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Trends and insights in Nature-Based Solutions: A bibliometric study

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Abstract

This study presents a comprehensive bibliometric analysis of global research trends in Nature-based Solutions (NbS) for climate resilience from 2010 to 2024. NbS are sustainable approaches that utilize natural ecosystems to mitigate climate change, enhance resilience, and support adaptation strategies. Utilizing data from the Scopus and Web of Science databases, a total of 765 documents were analysed after removing duplicates. The dataset reveals a significant growth in research on Nature-based Solutions, with an annual growth rate of 46.61%. These documents were published across 385 sources, with an average document age of 3.26 years, reflecting the field's recent expansion. The average rate of 21.99 citations per document highlights the academic impact of these studies. Collaborative research is prominent, with 3,214 authors contributing at a co-authorship rate of 4.87 authors per document, though single-authored works account for only 65 publications. International collaboration is moderate, with 18.56% of publications involving authors from multiple countries. The study explores key thematic areas, influential authors, leading institutions, and global collaboration networks. It also examines emerging research trends and the evolving focus on integrating Nature-based Solutions into climate resilience and climate adaptation strategies. This bibliometric review provides valuable insights that can guide future research, inform policy development, and support practitioners in scaling up the implementation of Nature-based Solutions for sustainable climate adaptation and resilience-building.

Keywords: Bibliometrics, Nature-based Solutions, Climate Resilience, Climate Adaptation, Climate Change, Ecosystem-based Adaptation, Research Trends

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1 Introduction

With climate crises intensifying across the globe, Nature-based Solutions (NbS) have emerged as a game-changer in the fight for climate resilience. By utilising the power of natural ecosystems such as forests, wetlands, and urban green spaces NbS offer sustainable, cost-effective strategies to combat climate change while enhancing biodiversity and human well-being. These solutions not only serve as natural shields against extreme weather events but also contribute to carbon sequestration, water regulation, and ecosystem restoration, making them a cornerstone of modern climate adaptation efforts.

Over the past few years, the scientific community has witnessed a surge in research on NbS, reflecting a growing recognition of their potential to address complex environmental challenges. Recent studies emphasize the increasing global focus on ecosystem-based approaches such as NbS and Eco-DRR for addressing climate resilience and disaster risks (Joseph et al., 2024). These approaches are gaining momentum for their sustainability, cost-effectiveness, and co-benefits for biodiversity and human well-being. Scholars and policymakers are increasingly exploring the intersections of NbS with urban planning, agriculture, and disaster risk reduction. Despite the expanding body of research, the field remains highly diverse, with varying methodologies, conceptual frameworks, and applications spanning multiple disciplines.

This bibliometric study aims to map the intellectual landscape, research trends, and knowledge evolution of NbS for climate resilience. By analysing key publications, influential authors, research collaborations, and thematic clusters, this study offers a comprehensive overview of how the field has developed over time. Originally coined as a term

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in the late 20th century, bibliometrics has its roots in the study of citations dating back to the 1920s, significantly advanced by the establishment of the Science Citation Index by Eugene Garfield, which allowed for systematic citation analysis (Godin, 2006). Such analyses illuminate the interconnectivity of scholarly work and map out the intellectual landscape of different disciplines, including emergent trends and research hotspots (Lima et al., 2023).

Bibliometrics assists in benchmarking institutional performance and identifying influential publications that shape research practices. Research indicates that publications featured in highly cited journals often correspond with major advances in their respective fields, thereby playing a critical role in guiding funding and investment in research initiatives (Ahmad et al., 2019). Bibliometric analysis has become an indispensable aspect of contemporary research assessment, equipping stakeholders with the tools needed to navigate and understand the complex domain of scientific production and innovation. It provides insight into the historical trajectories of research disciplines and serves as a predictor for future directions within scholarly inquiry (Öztürk, 2023; Xu et al., 2022).

The insights derived will help pinpoint research gaps, emerging innovations, and opportunities for interdisciplinary collaboration, ultimately shaping the future of NbS research and implementation. As the urgency for scalable climate solutions grows, understanding the scholarly discourse around NbS is more critical than ever. This study serves as a strategic guide for researchers, policymakers, and practitioners seeking to harness the power of nature in building a more resilient and sustainable world. One of the notable applications of NbS is observed in wastewater treatment infrastructure, particularly in Southeast Asia, where countries like Indonesia engage in climate resilience planning. Indonesian authorities have been investing in green infrastructure that integrates NbS to mitigate flooding impacts. This includes conducting vulnerability assessments and developing adaptation strategies that enhance the resilience of wastewater systems to extreme weather events (Goh et al., 2024).

