study utilizes the CNKI (China National Knowledge Infrastructure) database, employing CiteSpace software and content analysis methods to review relevant domestic research literature on urban heat islands over the past 20 years. By analyzing and summarizing research characteristics and frontier hotspots, this study aims to enhance the theoretical understanding of urban heat islands and offer insights and references for exploring new research directions and perspectives in this field.

2. DATA SOURCES AND RESEARCH METHOD

This study uses journal articles from the CNKI database as data sources, employing the keywords "urban" and "heat island" for advanced searches. The selection criteria included core journals, CSSCI journals, and CSCD source journals, covering a time span of 20 years (2001–2021). Data collection was conducted on December 18, 2021, resulting in a total of 1,850 articles. Excel and CiteSpace 5.8.R3 software were utilized to process the data. Excel was used to analyze the development trajectory of urban heat island research in China, while CiteSpace was employed to examine research hotspots and frontiers by analyzing data nodes such as "author," "institution," and "keyword."

3. CHARACTERIZATION OF THE STUDY

3.1. Year of publication

Using Excel software, a trend chart (Figure 1) illustrating the annual changes in the number of domestic urban heat island-related publications from 2001 to 2021 was generated. The analysis reveals that research on urban heat islands in China can be divided into three stages: (1) Initial Stage (pre-2004): The period before 2004 marked the beginning phase, with fewer than 40 publications per year, indicating relatively slow development. (2) Rapid Development Stage (2005–2009): During this phase, the number of publications increased significantly, rising from 47 in 2005 to 127 in 2009. This period witnessed the highest growth rate in publication volume, reflecting a growing interest among researchers in this field. (3) Steady Development Stage (2010–2021): In this phase, the annual number of publications stabilized at around 110, indicating sustained research interest and a steady level of activity in this domain.

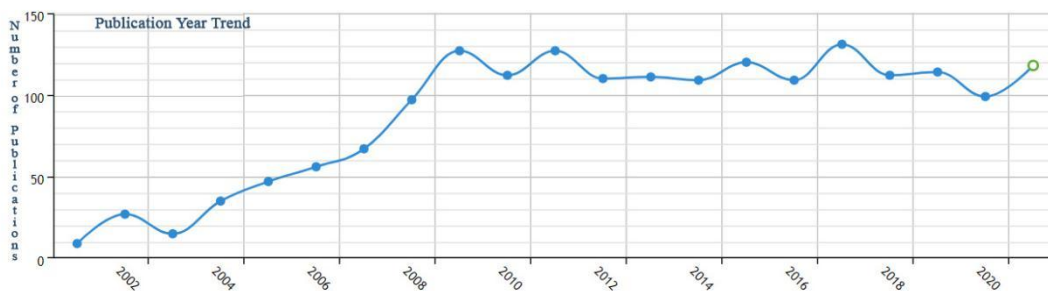


Figure 1 Chart of annual trends in the volume of research literature

3.2. Analysis by Research Institutions

The institutional knowledge map reveals the leading institutions and their collaborative relationships in the field of urban heat island research in China. By selecting the "Institution" node type in the Node Types section of the CiteSpace software, a collaborative network knowledge map of research institutions was generated (Figure 2). In the map, the number and size of the nodes reflect the frequency of co-occurrence, while the number and thickness of the links represent the degree of collaboration and closeness of relationships. The map shows sparse nodes with minimal connections, indicating that although there are many institutions involved in urban heat island research, their publication output is relatively low and dispersed. Additionally, institutional collaboration is limited, and cooperative relationships are weak. The institutions with higher publication output include the Chinese Academy of Meteorological Sciences, the Department of Atmospheric Sciences at Nanjing University, the College of Geography and Environmental Science at Northwest Normal University, the Research Center for Eco-Environmental Sciences at the Chinese Academy of Sciences, the National Meteorological Center, and the National Institute of Meteorology. Other notable contributors are the Department of Atmospheric and Oceanic Sciences at Peking University, the

School of Architecture at Tianjin University, and the College of Tourism and Environment at Shaanxi Normal University. This analysis indicates that the primary contributors are China's natural science research institutions and the China Meteorological Administration. However, a significant number of higher education institutions are also actively engaging in and contributing to urban heat island research.

