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Review Article

A REVIEW ON EXPLORING THE INTERPLAY OF URBAN HEAT ISLAND EFFECTS AND GROUNDWATER RECHARGE THROUGH A BIBLIOMETRIC PERSPECTIVE FROM 2000–2024

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ABSTRACT
Urban heat island (UHI) effects and groundwater recharge have emerged as critical intersecting themes in urban sustainability and climate adaptation research. This study applies bibliometric and network analysis to examine global scholarly trends, key contributors, thematic development, and citation patterns from 2000 to 2024. Using data sourced from Lens.org and analyzed via the Bibliometrix package in R, we mapped 480 publications across 174 sources. The findings highlight evolving research interests, key contributors, and future directions in this interdisciplinary domain.

***Keywords**: Urban Heat Island, Bibliometrix,Thematic, Citation,Sustainability*

INTRODUCTION

Rapid urbanization, changing land-use patterns, and climate variability have exacerbated Urban Heat Island (UHI) effects, intensified urban thermal conditions and altering hydrological processes such as groundwater recharge. This complex interplay has garnered significant academic interest as cities seek nature-based and data-driven solutions for resilience and sustainability.

Bibliometric analysis offers a systematic approach to assess the evolution, impact, and thematic trajectories of research in this emerging field. This study explores publication patterns, citation dynamics, influential authors and journals, and thematic hotspots, providing a comprehensive understanding of the field's development from 2000 to 2024.

The primary objective of bibliometric analysis is to quantitatively assess the productivity of scientific research outputs. The process of analyzing and mapping bibliographic data consists of these steps. This initial phase involves systematically searching the literature and conducting a thorough evaluation of the field. Bibliometric and Network analysis **-** This stage focuses on citation analysis and network analysis to identify publication trends, as well as the most influential journals, institutions, and authors. The interplay between Urban Heat Island (UHI) effects and groundwater recharge has garnered increasing attention in recent years, particularly in the context of urban climate resilience and sustainable water management. UHI, characterized by elevated temperatures in urban areas compared to their rural surroundings, results from extensive land surface modifications, impervious infrastructure, and anthropogenic heat emissions (Oke, 1982). This phenomenon not only intensifies local climate extremes but also disrupts hydrological cycles by altering evapotranspiration rates, surface runoff, and soil moisture dynamics (Grimmond & Oke, 1999; Li *et al.,* 2018).

Groundwater recharge, a critical component of urban water security, is significantly influenced by these changes. Several studies have established that increased surface temperatures and reduced pervious surfaces in urbanized zones hinder the natural infiltration of rainwater, leading to diminished recharge rates and heightened flood risks (Scanlon *et al.,* 2002; Lerner, 2009). However, more recent research points to the potential of engineered and nature-based interventions—such as green infrastructure, permeable pavements, and urban vegetation—to mitigate UHI effects while enhancing recharge potential (Kazemi *et al.,* 2011; Fletcher *et al.,* 2015).

The intersection of these two domains—urban heat mitigation and hydrological restoration—has fostered an emerging interdisciplinary research space. Scholars have increasingly emphasized the importance of integrating urban climatology, remote sensing, environmental modeling, and sustainability science (Santamouris, 2014; Pataki *et al.,* 2011). Despite this convergence, a clear mapping of research trends, key contributors, and thematic evolution has been lacking.

Bibliometric approaches have proven effective in addressing such gaps by offering quantitative insights into the structure, productivity, and impact of scientific output. Previous bibliometric studies in urban sustainability (Zupic & Čater, 2015; Khan *et al.,* 2021) have shown how analytical tools like citation analysis, co-authorship networks, and keyword mapping can illuminate research patterns and emerging areas. However, specific bibliometric evaluations focusing on the UHI–groundwater nexus remain limited.

This study, therefore, contributes a novel perspective by conducting a comprehensive bibliometric and network analysis of literature spanning 2000 to 2024. It seeks to capture how academic discourse has evolved around this topic, identify influential scholars and journals, and highlight the thematic directions shaping future inquiry. By doing so, it provides a foundational understanding of the intellectual landscape at the confluence of urban climate and hydrological research.

MATERIALS AND METHODS

This bibliometric analysis was conducted using data extracted from Lens.org, covering publications from 2000 to 2024. The "Bibliometrix" package in R Studio was employed to analyze publication trends, citation metrics, authorship, and keyword evolution. This bibliometric analysis was conducted using data extracted from Lens.org, covering publications from 2000 to 2024. The "Bibliometrix" package in R Studio was employed to analyze publication trends, citation metrics, authorship, and keyword evolution.

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Table 1: INFORMATION ABOUT THE DATA

DESCRIPTIONS	RESULTS
Time span	2000-2024
Sources (journals, Books , e.t.c)	174
Documents	480
Annual growth rate(%)	16.91
Document (average age)	7.29
Average citation per doc	46.09
References	27134
DOCUMENTS CONTENT	
Author’s keywords	238
AUTHORS	
Authors	3274
Authors of single authored Docs	45
AUTHORS COLLABORATION	
Single authored Docs	47
Co- Authors per doc	7.26
DOCUMENT TYPE	
Book chapter	4
Conference proceedings	3
Journal article	463
Journal Issue	1

The findings are then synthesized to interpret results and predict future research directions. All analyses are conducted in R Studio using the "Bibliometrix" package.

The findings are then synthesized to interpret results and predict future research directions. All analyses are conducted in R Studio using the "Bibliometrix" package.

Database selection: The bibliometric analysis data (Table: 1) were sourced from the www.lens.org.com