The importance of planning and managing ecosystems under changing climatic conditions cannot be understated. For instance, employing risk-sensitive conservation planning is critical to ensuring the sustainable provision of biodiversity and ecosystem services in the context of varying climate change impacts (Runting et al., 2018). Furthermore, the implementation of NbS like urban afforestation and wetland restoration has been shown to reduce risks associated with climate fluctuations, thus promoting greater ecosystem functionality and resilience (Barron et al., 2019). Forest management practices embody another dimension of NbS by enhancing both carbon sequestration and ecosystem health. Research highlights that properly managed forests can provide significant co-benefits, including stored carbon and enhanced biodiversity, thereby addressing both climate mitigation and adaptation goals simultaneously (Fargione et al., 2018).

Urban planning increasingly adopts NbS to address climate challenges and improve urban resilience. Initiatives such as creating green spaces and utilizing urban forestry can drastically mitigate urban heat effects while contributing to human health and environmental sustainability (Girardin et al., 2021; Barron et al., 2023). The integration of stakeholder participation, as shown in studies focusing on urban water management, further supports the implementation of NbS by addressing both local needs and enhancing ecological services in urban settings (Beceiro et al., 2020). The adoption of NbS across various contexts whether through infrastructure resilience, forest management, or urban planning illustrates a comprehensive approach to tackling the multifaceted challenges posed by climate change. These strategies not only help mitigate carbon emissions but also enhance the overall resilience of ecosystems and communities, ultimately promoting sustainable development (Barausse et al., 2022; O'Sullivan et al., 2020).

This study provides valuable insights that can guide future research, policy development, and real-world applications of NbS. As climate challenges intensify, NbS offers a powerful, nature-driven approach to building resilience, restoring ecosystems, and ensuring long-term sustainability. By strengthening global collaborations, integrating interdisciplinary research, and bridging the gap between science and policy, NbS can be scaled up effectively to create climate-resilient cities, protect vulnerable communities, and drive transformative environmental change.

1.1 Need and significance of the study

Climate change poses an urgent and complex challenge, requiring innovative and sustainable solutions to mitigate its impacts and enhance resilience. NbS have gained global recognition for their ability to utilise ecosystems in addressing climate-related risks, promoting biodiversity, and supporting human well-being. Despite their increasing adoption in policy and practice, a systematic understanding of global research trends in NbS remains limited. The significance of this study lies in its ability to map key developments, emerging themes, and collaboration networks within NbS research. By highlighting the evolving focus on climate resilience, climate adaptation, and sustainability, this study supports practitioners in scaling up NbS initiatives for long-term environmental and societal benefits. The insights gained from this bibliometric analysis will contribute to strengthening global efforts toward a more resilient and sustainable future.

1.2 Objectives

- To analyse the growth and development of NbS research
- To identify key contributors and collaboration networks
- To explore thematic areas and emerging research trends
- To provide insights for future research and policymaking

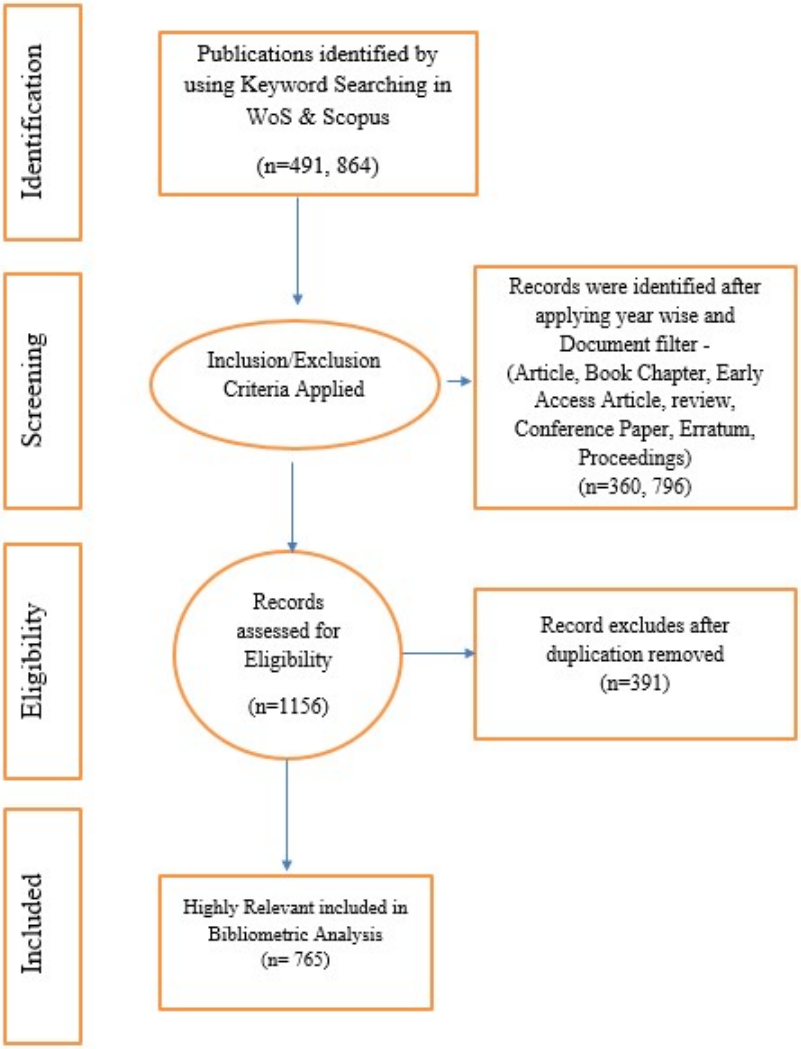

Fig. 1. Methodology flow chart.