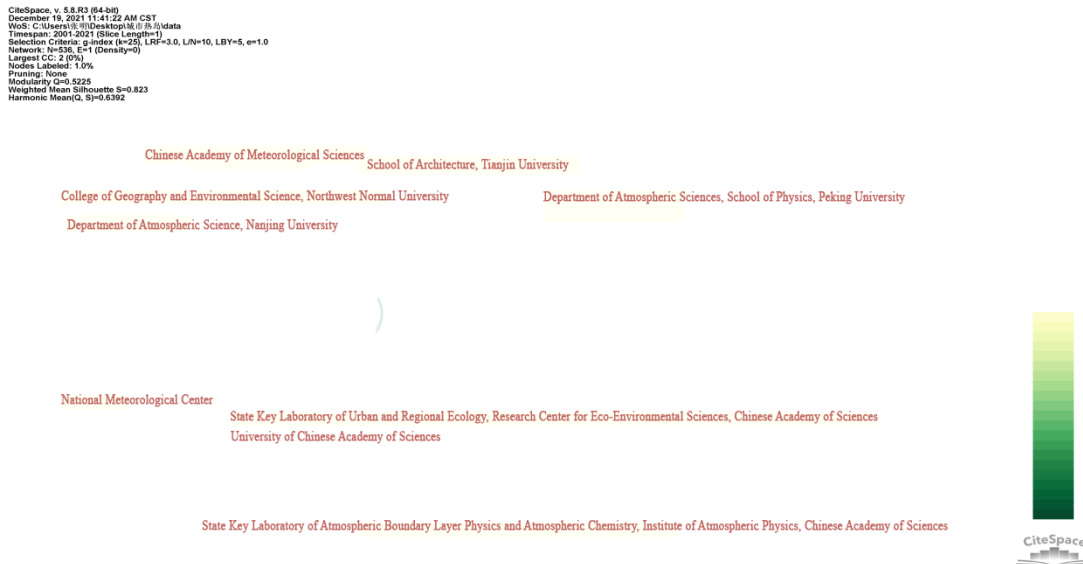


Figure 2 Knowledge map of collaborative network of urban heat island research organizations

3.3. Analysis of study authors

Analyzing the authors' collaboration network is helpful to identify the core figures and their degree of association in the field of urban heat island research in China. Using CiteSpace software, check “Author” as the node type in the Node Types area, and then draw the knowledge graph of the research authors' cooperation network (Figure 3). As shown in Figure 2, there are 708 nodes, 847 lines, and the network density is 0.0034, which indicates that the cooperation among scholars is not close. The figure also shows five academic groups with high publication volume in China: the Ren Guoyu team from the China Institute of Meteorological Sciences, the Jiang Weifang team from Nanjing University, the Miao Shiguang team from the Beijing Institute of Urban Meteorology of the China Meteorological Administration, the Wang Yongwei team from the Nanjing University of Information Engineering, and the Liu Yonghong team from the China Institute of Applied Remote Sensing, with 25, 19, 18, 17, and 15 publications, respectively, which are in the top five (Table 1) The number of articles published by these teams is 25, 19, 18, 17 and 15 respectively (Table 1). In general, it seems that the cooperation between authors in the field of urban heat island research is not close enough, and their research institutions are mostly self-contained or cooperating with neighboring institutions, and there is a lack of academic community of cross-regional, cross-institutional, and cross-field collaboration.

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 Nodes Labeled: 1.0%
 Pruning: None
 Modularity Q=0.5225
 Weighted Mean Silhouette S=0.823
 Harmonic Mean(Q, S)=0.6392



Figure 3 Urban Heat Island Research Author Collaboration Network Knowledge Map

Table 1 Statistical information on authors of studies with 10 or more publications

| Author | Frequency | Author | Frequency |
|---------------|-----------|--------------|-----------|
| Ren Guoyu | 25 | He Ping | 13 |
| Jiang Weimei | 19 | Liu Weidong | 12 |
| Miao Shiguang | 18 | Liu Hongnian | 11 |
| Wang Yongwei | 17 | Zeng Jian | 10 |
| Liu Yonghong | 15 | Meng Qinglin | 10 |
| Xu Hanqiu | 14 | Sun Ranhao | 10 |

