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Climate Change and Human Health: A Bibliometric Analysis of Global Research Trends

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Abstract

Climate variability significantly influences public health, shaping disease patterns, mortality rates, and the resilience of healthcare systems. This study presents a bibliometric analysis of global research on the relationship between climate variability and public health from 2000 to 2024. Drawing data from the Web of Science and PubMed, 4,746 publications were analysed using RStudio to identify research trends, influential works, leading contributors, and thematic developments in the field. Key bibliometric techniques such as citation analysis, co-authorship mapping, keyword co-occurrence, and thematic evolution analysis were employed to uncover the intellectual structure and trajectory of this domain. The findings reveal a notable surge in climate-health research over the past five years, reflecting increased interdisciplinary collaboration across environmental science, epidemiology, and health policy. While publication output remained modest in the early 2010s, foundational work during that period contributed to the field's exponential growth in recent years. Citation metrics highlighted the most impactful studies and journals, while country-level analysis illustrated evolving global contributions. Keyword analysis identified shifting research priorities, with growing attention to adaptation, resilience, and policy integration. Patterns in authorship and institutional affiliations underscored the expanding and international nature of climate-health research. This study offers valuable insights and a forward-looking perspective to guide evidence-based strategies for addressing climate-driven health challenges.

Keywords: Climate variability; Public health; Bibliometric analysis; Research trend; Climate change

1 Introduction

The intersection of climate variability and public health has emerged as a critical area of research, reflecting a growing recognition of the complex and multifaceted impacts of climate change on health outcomes. Climate variability influences various health determinants, leading to adverse effects that encompass both physical and mental health dimensions. For instance, recent studies have highlighted the direct correlations between climate factors such as temperature shifts and humidity levels with the

incidence of diseases, such as hand, foot, and mouth disease, indicating that climate variables play a significant role in health dynamics [1]. As climate perturbations intensify, the consequent stressors on mental health can exacerbate existing vulnerabilities, emphasizing the need for preparedness among healthcare professionals to address these rising challenges [2]. The climatic shifts contribute to the proliferation of vector-borne diseases, heat-related illnesses, respiratory disorders, and disruptions in food and water security, underscoring the urgency of understanding the interplay between climate variability and health outcomes [3].

Bibliometric analysis provides a robust methodological framework for quantitatively assessing research trends and the impact of scholarly contributions in this domain. By systematically evaluating the structure and evolution of scientific literature, bibliometric studies enable researchers, policymakers, and institutions to identify key research areas, influential studies, and emerging themes in climate and health research [4]. The application of bibliometric tools such as VOSviewer and Biblioshiny facilitates the visualization of citation patterns, co-authorship networks, and thematic clusters, offering a comprehensive understanding of the intellectual landscape within this interdisciplinary field [5].

A fundamental component of bibliometric analysis is citation analysis, which assesses the influence and relevance of scholarly articles through citation counts and co-citation networks [6]. This approach allows researchers to trace the evolution of knowledge, identifying foundational works and contemporary advancements that have shaped discourse on climate and health interactions [7]. The network analysis provides insights into research collaborations, institutional linkages, and funding influences, thereby highlighting the broader academic and policy implications of climate-health scholarship [8].

The integration of bibliometric analysis with systematic reviews and meta-analyses further enhances the reliability of research assessments, enabling a nuanced understanding of knowledge production in climate-health interactions [9]. As climate variability continues to impact public health across diverse geographic and socio-economic contexts, bibliometric approaches offer valuable tools for identifying research gaps, guiding policy interventions, and fostering interdisciplinary collaboration. This study employs bibliometric techniques to examine the scope, impact, and thematic evolution of research on climate variability and public health, with the aim of elucidating critical trends and informing future research directions.

Climate variability has emerged as a critical factor influencing public health worldwide. As extreme weather events, shifting disease patterns, and environmental stressors become more frequent, research in this domain has grown significantly. This study employs a bibliometric approach to analyse global research trends, collaboration patterns, and thematic developments in climate variability and public health. By providing a structured analysis of existing research, this study offers valuable insights into the trajectory of knowledge development and future directions in the field.

1.1 Need and significance of the study

Climate variability poses a growing challenge to global public health, influencing disease patterns, mortality rates, and healthcare systems. Understanding the linkages between climate fluctuations and health outcomes is critical for developing effective mitigation and adaptation strategies. A bibliometric analysis of this field provides a structured overview of existing research, identifying influential studies, collaborations, and emerging themes. This study is essential for guiding policymakers, healthcare professionals, and researchers in making informed decisions on climate-resilient health policies. It aids in recognizing research gaps, fostering international cooperation, and shaping future research agendas to enhance public health resilience in the face of climate change.

1.2 Objectives

- To examine global research trends in the field of climate variability and public health, highlighting the evolution of scholarly output over time.
- To identify the most influential contributors, including key authors, institutions, and countries that have significantly shaped the discourse on climate-health interactions.
- To analyse the co-occurrence of keywords and uncover major thematic clusters and emerging research fronts within the domain.
- To explore thematic areas and emerging research trends

2 Method

This study employs a bibliometric analysis to systematically examine global research trends in public health in perspective of climate change from 2010 to 2024. The data sourced from **Web of Science** (WoS) and **PubMed**, covering the period from 2000 to 2024. Bibliometric analysis is a quantitative research method used to evaluate the structure, impact, and trends within a scientific domain through statistical and network-based approaches. Inclusion criteria for this analysis includes articles, reviews, conference papers, and book chapters published between 2010 and 2024, and research focused explicitly on public health in the context of climate change (Figure 1). Exclusion criteria consist of duplicates and irrelevant documents were removed after an initial screening and non-peer-reviewed sources, such as editorials and opinion pieces, were excluded. After applying these criteria, the final dataset comprised 4,746 documents.