RESULTS AND DISCUSSION

3.1 Annual Scientific Production

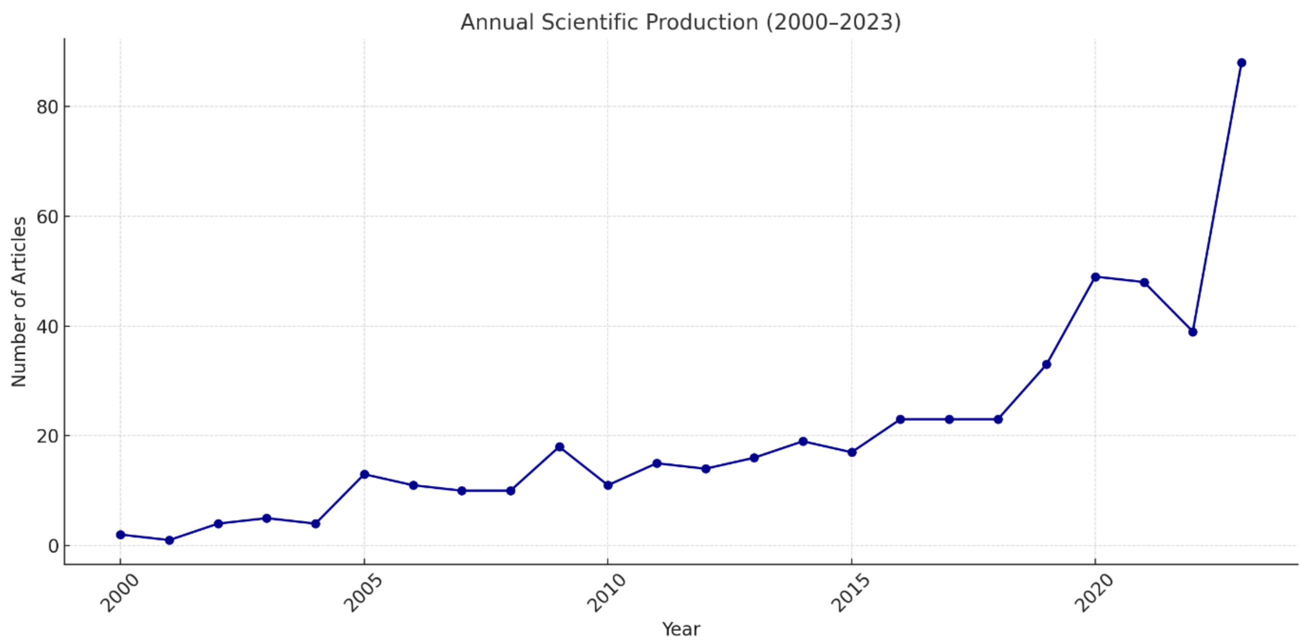

Fig. 1 Annual Scientific Production

The graph (Fig. 1) titled "Annual Scientific Production" displays the number of scientific articles published per year from 2000 to 2024. Early Years (2000–2005), The number of articles was very low, generally under 10 per year, with minor fluctuations in 2000-2005. 2006 -2015 a gradual increase is observed and it was steady around 2017-2019. In 2021-2023 there was significant increase in articles, peak was observed in 2021 and 2022 at around 45-47 articles before a slight dip in 2023.Moderate growth with some ups and downs, peaking around 2011 with a noticeable spike occurred during 2006-2015. A gradual increase is observed, particularly steady around 2017–2019, then a rise in 2020.Significant increase, peaking in 2021 and 2022 at around 45–47 articles, before a slight dip in 2023. A dramatic spike to over 85 articles, marking the highest annual output by far.

3.2 Authors local impact factor

The graph (Fig. 2) titled "Authors' Local Impact by H Index" displays a horizontal bar chart representing the H-index of various authors. The H-index is a metric used to measure both the productivity and citation impact of a researcher's publication.LI S has the highest H-index of 6, indicating a relatively high local impact. Lee, J.Y follows with an H-index of 5, Halder, B has an H-index of 4. Other Authors (e.g., Bandhopadhyay, J., Gupta, A., Li JY. etc.), All have an H-index of 3, suggesting moderate impact.