4. ANALYSIS OF RESEARCH HOTSPOTS

Keywords are the concentration and refinement of the core ideas and contents of the literature, which can reflect the theme of the literature, and the frequency represents the heat of the research. Using CiteSpace software, check “keywords” as node type in Node Types area, draw keyword co-occurrence map (Figure 4), and statistically organize the high-frequency keywords, mainly surface temperature, urbanization, remote sensing, etc., and the intermediary centrality is more than 0.1, and the time is concentrated in the period of 2001-2003 (Table 2). The time is all concentrated in 2001-2003 (Table 2). The keywords were analyzed by clustering (Fig. 5), which was set to 10 clusters, with the modularity of clustering (Modularity) $Q=0.5225 (>0.3)$, and the average profile (Mean Silhouette) $S=0.823 (>0.5)$, which showed a better overall clustering effect. Combined with the above data, using the content analysis method, the summarized research hotspots are mainly divided into 4 parts.

4.1. Causes of urban heat islands

1)urbanization. There is an obvious correlation between built-up ratio[1] and heat island intensity. The larger the urban population, the larger the scale, the more obvious the heat island effect[1].With the

increase of China's urbanization level and the acceleration of urban expansion, the harm produced by the heat island effect has become more and more serious, and many scholars have begun to study the relationship between urbanization and the urban heat island, such as the study of Beijing, Xi'an, Northwest China, the Yangtze River delta and other regions of the impact of urbanization on the urban heat island, the study of the representative figures are Ji Chongping[1], Gao Hongyan[2], Ren Chunyan[3], Cui Linli[4] etc, to explore the trend of the evolution of the urban heat island with the urbanization.

2) Changes in the nature of the urban subsurface. The subsurface is closely related to the urban thermal environment, and differences in the thermal inertia of the subsurface are a direct cause of the urban heat island effect[1]. In the city the main underlay is artificial impervious surface green space, water bodies and woodlands and other direct exchange with the atmosphere on the surface, of which the impervious surface is mainly in the city of the building wall, concrete roads, squares, parking lots and so on. The rapid development of the city is the city's original green space, water-based underlayment was replaced by a large area of impervious surface, and in the daytime impervious surface storage of heat than the green space water body more than 10% to 15% [5], and these heat is released at night, exacerbating the urban heat island effect.

3) Generation of anthropogenic heat. Urban anthropogenic heat refers to the large amount of waste heat generated in human production and life. The increase of urban population and the intensification of human activities, such as automobiles, factories, air conditioners and so on, emit a large amount of heat, which directly heats the atmosphere and raises the temperature of the urban area; at the same time, human activities also produce a large amount of CO₂, H₂O, N₂O, CH₄, CFC and other pollutant gases and dust, which form the "dust cover" and "air cover" covering the sky of the city, and aggravate the intensity of the urban heat island. "air cover", increasing the intensity of the urban heat island.[4]

4.2. Research Methodology for Urban Heat Island

1) Conventional meteorological observation. Comparative analysis using meteorological station observation data is the most primitive and traditional method to study the urban heat island: using historical data from meteorological stations and selecting different temperature indicators to study the characteristics and changes of the heat island effect in different development processes within a certain area. The time series data from weather stations can reflect the historical evolution of urban heat island. However, this method is greatly affected by the number of weather stations and the environment in which they are set up, and changes in measurement points, observation habits, and errors in measurement instruments will all affect the analysis results[7].

2) Numerical simulation. Numerical simulation method is the application of computer technology using the establishment of numerical models to simulate the urban heat island effect. The most widely used model is the boundary layer numerical simulation model, which is based on thermodynamics and kinetic theory, and analyzes the temporal and spatial changes of the balance of quantities and temperature field. Traditional meteorological observation method requires a lot of human and material resources, and is limited by natural conditions and human factors, while numerical simulation can effectively analyze the data of meteorological observation, which can provide the basis for quantitative analysis of the heat island effect[1].

3) Remote sensing inversion. Remote sensing inversion method is based on the differences in radiation values of different bands in which the features are located, the use of thermal infrared sensors to carry out large-area observation of urban surface temperature, and then through the calculation, interpretation and analysis of the spatial distribution of the heat of the features to obtain the method[2]. Remote sensing monitoring has been more and more widely used in China in recent years due to its wide observation range, good dynamics and low acquisition cost. At present, the more mainstream is to use Landsat TM images as data and single window algorithm to invert and verify the surface temperature.