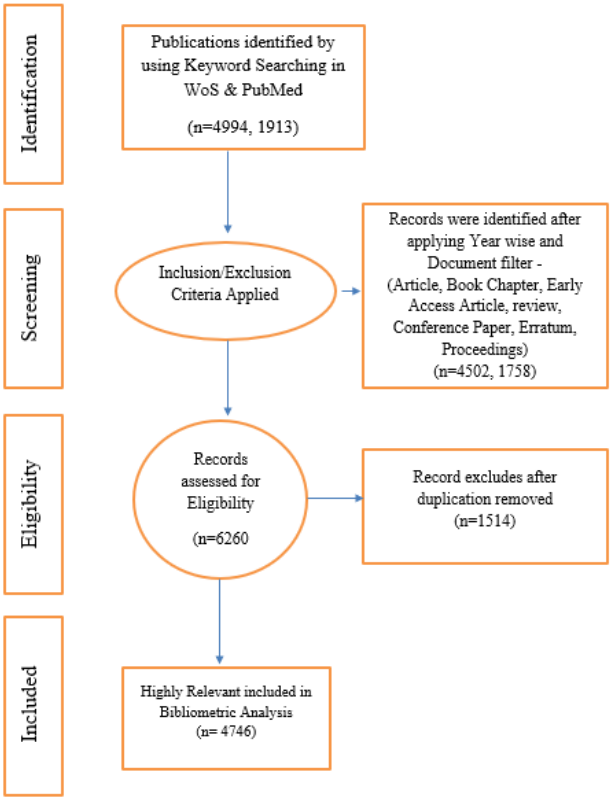

Fig. 1. Methodology Chart

2.1 Data Collection

The study utilized a structured search strategy to collect bibliometric data from **Web of Science** and **PubMed**, focusing on the intersection of climate variability and public health. The search query incorporated three major thematic components: climate variability, health outcomes, and specific disease impacts. The first component included keywords such as **"climate variability," "climate change," and "global warming,"** ensuring that all relevant studies on climatic changes and their effects were captured. The second component focused on public health and human well-being, using terms like **"public health," "human health," "disease burden," "morbidity," and "mortality."** This ensured the inclusion of research addressing both direct and indirect health consequences of climate fluctuations.

Web of Science: *TS=("climate variability" OR "climate change" OR "global warming") AND TS=("public health" OR "human health" OR "disease burden" OR "morbidity" OR "mortality") AND TS=("heatwaves" OR "extreme heat" OR "air pollution" OR "vector-borne diseases" OR "cardiovascular diseases" OR "respiratory diseases")*

Scopus: *(climate variability[Title/Abstract] OR climate change[Title/Abstract] OR global warming[Title/Abstract]) AND (public health[Title/Abstract] OR human health[Title/Abstract] OR disease burden[Title/Abstract] OR morbidity[Title/Abstract] OR mortality[Title/Abstract]) AND (heatwaves[Title/Abstract] OR extreme heat[Title/Abstract] OR air pollution[Title/Abstract] OR vector-borne diseases[Title/Abstract] OR cardiovascular diseases[Title/Abstract] OR respiratory diseases[Title/Abstract])*

To further refine the dataset, the search strategy incorporated terms related to specific health risks influenced by climate variability. This included **"heatwaves," "extreme heat," "air pollution," "vector-borne diseases," "cardiovascular diseases," and "respiratory diseases."** By employing this targeted keyword strategy, the study effectively gathered relevant literature spanning over two decades, providing a solid foundation for analysing publication trends, research collaborations, and emerging themes in climate-health research.

2.2 Data Processing

A total of 1758 articles were retrieved from PubMed and 4502 articles from Web of Science using the specified keywords. After removing duplicates,1514 unique articles were retained for further analysis. This dataset forms the basis for the bibliometric analysis, ensuring comprehensive coverage of relevant research. Duplicate records were removed, and articles unrelated to the primary theme were excluded after a detailed title and abstract screening. Bibliometric data such as publication year, author details, keywords, citation counts, and country affiliations were extracted for further analysis.

2.3 Data Analysis

The analysis was conducted using specialized bibliometric tools, Biblioshiny (an R-based bibliometric package) (Aria and Cuccurullo, 2017). The following techniques were applied:

- **Descriptive Analysis:** This involved the identification of publication trends, prominent journals, influential authors, and citation metrics.
- **Co-occurrence Analysis:** Keywords were analysed to visualize the thematic structure of the research field using network maps.
- **Thematic Mapping:** Themes were classified based on relevance and development degree using a two-dimensional analysis, categorizing topics into Basic Themes, Motor Themes, Niche Themes, and Emerging or Declining Themes.
- **Collaboration Network Analysis:** Country-level collaboration networks were assessed to identify leading research hubs and international partnerships.
- **Thematic Evolution Analysis:** Temporal changes in research focus were mapped using Sankey diagrams to trace the progression of topics over different time

periods.

2.4 Descriptive analysis of a bibliographic data frame

Annual Scientific Production

The study presents the annual publication trend on climate variability and public health research from 2000 to 2024. The number of articles published per year has shown a steady and exponential increase, indicating a growing academic interest in the field. In the early 2000s, the research output remained relatively low, with fewer than 50 articles published annually until 2007. However, from 2008 onwards, the number of publications began to rise significantly, surpassing 100 articles per year by 2013 (Figure 2).