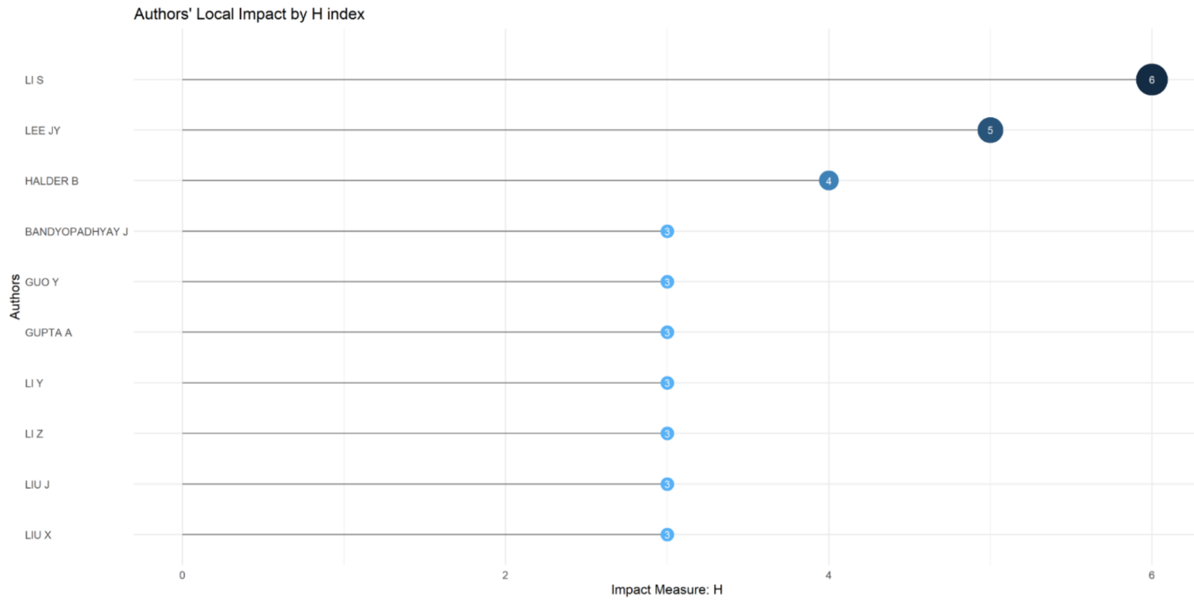

Fig. 2 Author's Local Impact Factor

3.3 Production over time

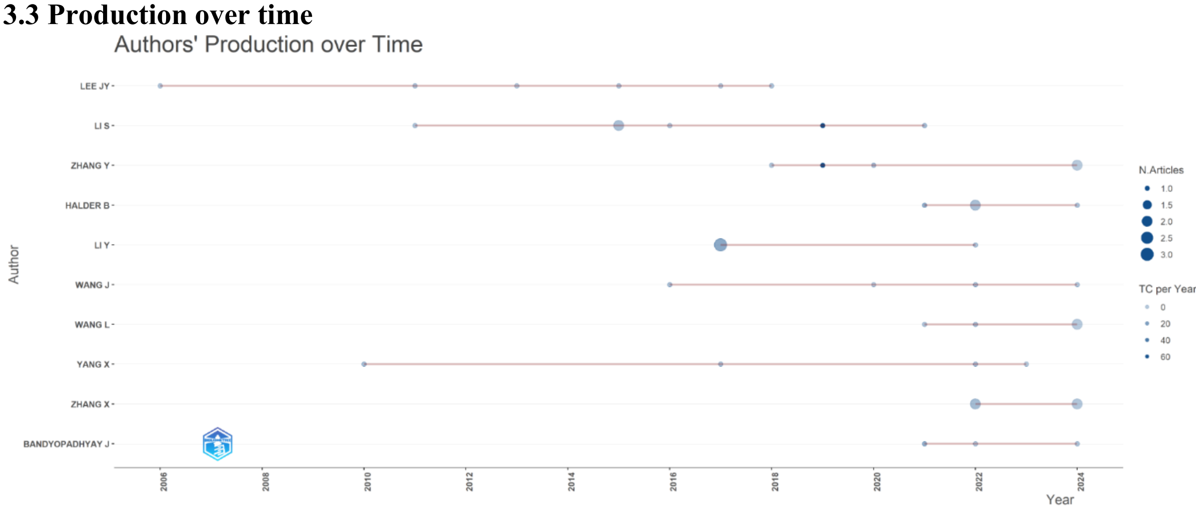

Fig. 3 Production over time

The above graph (Fig.3) visualizes the publication activity of various authors over the years, combining both quantity and citation impact. Size of bubbles represents the number of articles published (N. Articles) by the author in a given year. Color intensity (blue shades): Indicates Total Citations (TC) per year, where darker shades imply higher citation counts. Lee J.Y has a long publishing history from around 2005 to 2020, with steady output and moderate citation impact.LI S has publications concentrated around 2010 to 2021 with varying impact, including some dark blue bubbles indicating high citation years. Zhang Y and Halder B show increased productivity and impact especially in recent years (e.g., 2024), with larger, darker bubbles.LI Y had a particularly high-impact year in 2017, as suggested by a large dark blue bubble. Wang J and Wang L have moderate contributions with lower citation impact. Zhang X and Bandopadhyay J have recent publication activity in 2024 with moderate-to-high citation impact. Yang X shows consistent activity with a spike around 2010.

3.4 Average citation per year

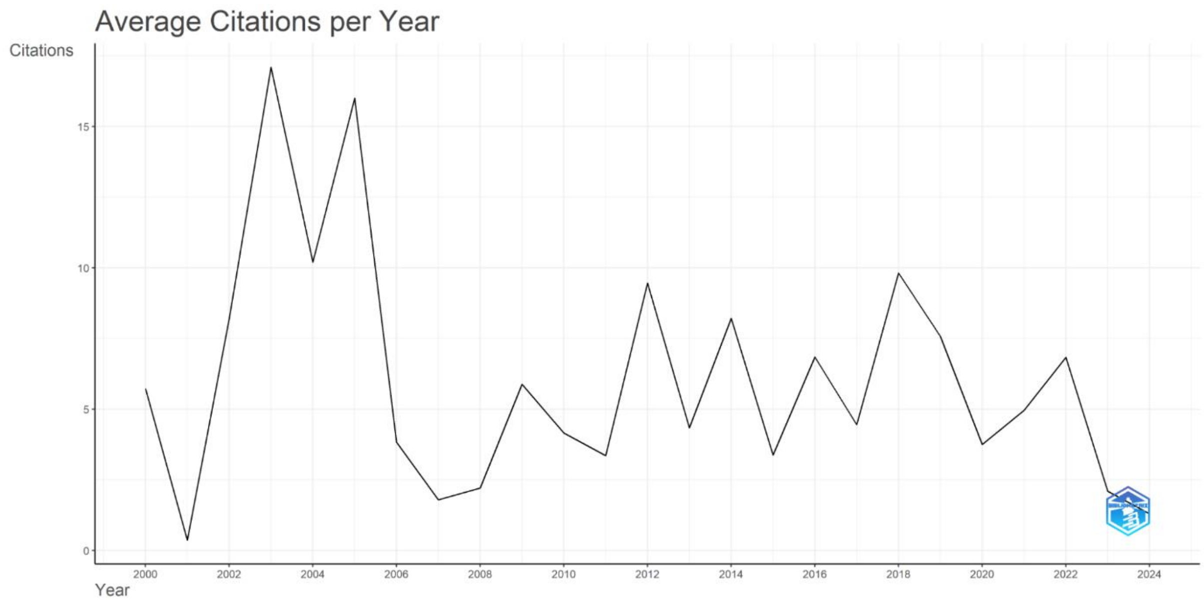

Fig. 4 Average Citations per Year

The chart (Fig. 4) shows the trend of how many citations articles received on average each year over a span of time. There's a significant spike in 2003 and 2005, with average citations reaching as high as 17–18 citations per article. This could indicate highly influential publications during those years. After 2005, average citations dropped sharply, and the trend fluctuates with smaller peaks and valleys. The average citations hover between 3 and 10, showing inconsistent impact year to year.A notable peak in 2018 shows another rise in average citations nearing 10.From 2020 onward, there's a clear downward trend, with average citations falling to around 1 by 2024.This may be due to the recency of publications not yet having time to accumulate citations.