2 Methodology

This study employs a bibliometric analysis to systematically examine global research trends in NbS for climate resilience from 2010 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 NbS in the context of climate resilience (Fig. 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, 765 documents were selected for analysis.

2.1 Data Collection

The study utilized specific keywords to conduct a comprehensive search in academic databases like Web of Science and Scopus. The primary keywords included *"Nature-Based Solutions (NbS)," "Ecosystem-Based Adaptation," "Green Infrastructure", "Nature-Based Interventions," "Nature -Based Solutions," "Nature Based Solutions," and "Nature Based Solutions NBS." These were combined with secondary keywords such as "Climate Resilience," "Climate Adaptation," "Climate Mitigation," and "Disaster Resilience."* The search query has been used for extracting documents from Scopus and Web of Science (WOS) are listed below;

Scopus*; TITLE-ABS-KEY ("nature-based solutions" OR "nbs" OR "ecosystem-based adaptation" OR "green infrastructure" OR "nature-based interventions" OR "ecosystem-based adaptation" OR "nature -based solutions" OR "nature based solutions" OR "nature based solutions nbs" OR "nature-based solutions") AND TITLE-ABS-KEY ("climate resilience" OR "climate adaptation" OR "climate mitigation" OR "disaster resilience" OR "natural climate solutions" OR "natural climate solutions ncs" OR "climate adaptation")*

WOS*; ts=("nature-based solutions" or "nbs" or "ecosystem-based adaptation" or "green infrastructure" or "nature-based interventions" or "ecosystem-based adapta-*

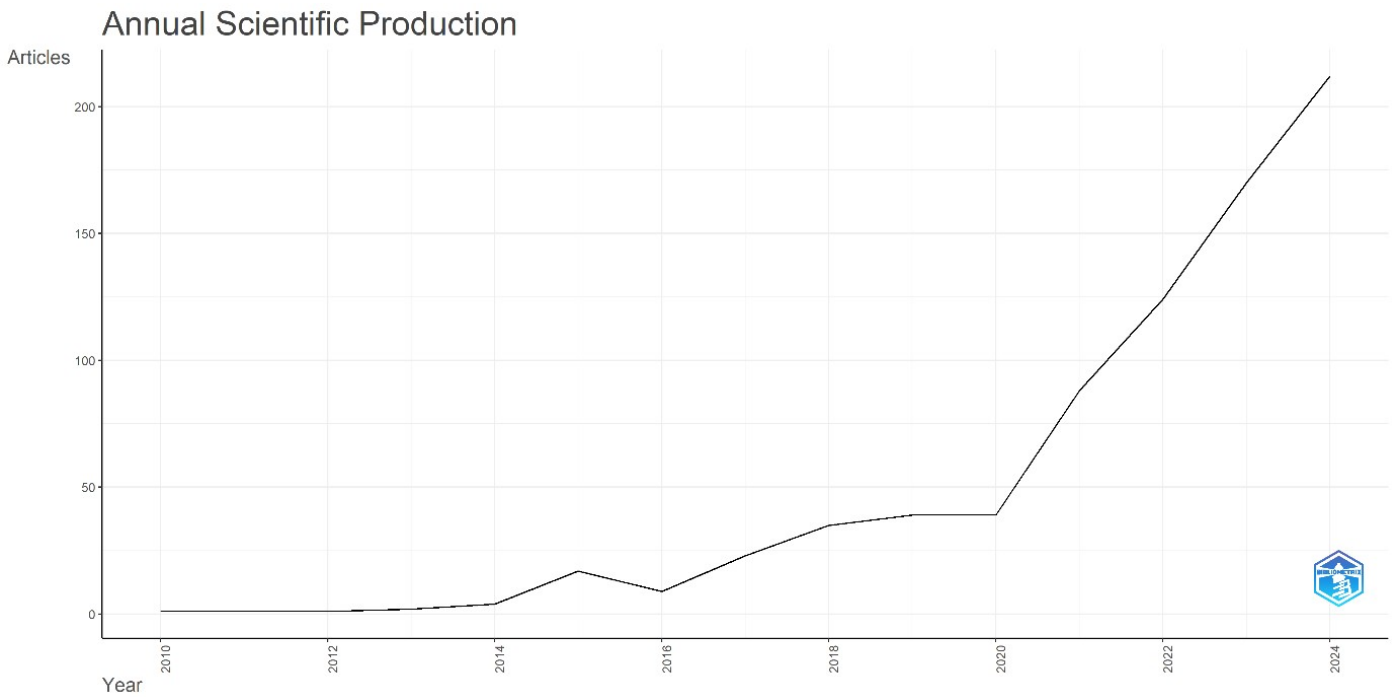

Fig. 2. Annual scientific production (all figures in this paper, except Fig. 6 has been prepared using *biblioshiny* (Aria and Cuccurullo, 2017)).