A sharp increase in research activity is evident from 2014 onwards, where the number of publications crossed the 150-mark and continued to rise consistently. The years 2018 to 2024 witnessed an accelerated growth phase, with annual publications reaching 262 in 2018, 318 in 2019, and exceeding 400 in 2020. The upward trend continued in subsequent years, with 494 articles published in 2021, 557 in 2022, and 653 in 2023. The most significant surge is observed in 2024, with 770 articles, marking the highest number of publications in a single year.

This increasing research output reflects the growing global awareness and scientific focus on the health impacts of climate variability. The spike in publications after 2018 suggests an intensified academic and policy-driven effort to understand and mitigate climate-induced health risks. The trend highlights the need for continued interdisciplinary collaboration and the integration of climate science with public health research to address emerging challenges.

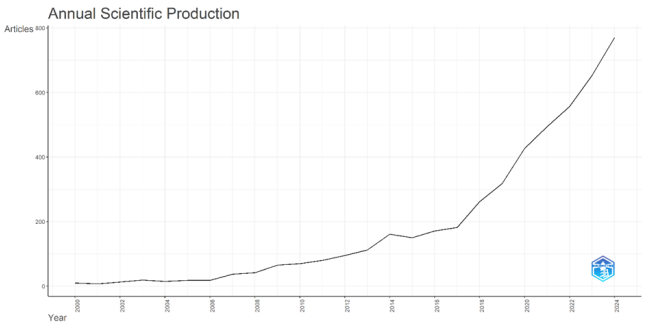

Fig. 2. Annual scientific production (all figures in this paper, except Figures 1 and 6has been prepared using biblioshiny (Aria and Cuccurullo, 2017)).

Most Relevant Sources

The analysis of the most relevant sources in climate variability and public health research highlights a concentration of publications in leading environmental and health-related journals. The ***International Journal of Environmental Research and Public Health*** emerges as the most prolific source, contributing 221 articles, followed closely by ***Science of the Total Environment*** with 208 articles. These two journals serve as key platforms for disseminating interdisciplinary research on climate-health interactions.

Other high-impact journals in this domain include *Environmental Research* (140 articles), ***Environment International*** (115 articles), and ***Environmental Research Letters*** (110 articles), all of which focus on the environmental determinants of health and sustainability. The ***International Journal of Biometeorology*** (82 articles) also features prominently, reflecting its role in exploring the relationship between climate and human health outcomes. Additionally, the journals ***Atmosphere*** (75 articles), ***Sustainability*** (65 articles), and ***Scientific Reports*** (62 articles) contribute significantly to the discourse on climate variability and its implications for public health.

Notably, ***Environmental Health Perspectives*** (60 articles), a well-respected journal in environmental health research, underscores the growing importance of climate change in health-related studies. The distribution of research across these journals demonstrates a multidisciplinary approach, with contributions spanning environmental science, public health, meteorology, and sustainability. This trend indicates a strong academic commitment to understanding and mitigating the health impacts of climate variability.

Core Sources by Bradford's Law

Bradford's Law, introduced by Samuel C. Bradford (1934), describes the dispersion of articles across scientific journals. It states that if scientific articles on a subject are arranged in decreasing order of productivity. Bradford's Law helps in identifying the most relevant journals in a field and is often applied in collection development and information retrieval in libraries[10]. The **Law** states that a small number of core journals contribute the highest number of relevant articles in a research field, while many other journals publish fewer relevant studies. The graph illustrates the application of Bradford's Law to identify core sources in climate variability and public health research. The shaded region represents the core sources, which contribute the highest number of articles in this field. These sources follow the Bradford distribution, where a small number of journals publish a disproportionate amount of research on the topic.

The ***International Journal of Environmental Research and Public Health, Science of the Total Environment, Environmental Research, Environment International, and Environmental Research Letters*** are among the most influential sources, as seen in the steep decline in article count beyond the core zone. As the rank of sources increases, the number of articles per source decreases significantly, aligning with Bradford's concept of zones of dispersion in scholarly publishing

(Figure 3).

This distribution highlights the importance of these core sources for researchers focusing on climate variability, extreme weather events, and their public health impacts. For comprehensive literature reviews or systematic studies, prioritizing these high-impact journals ensures access to the most relevant and frequently cited research in the field.

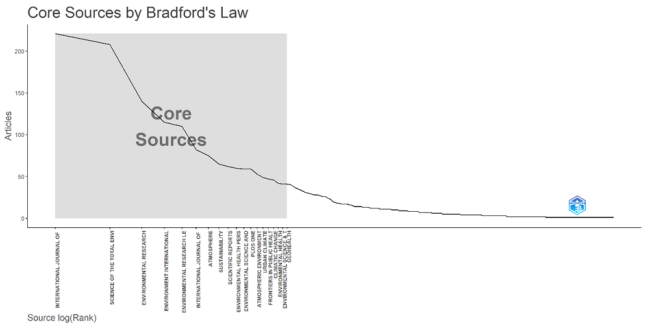

Fig. 3. Core Sources by Bradford's Law

Most Relevant Authors

The study identifies six leading authors based on total publications and fractionalized contributions. **ZHANG Y** is the most prolific, with **121 articles** and a fractionalized count of **13.29**, indicating substantial research output. **WANG Y** follows with **90 articles** and a fractionalized count of **11.99**, highlighting a strong presence in the field. **LIU Y** has **75 articles** and a fractionalized count of **8.65**, demonstrating consistent contributions. **GUO Y** published **63 articles** with a fractionalized count of **8.51**, reflecting notable participation in collaborative research. **WANG J** has **63 articles**, but their fractionalized count of **10.71** suggests a significant individual impact. **ZHANG X** contributed **61 articles** with a fractionalized count of **8.63**, maintaining a strong research presence.