4.3. Spatial and temporal characteristics of urban heat islands

Numerous studies have shown that the urban heat island has certain regularities in time and space. In time, it shows cyclic and non-cyclic patterns: cyclic changes are mainly daily and annual changes, and under clear and windless weather, the daily changes are more uniform, generally showing weak during the day and strong at night; annual changes mostly show strong in fall and winter and weak in summer[4, 12]. Non-periodic changes, on the other hand, are influenced by various factors such as local geographic location, topography, and climatic conditions, resulting in some areas not conforming to the cyclic pattern. In space, it is divided into horizontal and vertical distribution characteristics: the horizontal distribution characteristics refers to the trend of decreasing heat island intensity from the city center to the suburbs; while the vertical distribution characteristics refers to the spatial distribution of heat island varies according to the height, which is mainly manifested as the intensity of the heat island in the suburbs of the city at night will be weakened with the height increase.

4.4. Factors affecting urban heat island intensity

1) Spatial scale of urban green space. Urban green space can significantly reduce the surface temperature, the urban heat island has a mitigating effect, its cooling effect is the current urban heat island is widely concerned about the research field, according to the study of the different spatial scales will be divided into three scales[14]: local scale, landscape scale and regional scale. One of the more widely researched is the landscape scale, and the research object is mainly urban park green space, urban woodland or the whole urban green space. In terms of the shape of the green space, it mainly focuses on the area, perimeter, perimeter-area ratio of the green space to the water body, and the efficiency of the surrounding environment in mitigating the urban heat island effect.[15-17]; In terms of green space-related evaluation indicators, there are many studies on indicators such as leaf area index and three-dimensional green volume[18-20], And concluded that the cooling effect of green space is significantly positively correlated with the leaf area index and green volume; in terms of green space landscape pattern, the cooling effect of green space will increase with the increase of patch area, perimeter and shape index, but the growth trend is non-linear, showing the trend of increasing first, then decreasing and finally stabilizing[21-22].

2) Urban green space plant scale. It is mainly divided into three scales: plant species, plant community and vegetation index. Scholars quantitatively analyze and compare the cooling effect by determining the transpiration characteristics of major urban greening tree species to provide a basis for the selection of street trees[18]; Analysis of the effects of different plant configuration types on the urban heat island revealed that plant communities with complex structure, high plant height and high degree of depression had more significant cooling effects[24], Comparison of the cooling effect was made in the order of arborvitae > shrubby hedges > aquatic plants > arborvitae > shrubby grasses > lawn[25]; Using remote sensing images as the data source and the atmospheric correction method to obtain the surface temperature and normalized difference vegetation index (NDVI), it was concluded that the surface temperature in the area with high vegetation cover was significantly lower than that in the area with sparse or no vegetation, and that the surface temperature and NDVI showed a significant linear negative correlation[26].

3) Land use types. Studies on land use types mainly analyze the relationship between urban subsurface or land use and urban heat island by analyzing the relationship between urban subsurface or land use and urban heat island. Relevant studies have resulted in the order of contribution to the heat effect: urban and rural industrial, mining and residential land use > forested and cultivated land > water and grassland > unutilized land[27], Orders of cooling intensity: water > arboreal woodland > grassland > bare ground > built-up land[28].

5. RESEARCH TRENDS FRONTIER ANALYSIS AND OUTLOOK

In this study, we take 1 year as a time slice to map the time zone of urban heat island keywords (Fig. 6), which clearly shows the development and evolution of urban heat island research, and the time of keyword appearance and the size of the node where it is located demonstrates the time and importance of the emergence of related research. The results show that before 2010, the research focused on the analysis of the causes of urban heat island effect, the determination of heat island intensity, and the interaction between urban heat island and the surrounding environmental factors, etc. After 2010, the research mainly focuses on the use of advanced and mature modeling and remote sensing inversion techniques to explore the spatial and temporal characteristics of urban heat island in urban agglomerations, and also explores the optimal combination of the key factors affecting the urban heat island on different scales, etc. The research also focuses on the development and evolution of the key factors affecting the urban heat island. etc.