tion" or "nature-based solutions" or "nature based solutions" or "nature based solutions nbs" or "nature-based solutions") and ts=("climate resilience" or "climate adaptation" or "climate mitigation" or "disaster resilience")

2.2 Data Preprocessing

A total of 796 articles were retrieved from Scopus and 360 articles from Web of Science using the specified keywords. After removing duplicates, 765 unique articles were retained for further analysis. This dataset forms the basis for the bibliometric analysis, ensuring comprehensive coverage of relevant research on NbS and their role in climate resilience, adaptation, mitigation, and disaster resilience.

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

2.4.1 Annual Scientific Production

The graph of annual scientific production displays the upward trend in the number of articles published on NbS and Disaster Resilience from 2010 to 2024 (Fig. 2). The number of publications remained very low from 2010 to 2014, with around nine articles in total and only a slight increase each year. A significant growth began in 2015 with 17 articles, followed by steady increases, peaking sharply from 2021 onwards. The highest growth was recorded in 2024, with 212 articles, demonstrating the rapidly increasing academic interest in this field.

2.4.2 Average Citations Per Year

This shows that the Mean Number of Citations per Article (Mean TC per Art), which represents the average number of times each article published in a given year was cited,

peaked in 2016 at 142.44. The highest Mean Citation per Year (Mean TC per Year), which reflects the average number of citations received per year for articles published in a specific year, also occurred in 2016 at 14.24. This suggests that articles from that year had a significant academic impact. However, recent years show a decline in the Mean TC per Art, particularly in 2023 and 2024, likely due to the limited time for newer articles to accumulate citations. Despite the decrease in citations, the number of articles (N) has significantly increased, with 212 publications in 2024. This indicates a growing research interest, although citation metrics for newer publications will likely rise over time.

2.4.3 Most Relevant Sources

The study analysed 765 publications on NbS for climate resilience from 2010 to 2024, highlighting a substantial annual growth rate of 46.61%. The document average age of 3.26 years indicates a rapidly evolving research landscape. With an average of 21.99 citations per document, the field has demonstrated significant academic impact. Collaboration trends show that 3214 authors contributed to the publications, with an average of 4.87 co-authors per document, while international co-authorships accounted for 18.56% of the total publications. Publication patterns reveal a dominance of journal articles, with 528 articles forming the majority, followed by 92 reviews, 69 book chapters, and 52 conference papers. Recent years witnessed a steep rise in publications, particularly from 2021 to 2024, where the number of articles surged from 88 in 2021 to 212 in 2024. This trend highlights the growing importance in the field of NbS for climate resilience.

The citation analysis shows that while earlier publications achieved higher citation rates, recent years have lower mean citations per article due to limited time for citation accumulation. The highest mean citations per article (142.44 citations) were observed in 2016, with a mean of 14.24 citations per year. However, the rapid increase in recent publications suggests a strong momentum in knowledge generation that is expected to influence future studies.

Prominent journals in the field include *Sustainability*, with 38 articles, followed by *Science of the Total Environment* (26 articles), and *Nature-Based Solutions* (18 articles). These journals serve as key platforms for publishing research in this field, focusing on sustainable and nature-based approaches. Additionally, multidisciplinary outlets such as *Environmental Science & Policy* and *Frontiers in Environmental Science* contribute significantly to the literature, reflecting the cross-disciplinary nature of disaster management research.

2.4.4 Core Sources by Bradford's Law

Bradford's Law, introduced by 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 (Bradford, 1934).

The application of Bradford's Law helps identify the core sources in the field of NbS for climate resilience. According to this law, journals are divided into three zones: a core zone containing the highest number of relevant articles, followed by two additional zones that include journals with progressively fewer relevant articles. This helps researchers focus on the most influential and frequently used sources in the field. In this analysis, the shaded region represents the core sources that contribute the most to the literature. Journals like *Sustainability, Science of the Total Environment*, and *Nature-Based Solutions* are prominent in this zone, indicating their significant role in disseminating research on NbS (Fig. 3). As the number of articles per journal declines beyond the core, the sources become more specialized or peripheral.