Author Productivity through Lotka's Law

Lotka's Law, proposed by Alfred J. Lotka (1926) [11], describes the distribution of scientific productivity among authors. The vertical axis shows the **percentage of authors**, while the horizontal axis represents the **number of documents written**. The curve follows a **power-law distribution**, indicating that a small number of authors contribute a large number of publications, while the majority of authors produce only a few papers (Figure 4). The steep decline at the beginning suggests that most authors have written only **one or two papers**, while a very small fraction has authored a significantly higher number of documents. This pattern is consistent with Lotka's Law, which states that the number of authors publishing **n** papers is inversely proportional to $\mathbf{n}^2$.

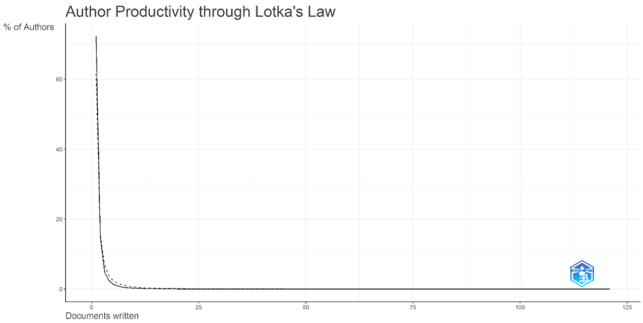

Fig. 4. Author Productivity through Lotka's Law

Authors' Local Impact

The top five authors in the study are **ZHANG Y, WANG Y, TONG S, GUO Y, and EBI K**—demonstrate significant research impact based on their **h-index, total citations (TC), and number of publications (NP)** (Table 1). These indicators reflect both their productivity and the influence of their research within the academic community.

ZHANG Y leads in terms of productivity, with **121 publications**, the highest among all authors. Their **h-index of 38** and **5219 total citations** indicate that their work has been widely referenced, signifying a strong academic presence. Despite having the most publications, their total citation count is lower than that of WANG Y, which suggests that while ZHANG Y is highly productive, the citation impact per publication may not be as high as some of the other leading authors. **WANG Y**, on the other hand, stands out with **the highest total citations (8509)**, even though they have fewer publications (**90**) compared to ZHANG Y. Their **h-index of 34** highlights the broad recognition of their work, indicating that a significant portion of their research has received substantial academic attention. This suggests that WANG Y's work is not only prolific but also highly influential in the field.

TONG S holds a **balanced position** with **54 publications**, an **h-index of 32**, and **4211 total citations**. While their publication count is lower than ZHANG Y and WANG Y, the relatively high h-index and citation count suggest a strong impact per publication. This indicates that TONG S's research is widely acknowledged and frequently referenced. **GUO Y** has published **63 papers**, placing them in a highly productive category, with an **h-index of 30** and **3353 total citations**. Their academic influence is notable, although their total citations are slightly lower compared to TONG S. This suggests that while GUO Y has contributed significantly to the field, their individual publications may not have received as many citations as those of TONG S or WANG Y.

EBI K is another highly cited researcher, with **49 publications, an h-index of 29, and 5455 total citations.** Despite having a lower number of publications compared to ZHANG Y and WANG Y, EBI K's high citation count indicates that their work has had a substantial impact. This suggests that

their research is influential, even with a relatively smaller number of papers. These five authors demonstrate exceptional academic productivity and impact. While some, like **ZHANG Y**, excel in the number of publications, others, such as **WANG Y and EBI K**, have achieved high citation counts, indicating that their work is highly regarded and widely referenced in the academic community.

Table 1. Author Local Impact

Author	H_Index	Total Citation	Number of Publication
ZHANG Y	38	5219	121
WANG Y	34	8509	90
TONG S	32	4211	54
GUO Y	30	3353	63
EBI K	29	5455	49
KINNEY P	26	2272	40
WANG J	26	1826	63
WANG X	25	2903	48
LIU J	24	3342	55
SCHWARTZ J	24	4554	34

Source: Created by the investigator

Most Relevant Affiliations

Institutional contributions are crucial in advancing re-search and developing innovative solutions. Key institutions drive knowledge production, offering insights into regional expertise, collaboration, and research influence[12]. **The University of California** leads the list with **398 published articles**, making it the most prolific institution in terms of research output. **Harvard University**, a globally renowned Ivy League institution, follows with **315 articles**.

The Chinese Academy of Sciences (CAS) ranks third with **305 articles**. **The University of London** and **University College London (UCL)** have **263 and 205 articles**, respectively. Other notable institutions include the **London School of Hygiene and Tropical Medicine (196 articles)** and the **University of Washington (192 articles)** recognized for its leadership in climate research and public health studies. The **Columbia University (182 articles), Peking University (176 articles), and Tsinghua University (164 articles)** also feature on the list, reflecting their contributions to high-impact research, particularly in sustainability, technology, and policy development. This diagram highlights the dominance of institutions from the **United States, the United Kingdom, and China**, reinforcing their roles as global leaders in research and innovation.

Corresponding Author's Countries

Scientific research has increasingly become a collaborative effort, with countries contributing varying degrees of single-country and multi-country publications. Analysing the distribution of research output provides insights into the global research landscape and the extent of international collaboration.