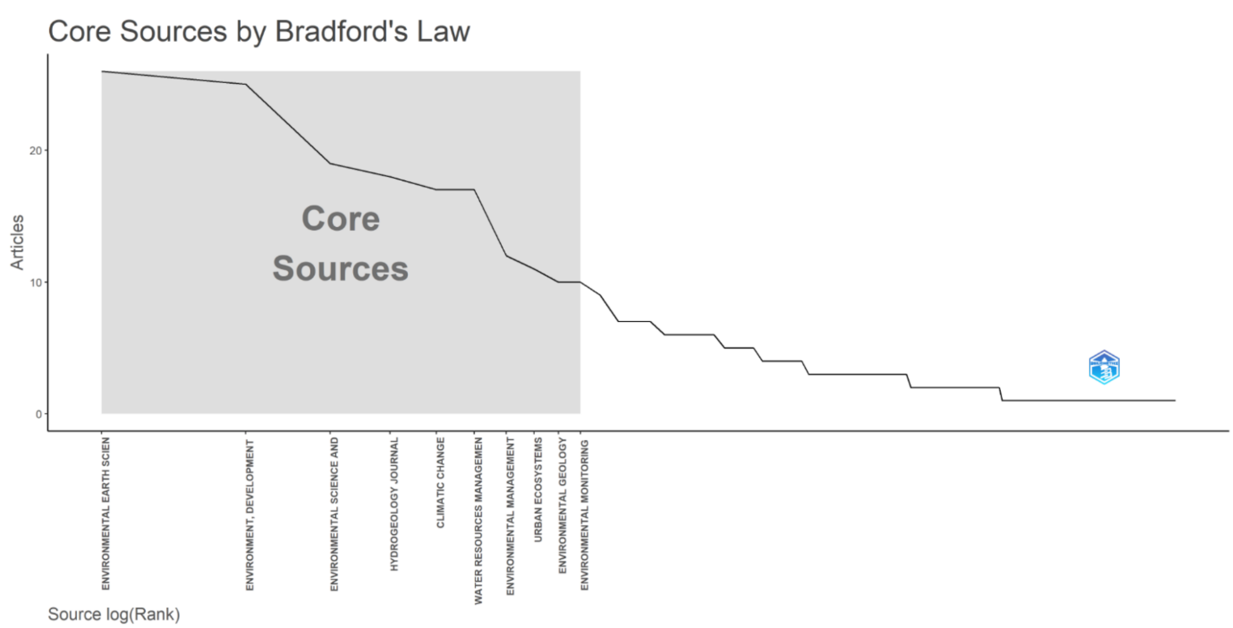

Fig. 5 Core Sources by Bradford's Law

3.5 Core Source by Bradford's Law

This graph titled "Core Sources by Bradford's Law" (Fig. 5) visually represents how scientific articles are distributed across journals, using Bradford's Law of Scattering. Bradford's Law describes how articles on a specific subject are distributed across journals. A core set of journals publishes the most articles. A second zone of journals publishes fewer. A third, larger zone publishes even fewer. These include journals like Environmental Earth Sciences, Environment, Development, Environmental Science and, etc. They have the highest productivity, each contributing 10–25+ articles. After the core zone, the number of articles per journal drops sharply. This illustrates the diminishing returns: a small number of journals account for a large share of articles. The unshaded part represents journals that publish fewer articles, following the typical "long tail" distribution.

3.6 Author Productivity through Lotka's Law

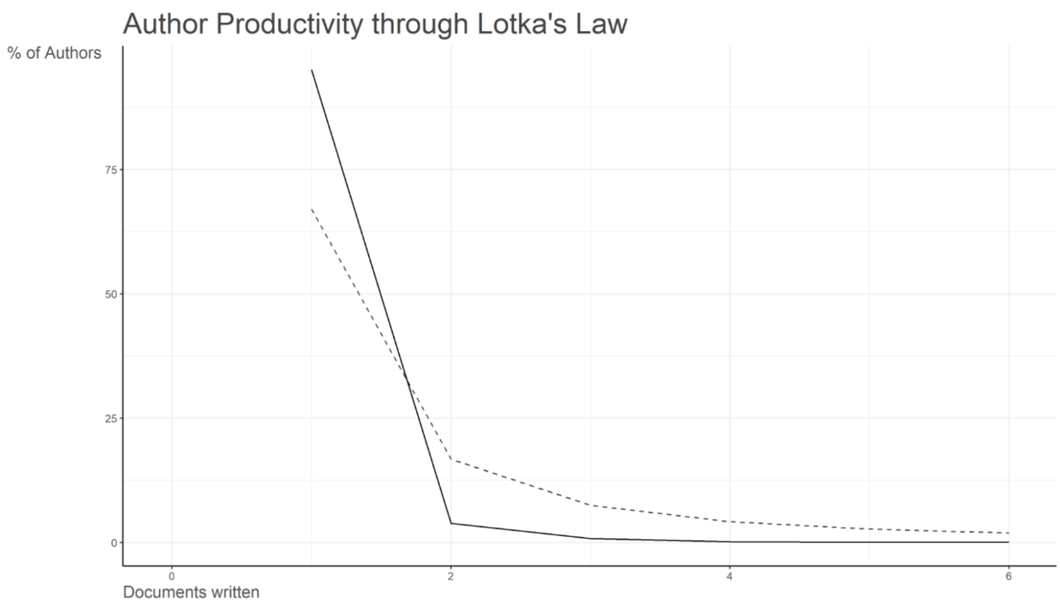

Fig. 6 Author productivity through Lotka's law

This graph titled illustrate (Fig. 6) how scholarly output is distributed among authors, following Lotka's Law. Lotka's Law is a bibliometric principle stating that. The number of authors publishing *n* papers is about $1/n^2$ of those publishing one paper. Most authors write only one paper. A small number write two. Even fewer write three or more. Nearly 90% of authors have written just one paper. A dramatic decrease occurs as you move to authors with 2 or more publications. The graph shows a long tail, confirming that a small number of authors are highly productive. A few authors contribute a disproportionately high number of publications. The dashed line (Lotka's Law prediction) closely follows the solid line, indicating that the actual author productivity aligns well with the theoretical model (the Good fit theory)

3.7 Most Global Cited Documents

This graph titled visualizes the most influential academic documents based on the number of global citations they have received (Fig. 7). Top cited documents are-Beniston M., 2003, Climatic Change — 1150 citations. Cramer W., 2018, Nature Climate Change — 993 citations, Haase D., 2014, Ambio — 815 citations, Serdeczny O., 2016, Regional Environmental Change — 667 citations, Groffman PM., 2009, Biogeochemistry — 584 citations. The document by Beniston (2003) is the most cited, indicating it has had the largest academic impact in the field. Most of the top-cited documents are published in high-impact journals like Climatic Change and Nature Climate Change. The distribution shows a steep drop-off in citation counts after the top few papers — typical in bibliometric data where a few works receive disproportionate attention.