The application of Bradford's Law highlights the concentration of knowledge in a small number of journals, making these core sources essential for researchers seeking comprehensive insights into the field. This analysis can guide future research efforts by identifying key journals for literature review and publication

2.4.5 Sources' Production over Time

This study displays the cumulative occurrences of articles published by key sources over time, reflecting their contribution to this field. It shows a significant surge in publications since 2021, establishing itself as the leading source. *Science of the Total Environment* also exhibits a steady increase, particularly from 2020 onward, indicating its role in multidisciplinary environmental research.

The journal *Nature-Based Solutions* has gained notable momentum, particularly in recent years, reflecting the growing emphasis on nature-driven approaches to disaster resilience. *Environmental Science & Policy* and *Landscape and Urban Planning* demonstrate consistent contributions, suggesting their relevance in policy-making and urban resilience research. This upward trend across multiple journals highlights the expanding academic interest in NbS, with a focus on integrating NbS and sustainable practices into disaster management frameworks. The cumulative growth also signifies a broadening research landscape with cross-disciplinary collaboration.

2.4.6 Most Relevant Authors

The most relevant authors contributing to research on NbS for climate resilience. Frantzeskaki N leads with ten articles, indicating a significant influence in the field, particularly in areas related to urban resilience and NbS. Pauleit S follows with seven articles, reflecting expertise in sustainable urban planning and green infrastructure.

Authors like Mabon L, Van B P, and Wamsler C, each with six articles, have made notable contributions, often focusing on climate adaptation and community resilience. Similarly, researchers such as Anguelovski I, Boogaard F, Geneletti D, Moglia M, and Smith P have published five articles each, contributing valuable insights into disaster resilience strategies, policy interventions, and nature-based adaptation.

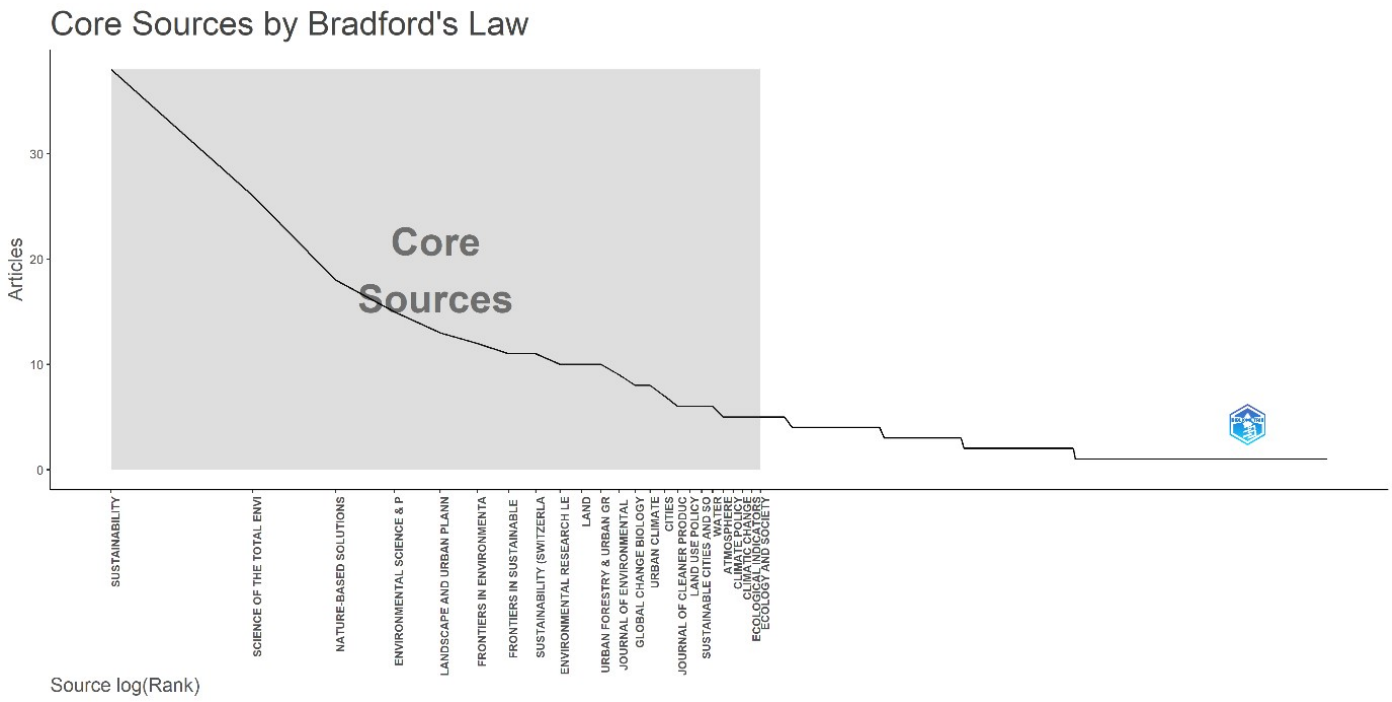

Fig. 3. Core sources by Bradford's Law.