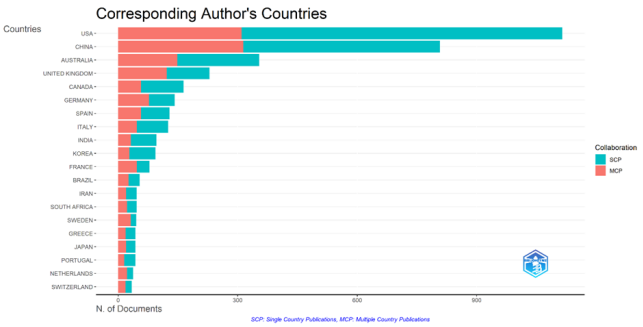

Fig. 5. Corresponding Authors Countries

The United States (USA) dominates the research landscape with **1,115 articles**, accounting for **23.5%** of total publications. A significant portion (**805 articles**) are single-country publications (SCP), while **310 articles (27.8%)** involve international collaboration (MCP). This reflects the country's robust research infrastructure, extensive funding, and strong institutional networks that allow for both independent and collaborative research initiatives (Figure 5).

China follows closely with **808 articles (17%)**, demonstrating its rise as a major global research hub. Of these, **494 articles** are single-country publications, whereas **314 (38.9%)** involve international collaboration. Australia ranks third with **354 articles (7.5%)**, showing a strong commitment to international research partnerships. While **206 articles** are single-country publications, **148 (41.8%)** are multi-country collaborations, indicating a high level of international engagement.

With **229 articles (4.8%)**, the United Kingdom (UK) maintains a significant presence in global research. More than half (**53.3%**) of these publications involve multi-country collaborations, emphasizing the UK's reliance on international networks to drive scientific advancements.

Canada contributes **164 articles (3.5%)**, with **107 single-country** and **57 multi-country** publications, translating to a **34.8%** collaboration rate. Germany stands out with **142 articles (3%)** but boasts the highest international collaboration rate (**54.2% MCP**), highlighting its commitment to global research partnerships. Other significant contributors include **Spain (129 articles, 44.2% MCP), Italy (125 articles, 37.6% MCP), India (96 articles, 33.3% MCP), and Korea (93 articles, 30.1% MCP)**. These countries are steadily expanding their research presence, with increasing participation in cross-border collaborations.

Countries' Production over Time

The study reveals a significant increase in article production across all five countries Canada, the United Kingdom,

the USA, Australia, and China—from 2000 to 2024. The USA consistently leads in total output, demonstrating steady growth throughout the period. The United Kingdom follows, showing an impressive relative growth rate of 60,850%, despite starting with a low article count. Canada and Australia exhibit moderate yet consistent growth, with Australia accelerating significantly after 2010. China stands out with an exponential rise in production, surpassing Canada and Australia after 2015 and closing in on the UK and USA in recent years (Table 2).

Analysing yearly growth trends, the USA maintains a stable long-term increase, while the UK shows a similar pattern with a slight slowdown post-2020. Canada and Australia follow a steady trajectory, with Australia's production surging significantly in the last decade. China, however, exhibits the most dramatic acceleration, particularly after 2010, with its average annual growth rate increasing over time. This trend suggests that China could surpass the USA in research output within the next decade. Meanwhile, the UK remains a strong contender, potentially catching up with the USA, while Canada and Australia continue their steady contributions to global research. Overall, the findings indicate a shifting research landscape, with China emerging as a dominant force, challenging the long-standing leadership of the USA.

Table 2. Growth Rate of Production

Country	Avg. Annual Growth (2000-2010)	Avg. Annual Growth (2010-2020)	Avg. Annual Growth (2020-2024)
USA	29.80%	29.80%	12.90%
United Kingdom	29.30%	29.70%	13.00%
Canada	31.30%	31.20%	12.70%
Australia	39.50%	30.20%	12.50%
China	57.40%	58.30%	18.40%

Source: Created by the investigator

Most Cited Countries

The study analysed a total of 4,746 research articles published between 2000 and 2024, examining the citation impact and research output of various countries (Figure 6). The **USA** leads in total citations (72,828), reflecting its strong research influence, although its average citation per article is 65.3. **Australia** and the **United Kingdom** follow closely in citation impact, with average citations per article at 68.9 and 69.0, respectively.

China, despite its significant research production, has a lower average citation rate of 27.1, suggesting a focus on quantity rather than citation impact. **Germany** stands out with the highest research impact among major contributors, having an average of 72.9 citations per article. **Italy** and **Spain** show moderate total citations, with average citations per article of 47.6 and 42.9, respectively. **Canada**, with a steady research output, has an average citation rate of 31.9 per article, indicating moderate impact.

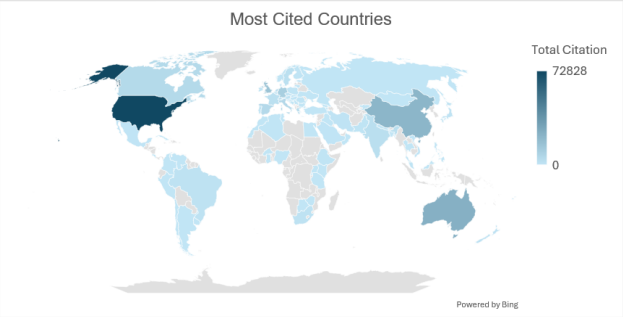

Fig. 6. Most Global Cited Documents

Interestingly, **Greece** records the highest average citations per article at 89.6, despite a lower total citation count, indicating that its research, while limited in volume, is highly influential. The study reveals that while the **USA** dominates in total citations, countries like Germany, Australia, and Greece exhibit higher research impact per publication.