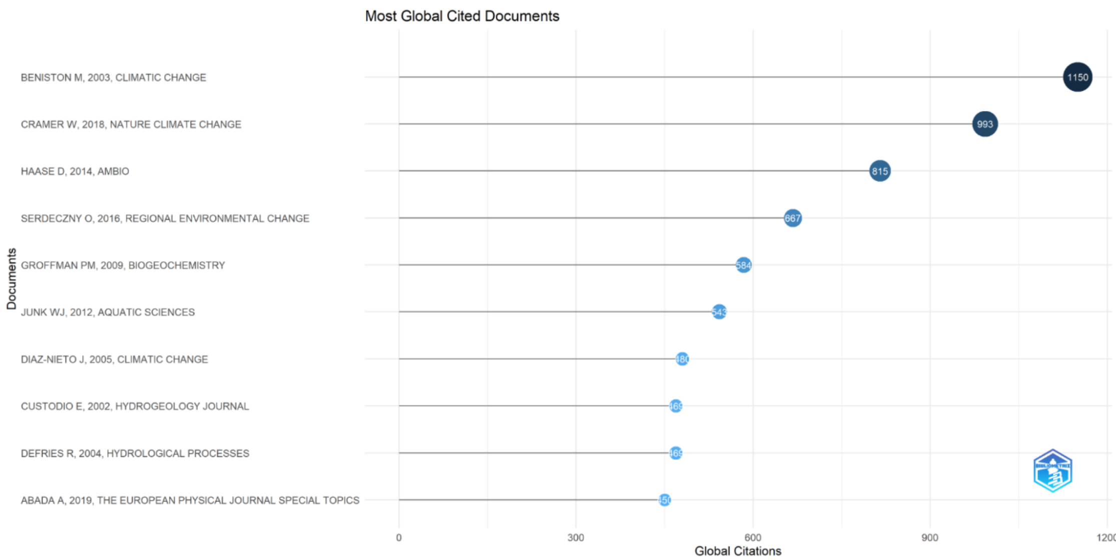

Fig. 7 Most global cited documents

3.8 Most relevant Authors

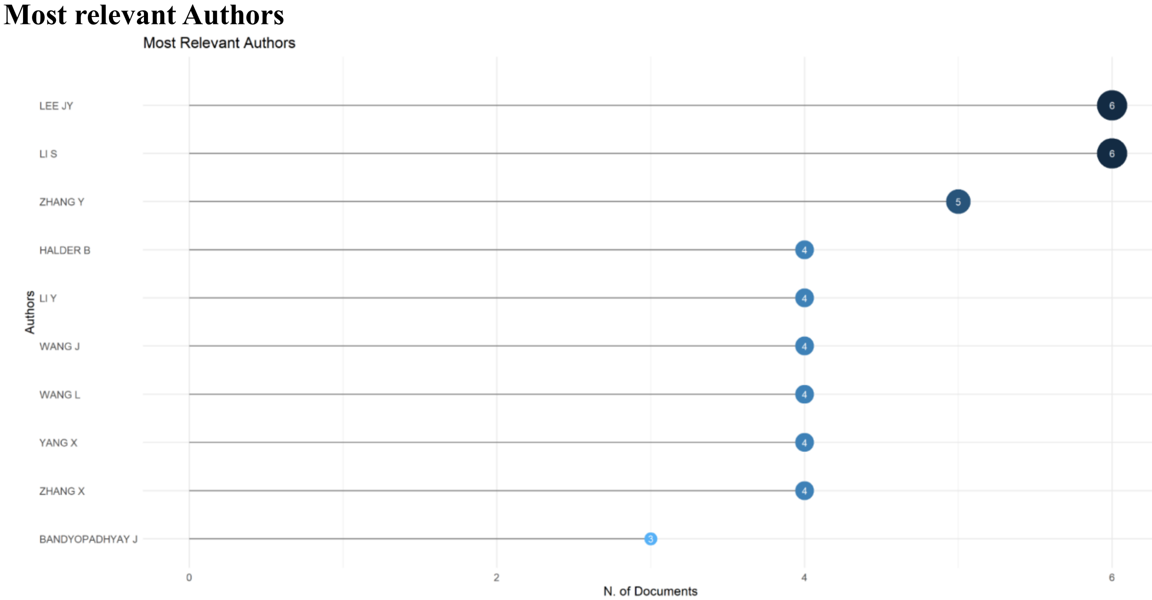

Fig. 8 Most relevant authors

The graph visually represents the number of documents per author, with larger dots indicating a higher number of documents, highlighting the most relevant authors based on this metric. LEE JY, LI S, and WANG J each have the highest count, with 6 documents each. Zhang Y follows closely with 5 documents. Authors with 4 documents each-Halder B, Li Y, Wang L, Yang X, and Zhang X are in this group. Author with the least documents: Bandopadhyaya J has 3 documents (Fig.8).

3.9 Most relevant sources

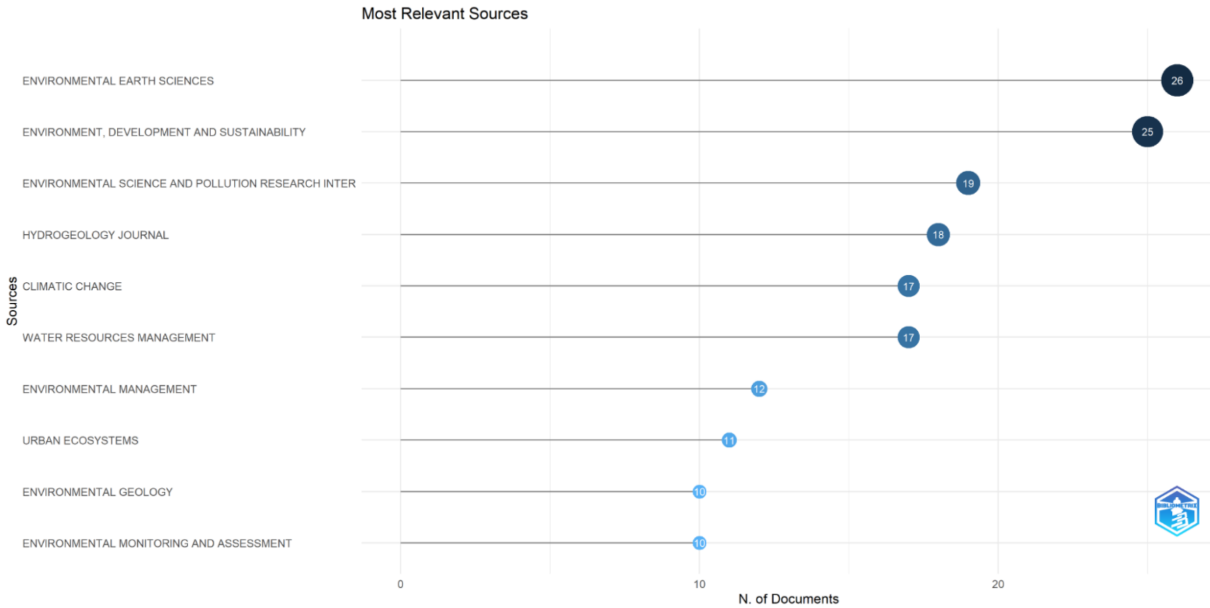

Fig. 9 Most relevant sources

This graph displays the most relevant sources (journals or publications) based on the number of documents published in each sources. Environmental Earth Sciences is the top source with 26 documents. Environment, Development and Sustainability closely follows with 25 documents. Environmental Science and Pollution Research International has 19 documents. Hydrogeology Journal has 18 documents. Both Climatic Change and Water Resources Management have 17 documents. Other Sources-Environmental Management: 12 documents, Urban Ecosystems: 11 documents, Environmental Geology and Environmental Monitoring and Assessment: 10 documents each (Fig. 9).