2.4.7 Author Productivity through Lotka's Law

Lotka's Law, proposed by Lotka (1926), describes the distribution of scientific productivity among authors. This means that a small number of researchers contribute a large number of publications, while the majority of authors publish only a few papers. The Author Productivity based on Lotka's Law, which describes the distribution of scientific productivity within a field. According to Lotka's Law, a small number of authors contribute a large number of publications, while the majority of authors contribute only one or two papers. (Fig. 4)

In this analysis, the steep decline in the curve confirms that a significant percentage of authors have written just one document, representing the largest portion of contributors. A smaller group of highly productive authors, as indicated by the tail of the curve, have published multiple papers. The dotted line likely represents the theoretical distribution, while the solid line reflects the actual observed productivity. This pattern is typical in academic publishing, where prolific authors such as Frantzeskaki N and Pauleit S lead the research landscape. The results emphasize the importance of these core contributors in advancing knowledge in NbS for climate resilience while the broader community of single-paper authors contributes diverse perspectives.

2.4.8 Authors' Local Impact

The Total Citations (TC) and h-index of the most influential authors in this field are Frantzeskaki N and Pauleit S lead with an h-index of 7, reflecting their significant contributions and high citation impact. Frantzeskaki N has amassed 2170 citations across 10 publications, while Pauleit S has received 1164 citations from 7 articles, demonstrating substantial influence in the domain. Other notable contributors include Wamsler C with an h-index of 6 and 489 citations from 6 papers, and Anguelovski I and Geneletti D with an h-index of 5 and over 400 and 950 citations, respectively. Mabon L and Smith P also hold strong positions with multiple publications and commendable citation counts.

These authors have played a pivotal role in shaping the discourse on NbS, with a particular focus on climate resilience, sustainable urban planning, and environmental management. Their collective contributions provide a solid foundation for future research in disaster management and related fields.

2.4.9 Most Relevant Affiliations

Institutional contributions are crucial in advancing research and developing innovative solutions. Key institutions drive knowledge production, offering insights into regional expertise, collaboration, and research influence. Their leadership in NbS research is evident in contributions to climate resilience, disaster preparedness, and sustainable solutions, often fostering interdisciplinary collaboration to integrate technology with policy for enhanced disaster management.

The analysis highlights that the Wageningen University and Research leads with 32 articles, demonstrating its substantial focus on sustainable development and climate adaptation. Similarly, prominent institutions like the University of Oxford (23 articles) and Lund University (19 articles) are making noteworthy contributions. Other influential contributors include Griffith University, Stanford University, and the Technical University of Munich, each with 16 publications, reflecting their commitment to advancing scientific understanding and practical applications in disaster management.