Most Cited Documents

The study identifies the most cited research papers in the dataset, highlighting their significant impact in the academic community. The most cited paper, authored by Lelieveld J. in 2015 and published in *Nature*, has received 3,996 citations, indicating its strong influence. This is followed by Visseren F.'s 2021 paper in *European Heart Journal* with 2,543 citations and Naghavi M.'s 2017 study in *The Lancet*, which has been cited 2,493 times.

Other highly cited works include Manisalidis I.'s 2020 paper in *Frontiers in Public Health* (2,336 citations) and Hughes T.'s 2017 publication in Nature (2,212 citations). Additionally, Patz J.'s 2005 study in *Nature* has accumulated 2,055 citations, showcasing its long-standing relevance. The dataset also features influential studies by Vos T. (2017, *The Lancet*, 1,738 citations), Kovats R. (2008, *Annual Review of Public Health*, 1,240 citations), and Jacobson M. (2009, *Energy & Environmental Science*, 1,195 citations).

Finally, Smale D.'s 2019 paper in *Nature Climate Change* rounds out the top ten with 1,056 citations. These highly cited papers span various disciplines, reflecting a strong focus on public health, climate change, and environmental sciences. Their high citation counts indicate significant contributions to their respective fields, shaping research directions and policy discussions.

Most Frequent Words

The most frequent words in the dataset highlight key themes and research focus areas. The term **"climate change"** appears **1,548 times**, indicating its central role in the studies analysed. This is followed by **"mortality"** with **1,325 occurrences**, suggesting a strong link between environmental factors and human health outcomes. **"Air pollution"** is another prominent term, appearing **977 times**, reflecting concerns about its effects on public health. Other frequently used words include **"temperature"** (**733 occurrences**) and **"impact"** (**678 occurrences**), emphasizing the significance of temperature variations and their consequences (**Fig: 7**). The term **"health"** appears **599 times**, reinforcing the focus on human well-being in relation to environmental factors. Additionally, **"impacts"** (**414 occurrences**) and **"exposure"** (**395 occurrences**) indicate an emphasis on studying the effects of environmental hazards. Words like **"risk"** (**383 occurrences**) and **"ambient temperature"** (**300 occurrences**) further underscore concerns related to climate and its influence on health and safety. Overall, the frequent use of these terms highlights the study's focus on climate change, air pollution, temperature variations, and their direct and indirect effects on human health and mortality.

Fig. 7. Word Cloud

Words' Frequency over Time

The frequency analysis of key terms over time (2000–2024) shows a significant rise in research interest and discourse surrounding climate change and its related health impacts. The term **"climate change"** has seen an exponential increase from **0 mentions in 2000** to **1,548 mentions in 2024**, highlighting the growing global concern. Similarly, **"mortality"** and **"air pollution"** have surged from low initial counts to **1,325 and 977 mentions**, respectively, reflecting the increasing awareness of health risks associated with environmental changes.

The rise in **"temperature"** (from **2 mentions in 2000 to 733 in 2024**) and **"impact"** (from **1 to 678**) signifies the expanding focus on the effects of climate variability. **"Health"**, **"exposure"**, and **"risk"** have also grown substantially, emphasizing the human dimension of climate-related hazards. Meanwhile, **"ambient temperature"**, which had no mentions in the early 2000s, has progressively gained relevance, reaching **300 mentions in 2024**. This trend suggests a shift in research priorities, with increasing attention to the health implications of climate change, air pollution, and rising temperatures. The study highlights how climate and environmental health issues have become more prominent in scientific discourse, particularly in the last decade.

Co-occurrence Network Diagram

The Diagram visualizes the relationships between keywords plus that frequently appear together in academic literature. The size of the nodes represents the frequency of each keyword, while the edges (lines) indicate the strength of their co-occurrence. Keyword Plus consists of terms automatically assigned by databases (such as Web of Science or Scopus) that reflect the core concepts of a research article. In this diagram, **"climate-change," "mortality," "air-pollution," "impact," and "health"** are the most prominent keywords, indicating that they are central themes in the research field. The network is color-coded into different clusters, representing distinct research subfields (Figure 8). The **green cluster** focuses on health impacts, including **heat waves, public health, and stress**, while the **purple cluster** is related to air quality and pollution, including **PM2.5, ozone, and emissions**. The **blue cluster** appears to be related to temperature and extreme weather events. This visualization helps researchers understand how different themes are interconnected, identify emerging research areas, and explore dominant trends in the literature.

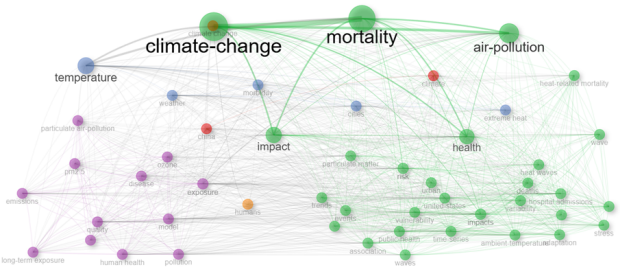

Fig. 8. Co-occurrence Network Diagram

Thematic Map

The thematic map presents a structured visualization of research themes categorized based on their relevance (centrality) and level of development (density). The **motor themes** include highly relevant and well-developed topics such as climate change, mortality, and impact. These themes are central to the research field, indicating their widespread significance in academic discourse. Additionally, particulate matter, emissions, and air quality emerge as dominant themes, high-

lighting their strong connection to environmental and public health concerns. The positioning of these themes suggests that they drive advancements in the field and serve as key areas of focus for interdisciplinary studies (Figure 9).