Keyword emergence can represent the research direction with greater influence in a certain period of time, and we can judge the frontier and development trend of urban heat island through the change of the frequency of the emergence of mutated words. In the analysis of keywords for urban heat island, a total of 20 emergent words were obtained (Fig. 7), and after eliminating invalid keywords, the top three emergent words were “surface temperature”, “thermal environment”, “sponge city”, and “sponge city”, which emerged before 2010. After excluding invalid keywords, the top three emerging keywords are “surface temperature”, “thermal environment”, and “sponge city”, and the high emerging keywords before 2010 are “ecological environment”, “bright temperature”, and “impact factor”, “urban expansion”, and “thermal environment”, “urban form”, “cooling effect”, “ground temperature effect”, and “urbanization”, which continue to emerge from 2010 to the present. “; “surface temperature”, “landscape pattern”, “sponge city”, “spatio-temporal pattern “. From the above, it is summarized that the cutting-edge trends in urban heat island research are mainly divided into 4 categories.

1) Evaluation indicators of thermal environment: the current assessment of the intensity of heat island is mainly based on the surface temperature, air temperature, the lack of human feelings, and human comfort as a physiological indicator can be a good reflection of the thermal environment, the future study can be used as an important indicator, so as to broaden the evaluation criteria and improve the assessment system.

2) Sponge city. Sponge city through a more rational spatial layout of land use, compared with the old and new urban areas without sponge city planning, can better reduce the ground temperature, effectively improve the local ventilation environment, so as to play a role in mitigating the effect of heat island effect [29]. This research in the domestic research is less, belongs to the frontier field, in the future can focus on sponge city materials, mode differences on the impact of heat island effect, and at the same time by the study of a certain area rises to the whole city or even urban agglomeration of the theoretical level.

3) Landscape pattern. The research of landscape pattern on mitigating urban heat island currently focuses on plant species, community characteristics and green space area, green volume, ndvi, degree of depression, and in the later stage, we can pay more attention to find a threshold value for mitigating urban heat island through different combinations of the proportion of each element of the landscape to find the optimal solution.

4) Spatio-temporal pattern. Spatial and temporal characteristics have always been one of the core hotspots of urban heat island research. If the temporal and spatial resolution of satellites can be improved on the basis of the existing technology, and if multi-source data can be utilized to accurately reflect the spatial change characteristics in consecutive time periods, it will provide a more scientific and high-precision countermeasure to mitigate the urban heat island.

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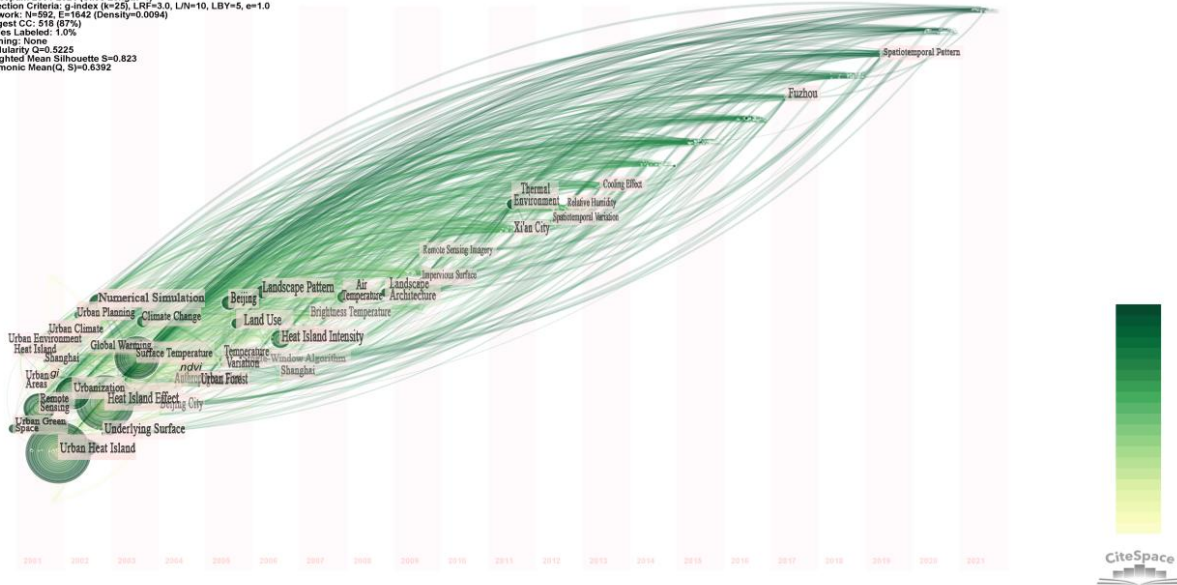