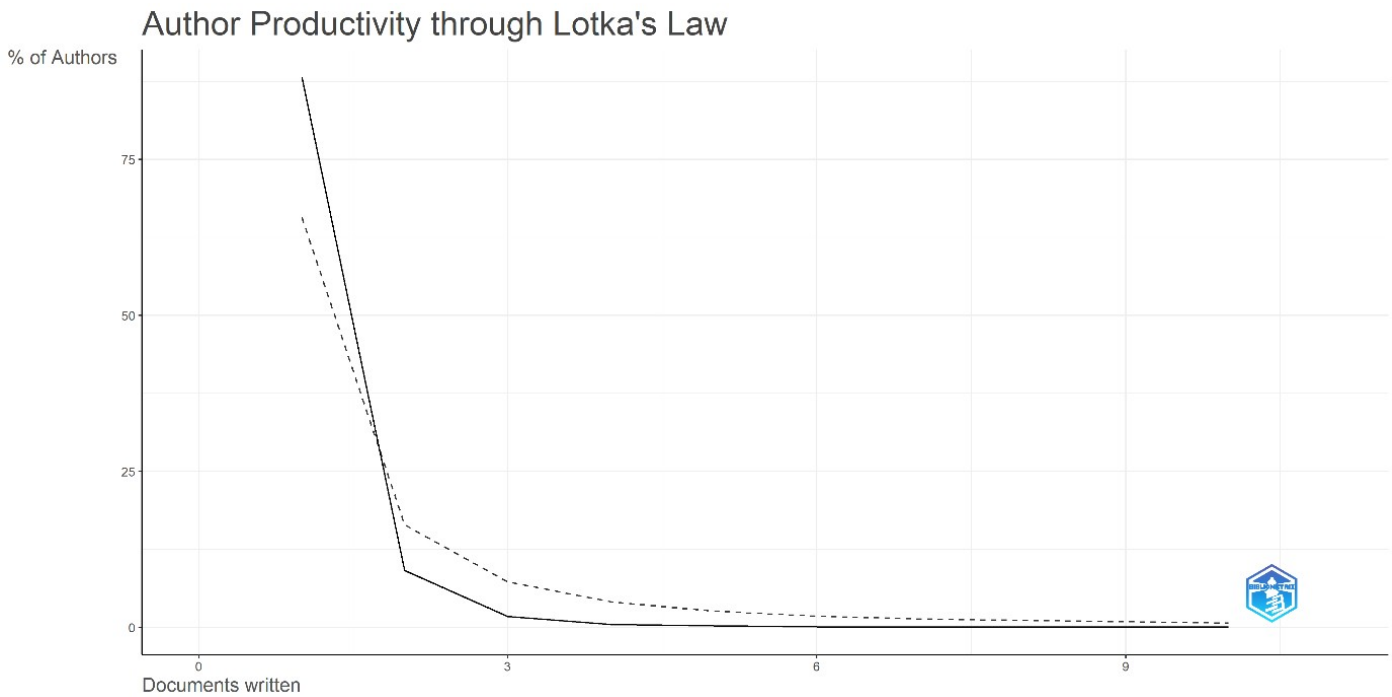

Fig. 4. Author productivity through Lotka's Law.

2.4.10 Corresponding Author's Countries

The distribution of corresponding authors by country provides valuable insights into regional research leadership and collaborative patterns. The USA leads with 13.7% of the total articles, showcasing its dominance in disaster management research. Notably, 83.8% of the articles from the USA are Single Country Publications (SCP), while 16.2% are Multi-Country Publications (MCP), reflecting its balanced approach towards both domestic and international collaborations (Fig. 5).

The United Kingdom and the Netherlands follow with 6.9% and 6.5% of the articles, respectively. Interestingly, both countries exhibit higher levels of international collaboration, with the UK recording 32.1% MCPs and the Netherlands at 28% MCPs, indicating their active participation in global research networks. Germany and China contribute 5.6% and 5.2% of the total articles, respectively. While Germany has an international collaboration rate of 16.3%, China demonstrates a strong focus on domestic research with 87.5% SCPs. Similarly, India shows a preference for domestic publications, with 87.5% SCPs and only 12.5% MCPs. In contrast, Australia and Spain exhibit significant cross-border collaboration, with 32.4% MCPs and 36% MCPs respectively. This highlights their emphasis on international partnerships to enhance disaster management research. Italy also maintains a moderate collaboration rate, with 25% MCPs out of its 4.7% contribution. While Canada accounts for 2.7% of the publications, it stands out for its exceptionally high domestic publication rate, with 95.2% SCPs and minimal international collaboration.

This analysis addresses the diverse research strategies adopted by countries, from robust domestic research to strong international collaborations, contributing to the global discourse on effective NbS for climate resilience.

2.4.11 Countries' Scientific Production

The scientific production in the domain of NbS for climate resilience reflects the significant contributions from various countries. The USA leads with an impressive 314 publications, addressing its strong research capacity and institutional focus NbS**.** Following the USA, the Netherlands and the United Kingdom (UK) demonstrate substantial scientific output with 125 and 116 publications respectively. These countries are known for their active research on sustainable infrastructure and climate resilience, often contributing through international collaborations.

Germany ranks fourth with 108 publications, reflecting its focus on advanced technological applications in disaster risk reduction. Australia closely follows with 100 publications, driven by its proactive research on climate adaptation and ecosystem-based approaches, particularly in response to natural hazards like bushfires and droughts. China and Italy have also made 86 and 72 publications respectively. Spain and Sweden contribute 60 and 52 publications respectively, with emphasis on NbS and collaborative international projects. India, with 44 publications, has shown increasing interest in NbS researches.

While the analysis reveals a clear dominance of Western countries in publishing on NbS, there is a noticeable underrepresentation of research output from regions that are highly vulnerable to climate change, such as Southeast Asia, Sub-Saharan Africa, and parts of Latin America. This imbalance raises important questions about the global inclusivity and equity of NbS research. One possible explanation for this disparity is the presence of several systemic barriers in these regions. These include limited access to research