The **niche themes** contain topics that are well-developed but exhibit lower relevance to the broader research domain. Air pollutants/analysis and particulate matter/analysis fall within this category, indicating a solid research foundation but a relatively specialized application. Furthermore, pregnancy appears in this quadrant, suggesting an established body of work linking environmental factors to maternal and neonatal health outcomes. These themes, while not as central as motor themes, contribute valuable insights to specific subfields within climate and health research.

In contrast, the **basic themes**, which are highly relevant but less developed. This section includes air pollution, impacts, and exposure, suggesting that these topics are foundational to the research field but require further investigation to enhance their theoretical and empirical depth. The presence of cities, climate, and China in this quadrant indicates an increasing focus on urban environments and regional case studies in climate research. The positioning of these themes suggests that they form the building blocks of ongoing and future research efforts.

The **emerging or declining themes**, consists of topics that exhibit both low centrality and low development. Themes such as ecosystem and Australia appear in this quadrant, which may indicate either a diminishing focus or an emerging area yet to gain prominence. The placement of these themes suggests that they are either losing relevance in the broader research landscape or are in the early stages of academic exploration.

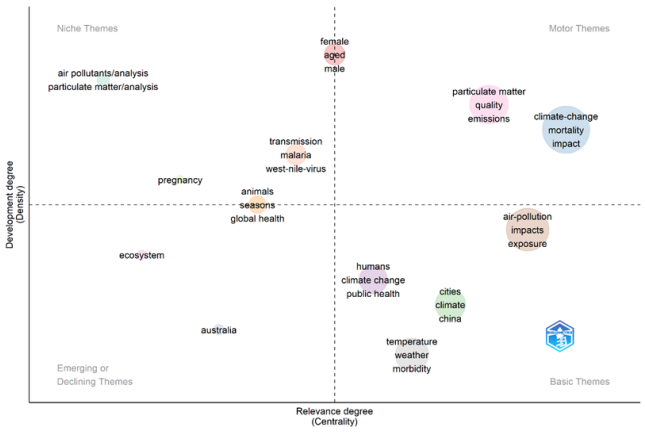

Fig. 9. Thematic Map

The thematic map highlights the central role of climate change, mortality, and air pollution in contemporary research while also identifying gaps in emerging areas. The analysis suggests that while some themes are well-established and continue to drive research, others remain underdeveloped despite their relevance. The evolving nature of research priorities is evident in the shifting significance of themes over time, reflecting broader societal and scientific concerns. This thematic mapping helps in understanding the structure of the research domain, identifying major research trends, and exploring interdisciplinary linkages across various subfields.

Thematic Evolution

The thematic evolution diagram presents a longitudinal analysis of research trends across four distinct time periods: **2000–2007, 2008–2014, 2015–2018, and 2019–2024**. This visualization illustrates the dynamic nature of scientific discourse, highlighting the emergence, persistence, and transformation of key research themes over time (Figure 10).

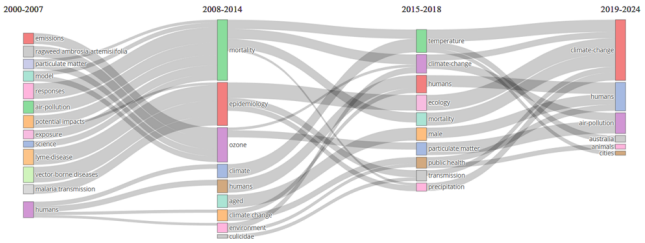

Fig. 10. Thematic Evolution

During the **2000–2007** period, the research landscape was characterized by a strong focus on environmental and health-related themes, such as emissions, air pollution, particulate matter, potential impacts, exposure, and vector-borne diseases. The presence of malaria transmission and lyme disease suggests an early interest in the intersection between climate and disease ecology. The term humans appear, indicating a growing recognition of the human dimension in climate and environmental studies.

In the **2008–2014** period, the thematic structure shifted towards a more refined focus on health outcomes and atmospheric sciences. The emergence of mortality, epidemiology, ozone, climate, and environment reflects an increasing concern with the direct and indirect effects of climate change on human health. The presence of aged as a theme suggests a focus on vulnerable populations, possibly linking climate and air pollution to aging-related health risks. Additionally, climate change emerges as a major thematic category, indicating a shift toward broader discussions on long-term environmental change.

Between **2015 and 2018**, the research landscape further evolved to incorporate interdisciplinary themes such as temperature, climate change, humans, ecology, mortality, public health, and precipitation. This period reflects a growing integration of climate science with public health and ecological concerns. The continued presence of particulate matter and transmission suggests ongoing research on air quality and

disease spread, reinforcing the connections between environmental change and epidemiological dynamics.

The **2019–2024** period exhibits a strong consolidation around climate change, which becomes the most dominant theme. The persistence of humans, air pollution underscores the continued emphasis on human-centered climate research. Additionally, new themes such as Australia, animals, and cities emerge, signaling a geographical and ecological diversification of research interests. The inclusion of cities highlights an increasing focus on urban environments, possibly in response to growing concerns over climate adaptation and mitigation in densely populated areas.

The thematic evolution diagram reveals a clear trajectory from environmental pollution and disease transmission toward a more comprehensive examination of climate change, health, and urban systems. The increasing centrality of climate-related themes suggests a broader recognition of climate change as a fundamental driver of socio-environmental transformations. Furthermore, the emergence of new geographic and ecological themes reflects the expanding scope of contemporary climate research, encompassing both human and non-human dimensions.

Factorial Analysis

Factorial analysis, in this case using Multiple Correspondence Analysis (MCA), is a method used to identify patterns and relationships among different concepts or keywords in research. It helps to visualize how closely related certain topics are and how research in a specific field is structured (Figure 11).