3.10 Most relevant words

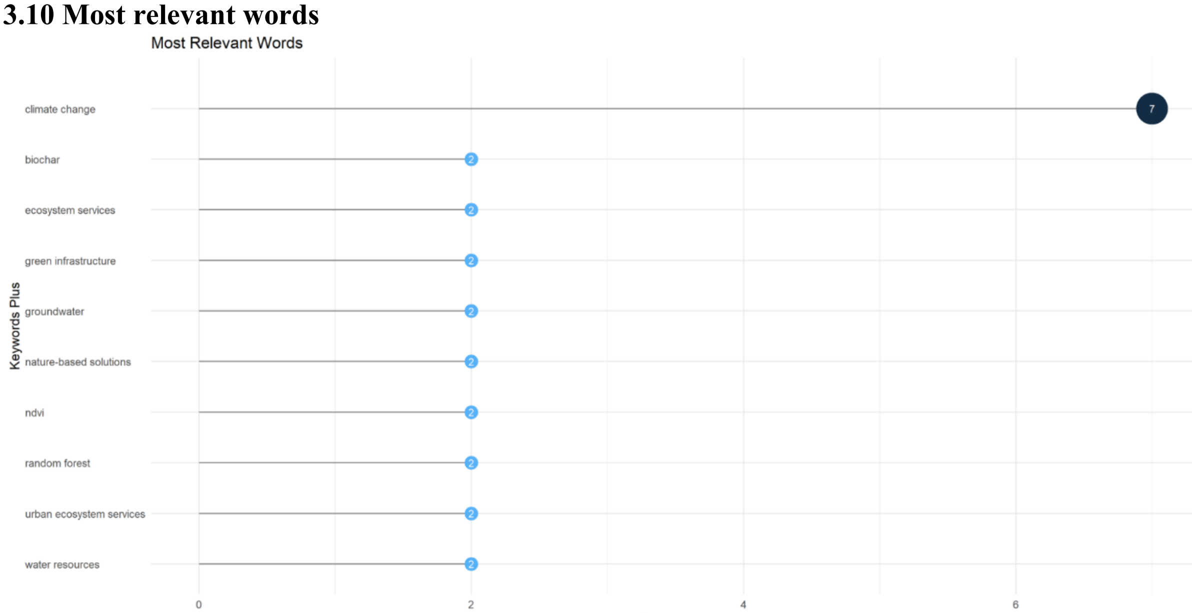

Fig. 10 Most relevant words

This graph displays the Most Relevant Words (from the “Keywords Plus” metadata) based on the number of occurrences in the analysed documents (Fig. 10). "Climate change" is the most frequently occurring keyword, with 7 occurrences, significantly higher than the rest .Other Keywords (with 2 occurrences each): Biochar, Ecosystem services, Green infrastructure, Groundwater, Nature-based solutions, NDVI (Normalized Difference Vegetation Index),Random forest (likely referring to a machine learning algorithm),Urban ecosystem services, Water resources .This suggests that climate change is a dominant theme in the dataset, while the other keywords represent a broader spread of emerging or supporting topics within the same research area.

3.11 Sources production over the time

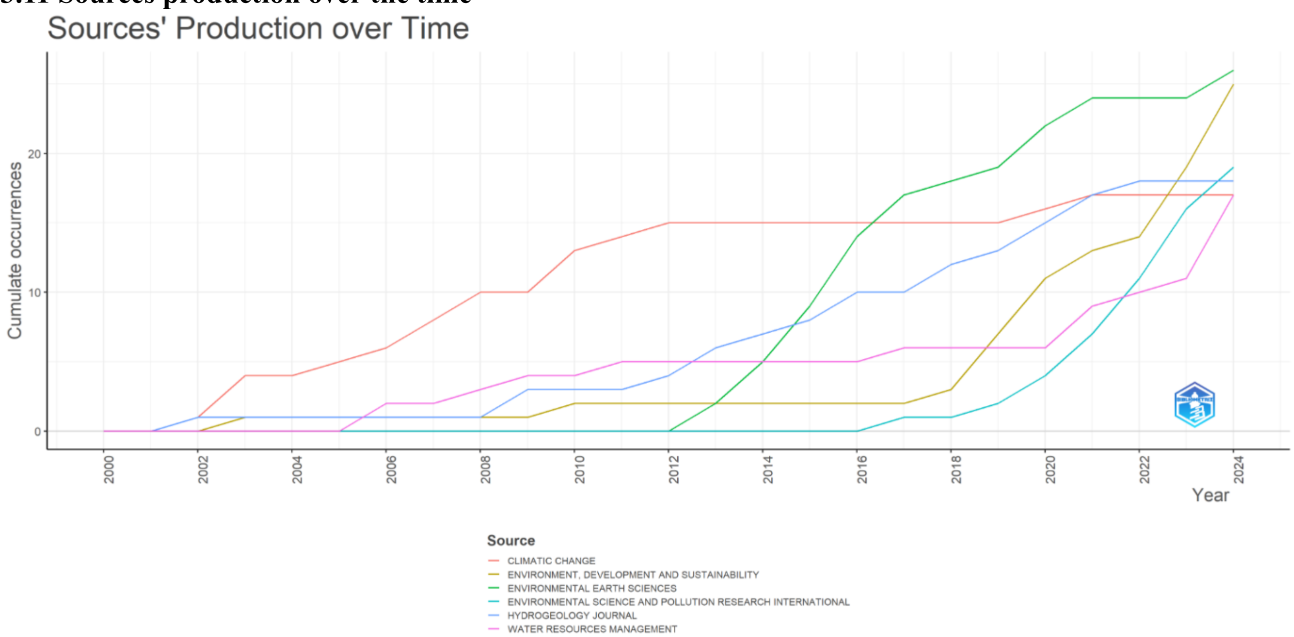

Fig. 11 Sources production over the time

The graph (Fig. 11) illustrates the cumulative publication trends of key journals from 2000 to 2024, highlighting shifts in research focus over time. Environmental Earth Sciences and Environment, Development and Sustainability show the most significant growth, emerging as leading sources by 2024. Environmental Science and Pollution Research International maintains steady growth, while Climatic Change plateaus after 2015, indicating a potential shift in focus. Hydrogeology Journal and Water Resources Management show modest but increasing contributions, particularly after 2020. Overall, the data reflects evolving research interests and the rising prominence of certain journals in the field.