Fig. 6 Time zone map of urban heat island keywords
Top 20 Keywords with the Strongest Citation Bursts

| Keywords | Year | Strength | Begin | End | 2001 - 2021 |
|-----------------------------|------|----------|-------|------|-----------------------------|
| Urban Environment | 2001 | 5.15 | 2001 | 2004 | [Red bar from 2001 to 2004] |
| City | 2001 | 4.55 | 2001 | 2010 | [Red bar from 2001 to 2010] |
| Urban Climate | 2001 | 4.53 | 2001 | 2007 | [Red bar from 2001 to 2007] |
| Ecological Environment | 2001 | 3.51 | 2001 | 2008 | [Red bar from 2001 to 2008] |
| Guangzhou | 2001 | 3.6 | 2004 | 2010 | [Red bar from 2004 to 2010] |
| Temperature Variation | 2001 | 4.88 | 2005 | 2010 | [Red bar from 2005 to 2010] |
| Brightness Temperature | 2001 | 3.8 | 2005 | 2011 | [Red bar from 2005 to 2011] |
| Influencing Factors | 2001 | 3.55 | 2008 | 2010 | [Red bar from 2008 to 2010] |
| Air Temperature | 2001 | 8.08 | 2009 | 2011 | [Red bar from 2009 to 2011] |
| Urban Expansion | 2001 | 3.21 | 2010 | 2015 | [Red bar from 2010 to 2015] |
| Temperature | 2001 | 3.21 | 2010 | 2015 | [Red bar from 2010 to 2015] |
| Thermal Environment | 2001 | 6.85 | 2014 | 2021 | [Red bar from 2014 to 2021] |
| Spatiotemporal Distribution | 2001 | 3.11 | 2014 | 2018 | [Red bar from 2014 to 2018] |
| Urban Morphology | 2001 | 3.17 | 2015 | 2021 | [Red bar from 2015 to 2021] |
| Cooling Effect | 2001 | 3.62 | 2016 | 2021 | [Red bar from 2016 to 2021] |
| Land Surface Temperature | 2001 | 6.86 | 2017 | 2021 | [Red bar from 2017 to 2021] |
| Fuzhou | 2001 | 4.52 | 2017 | 2021 | [Red bar from 2017 to 2021] |
| Landscape Pattern | 2001 | 4.25 | 2017 | 2021 | [Red bar from 2017 to 2021] |
| Sponge City | 2001 | 4.54 | 2018 | 2021 | [Red bar from 2018 to 2021] |
| Spatiotemporal Pattern | 2001 | 3.58 | 2019 | 2021 | [Red bar from 2019 to 2021] |

Fig. 7 Keyword emergence map in the field of urban heat island

6. CONCLUSIONS AND RECOMMENDATIONS

Based on “urban heat island”, we analyzed the relevant literature from CNKI database in the past twenty years (2001-2021) by using CiteSpace software, systematically presenting the overview and development dynamics of domestic journals, expanding the theoretical understanding of the research on urban heat island and identifying the research hotspots and cutting-edge trends, and arriving at the following conclusions. The main conclusions are as follows:

- 1) China's urban heat island research is roughly divided into 3 stages, and the number of literature now remains stable.
- 2) There are many research institutions but fewer publications, which are more independent and lack of collaborative and cooperative academic communities across regions, institutions and fields. In the future, research perspectives should be diversified, focusing on multidisciplinary crossover, strengthening disciplinary cooperation, international exchanges, and studying the impacts of urban heat island more extensively in order to face the various challenges brought by urban heat island.
- 3) The research hotspots focus on the causes, research methods, spatial and temporal characteristics and influencing factors of urban heat island. Through the analysis of the research hotspots, the countermeasures to mitigate urban heat island are mainly to improve the material type of the subsurface, reduce the anthropogenic heat emission and air pollution, protect and increase the area of green space and water body, and improve the land use planning and urban layout.
- 4) The research trend frontiers focus on four themes: evaluation indexes of thermal environment, sponge city, landscape pattern and spatio-temporal pattern. As only journals were selected as research data, it lacks comprehensive analysis and has certain limitations. Later on, we supplement 2 urban heat island research trend frontiers by analyzing multiple types of literature through other domestic channels: urban building design and use of materials; and the construction of ventilation corridors. The supplemented conclusions will be combined with the four frontier trends proposed in this paper to analyze the urban heat island in multiple dimensions, levels and perspectives, which will provide reference for further research on the heat island effect.

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