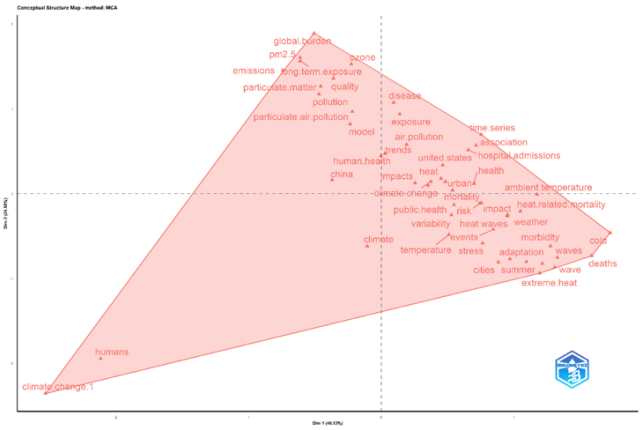

Fig. 11.

A Multiple Correspondence Analysis (MCA) was conducted to examine the conceptual structure of research on climate variability and its impact on public health. The resulting map reveals three distinct clusters, reflecting major thematic areas in the literature. On the left side of the map, a cluster dominated by keywords such as ***"climate change", "humans"***, and ***"global burden"*** represents studies that assess the overarching impacts of climate change on human health, often at a global scale. The upper cluster is characterized by terms like ***"pm2.5", "particulate matter", "air pollution", and "emissions"***, indicating a significant body of research focused on air pollution and its long-term health effects, particularly concerning respiratory and cardiovascular diseases. On the right side of the map, a cluster centered around terms such as ***"heat waves", "extreme heat", "ambient temperature", and "heat-related mortality"*** highlights research that investigates the direct health impacts of temperature extremes, including increased morbidity, mortality, and hospital admissions. The two dimensions derived from the analysis provide additional insights into the structure of the research field. **Dimension 1 (46.53%)** represents a continuum from general climate change discussions to more specific public health concerns, with studies on global assessments positioned on the left and localized health impacts on the right. **Dimension 2 (24.94%)** differentiates research based on thematic focus, with pollution-related health impacts dominating the upper part and heat stress, mortality, and adaptation strategies occupying the lower part. The conceptual structure map thus offers a comprehensive overview of the existing literature, shedding light on the interconnected nature of climate variability and public health research. This visualization not only highlights dominant research themes but also identifies potential gaps, providing a valuable foundation for future interdisciplinary investigations.

Collaboration Network

The **Collaboration Network Diagram** illustrates the co-authorship relationships among researchers, where each node represents an author, and the connections signify joint publications. The size of the nodes indicates the prominence or influence of an author, with larger nodes suggesting a higher number of collaborations. Distinct colors differentiate various research groups or clusters, revealing how closely authors work together within specific academic communities (Figure 12).

In the diagram, **Zhang Y and Wang Y** appear as central figures, indicating their extensive collaborations across multiple researchers. The **blue cluster** represents a highly interconnected group of authors working closely together, while the **red cluster** shows another set of researchers with strong internal collaborations, featuring key contributors like **Liu Y and Guo Y**. Additionally, some authors, such as **Bi P and Hansen A**, act as bridges between different research groups, connecting separate clusters and facilitating interdisciplinary collaborations. This network visualization helps in identifying influential researchers, understanding collaboration patterns, and discovering potential co-authors for future research.

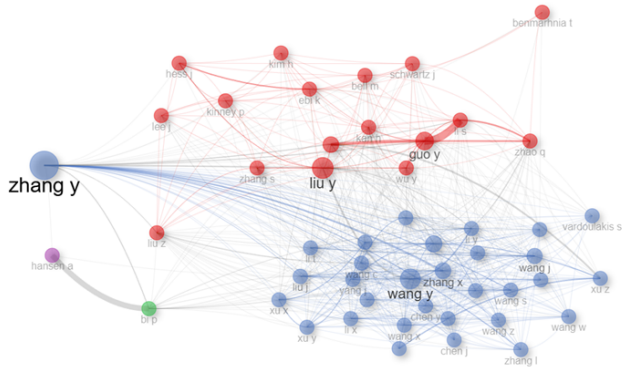

Fig. 12. Authors Collaboration Network

3 Conclusion

The findings reveal an exponential rise in publications over the past two decades, with the highest surge occurring post-2010, reflecting increased global awareness of climate-driven health risks. The high citation rate of 42.49 per document suggests that research in this field has had a significant academic and policy impact. International collaborations account for 38.26% of the total publications, emphasizing the global nature of research in climate variability and health. This strong collaborative framework highlights the interconnected challenges posed by climate change and the necessity for collective scientific efforts to address them. The study also differentiates between single-authored and collaborative works, with only 219 documents being single-authored, indicating a strong tendency toward teamwork and interdisciplinary engagement. The average number of co-authors per document (6.57) further supports this trend. A thematic analysis of author keywords indicates the evolution of key research areas, including vector-borne diseases, heat stress, air pollution, climate resilience, and health adaptation strategies. These themes demonstrate the increasing intersection between climate science, epidemiology, and public health policy. As climate change continues to pose unprecedented health challenges, the research landscape is expanding to include innovative solutions for mitigation and adaptation. This study underscores the dynamic growth of research on climate variability and public health. The increasing trend of international and interdisciplinary collaborations suggests that future studies should focus on regional disparities, policy interventions, and technological advancements in climate-health mitigation. Strengthening interdisciplinary partnerships and fostering evidence-based policymaking will be crucial in addressing the complexities of climate-driven health issues.

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