Urban Heat Island (UHI) effects and groundwater recharge are increasingly intersecting concerns in the context of urban sustainability and climate adaptation. Rapid urbanization, land surface modifications, and climate variability have intensified the thermal environment of cities, creating localized heat zones that not only affect urban liability but also influence hydrological processes, including the potential for groundwater recharge. As cities explore nature-based and data-driven solutions to mitigate UHI and ensure water security, academic interest in this nexus has grown significantly. Bibliometric analysis provides a systematic means to explore the evolution, impact, and thematic directions of scholarly output in this emerging interdisciplinary field. By mapping publication trends, source impact, thematic focus, and keyword dynamics, this study aims to illuminate research trajectories and identify core areas of development, gaps, and future directions.

3.12 Sources local impact by H index

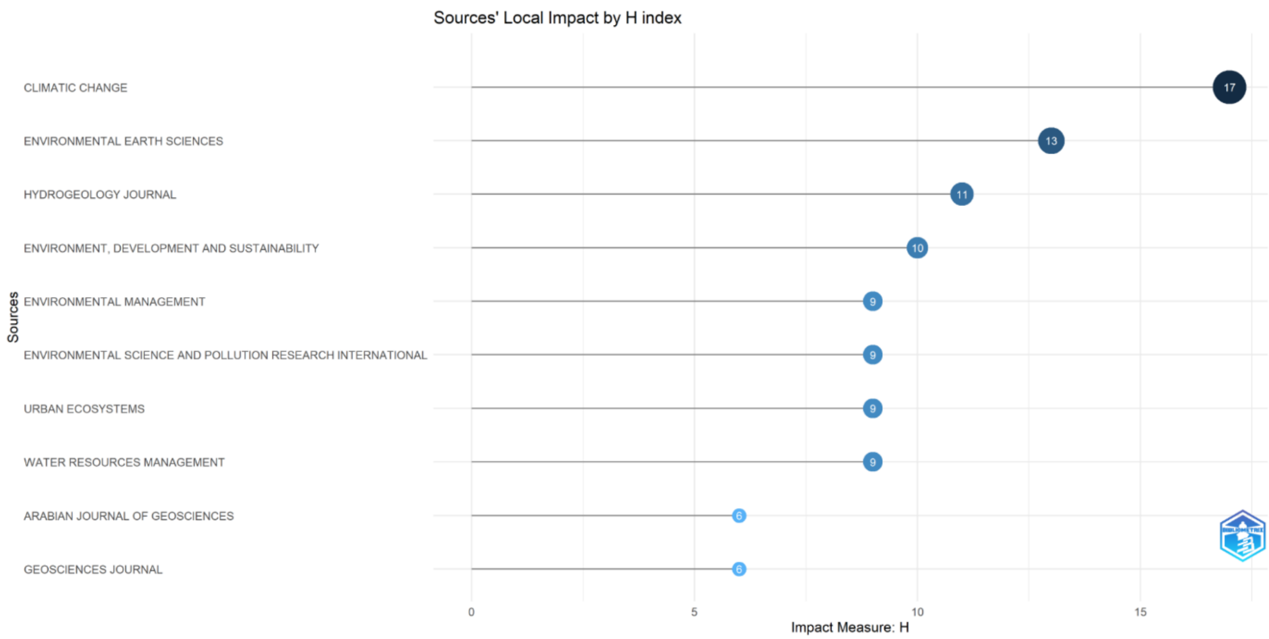

Fig. 12 Sources' Local Impact by H index

The graph titled "Sources' Local Impact by H index" (Fig. 12) displays the H-index for different academic journals, measuring their local impact within a specific research context. The H-index indicates the number of publications (H) in the journal that have received at least H citations, representing both productivity and citation impact. Climatic Change leads with the highest H-index (17), indicating strong influence, followed by Environmental Earth Sciences (13), and Hydrogeology Journal (11). Several journals, including Environmental Management and Urban Ecosystems**,** show moderate impact (H-index of 9), while Arabian Journal of Geosciences and Geosciences Journal have the lowest (6). Despite a plateau in publication growth, Climatic Change remains the most influential, highlighting its lasting citation strength.

3.13 Thematic map

The graph above entitled "Thematic Map"(Fig. 13) is a strategic diagram used to analyse the structure and development of research themes based on two dimensions: X-axis (Relevance degree / Centrality): Indicates how important or connected a theme is within the broader research field. Y-axis (Development degree / Density): Measures how well-developed or internally coherent the theme is. Basic Themes: Climate change and bio char are central and widely studied but need deeper development, forming the foundation of the research field. Niche Themes: Ecosystem services, green infrastructure, and urban ecosystem services are well-developed but less connected to the broader research landscape, indicating specialized focus. Emerging or Declining Themes: Natural hazards, urban adaptation, and green solutions are currently underdeveloped and peripheral, possibly indicating new or fading areas of research. Transitional/Technical Themes: NDVI and random forest are moderately developed and connected, likely representing useful methodologies applied across various topics.

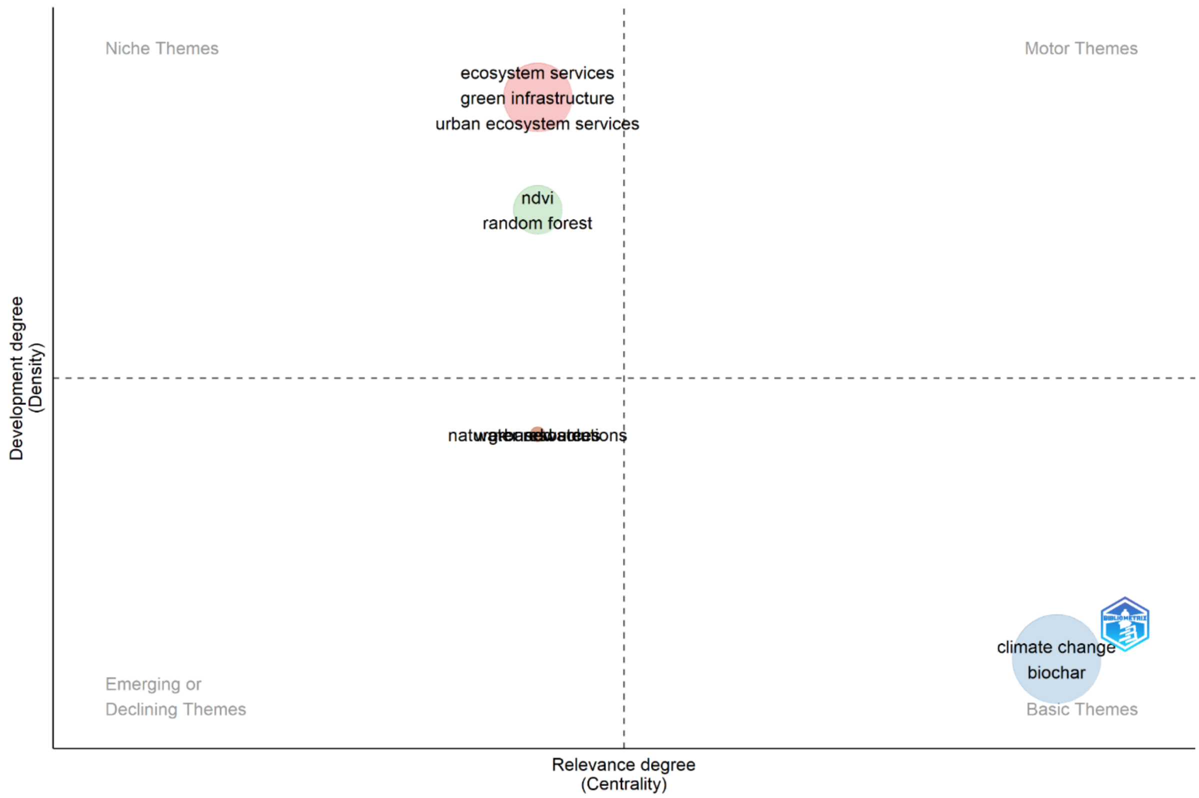

Fig. 13 Thematic map

3.14 Words Frequency over Time

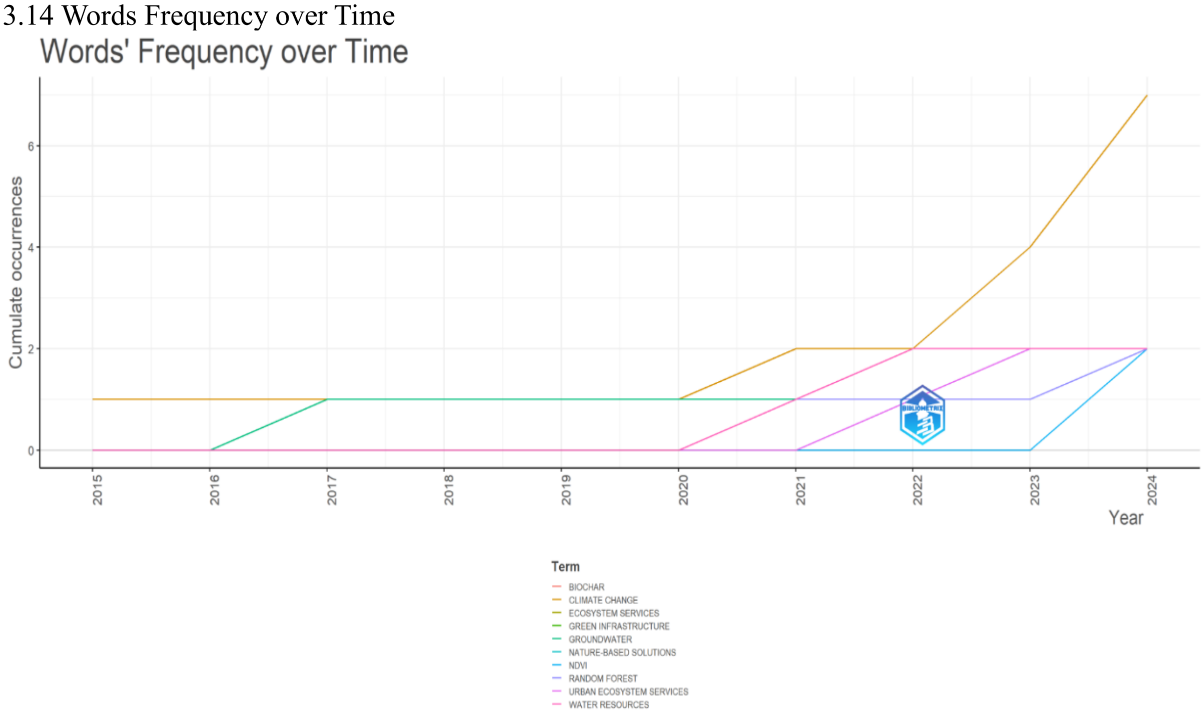

Fig. 14 Words' frequency over time

The graph (Fig. 14) shows the cumulative occurrences of selected key terms in publications from 2015 to 2024. It illustrates how frequently specific research topics or keywords have appeared over time, offering insight into trends in academic interest. The graph "Words' Frequency over Time" illustrates the cumulative use of key research terms from 2015 to 2024, highlighting evolving academic interests. "Climate change" shows the most significant and sustained growth, especially after 2020, indicating increasing scholarly focus. "Biochar" also demonstrates steady relevance since 2015. Terms like "ecosystem services" and "urban ecosystem services" gain momentum post-2020, reflecting growing attention to sustainability themes. Meanwhile, "green infrastructure" shows early growth but later stagnation, suggesting waning interest. Recently emerging terms such as "random forest," "NDVI," and "nature-based solutions" (notably appearing around 2022–2023) indicate new areas of methodological or thematic exploration. Overall, the graph reveals both enduring topics and rising themes shaping current research trends.

CONCLUSION

This bibliometric study offers a comprehensive overview of the evolving research landscape at the intersection of Urban Heat Island (UHI) effects and groundwater recharge from 2000 to 2024. The analysis reveals a growing body of interdisciplinary work reflecting the increasing urgency to address urban climate challenges and sustainable water management. Key findings show a notable rise in research activity post-2015, with significant contributions from a core group of authors and journals. The thematic analysis highlights "climate change" as the dominant research focus, while emerging themes such as "nature-based solutions" and "urban ecosystem services" reflect a shift toward integrated, sustainable urban planning approaches. The application of bibliometric laws, such as Lotka's and Bradford's, underscores the concentration of knowledge production among a small number of authors and high-impact journals, suggesting the presence of influential thought leaders and publication venues in this field.

Looking ahead, future research should prioritize deeper integration of remote sensing, machine learning tools, and hydrological modelling to better capture the dynamic interplay between urban thermal regimes and subsurface water systems. A greater emphasis on policy-relevant and region-specific studies can also help translate academic findings into actionable climate adaptation and urban resilience strategies.

In sum, this study not only charts the trajectory of current research but also provides a roadmap for scholars, practitioners, and policymakers aiming to advance sustainable urban environments in the face of escalating climate variability.

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