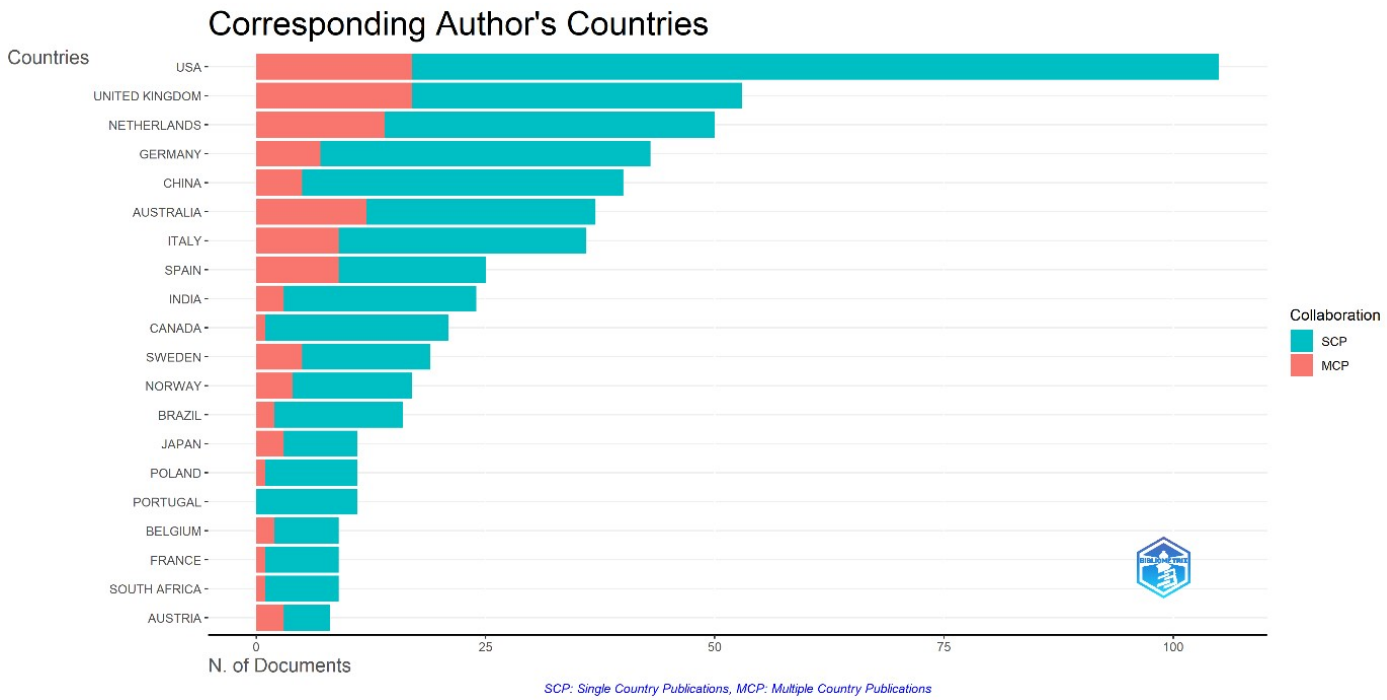

Fig. 5. Corresponding author's countries.

funding, inadequate institutional infrastructure, language barriers, and reduced opportunities for international collaboration and publication in high-impact journals. The prioritization of immediate socio-economic challenges in vulnerable countries may divert attention from long-term climate adaptation research. Addressing these barriers is crucial to ensure that NbS research is informed by diverse ecological, cultural, and socio-political contexts. Encouraging more inclusive funding strategies, capacity-building initiatives, and regional collaborations could enhance the representation of vulnerable regions in the global NbS research landscape.

2.4.12 Most Cited Countries

The most cited countries in the field of NbS for climate resilience reflect the influential role certain nations play in shaping the discourse and advancing knowledge. The United Kingdom (UK) stands out as the most cited country, with 2617 total citations and an average of 49.40 citations per article. This high citation count suggests a strong academic impact, likely driven by the country's leadership in climate resilience research and its emphasis on policy-driven studies (Fig. 6).

The USA follows with 2308 citations at an average of 22.00 citations per article, indicating its extensive research output and contributions to technological advancements in disaster management. While its average citation per article is comparatively lower, its vast number of publications still ensures significant influence. The Netherlands and Germany also demonstrate notable academic impact, with 1539 and 1450 citations, respectively. With average citation rates of 30.80 and 33.70, these countries are recognized for their contributions to sustainable development, urban resilience, and NbS.

Australia has a substantial academic influence, accumulating 1416 citations with an average of 38.30 citations per article, showcasing its focus on disaster adaptation strategies and regional resilience efforts. Meanwhile, Sweden has an exceptional average citation rate of 73.80, reflecting the significant recognition and impact of its research, despite a relatively smaller number of publications compared to other leading countries. Italy and Spain also maintain strong citation metrics with 875 and 711 citations respectively, driven by their expertise in regional disaster management and ecosystem-based adaptation approaches. Brazil and China contribute to the global knowledge pool, with 379 and 365 citations, though China's lower average citation rate (9.10) suggests a more recent entry into the field, with emerging research awaiting broader recognition.

2.4.13 Most Global Cited Documents

The most globally cited documents in the field of NbS demonstrate significant contributions to academic discourse. In *Science of the Total Environment* leads with 821 citations and 91 citations per year, reflecting its considerable impact. In *Ecology and Society* has 780 citations with 78 citations per year, emphasizing its lasting relevance in ecological resilience and urban planning. In *Philosophical Transactions of the Royal Society B* has gained 769 citations with an impressive 128 citations per year, focusing on NbS and climate adaptation. In *Environmental Science & Policy* has 648 citations and 72 citations per year, highlighting the importance of interdisciplinary research in disaster management. The repeated presence of authors like Frantzeskaki N and Derkzen M in the most cited documents underscores their influential role in areas such as landscape

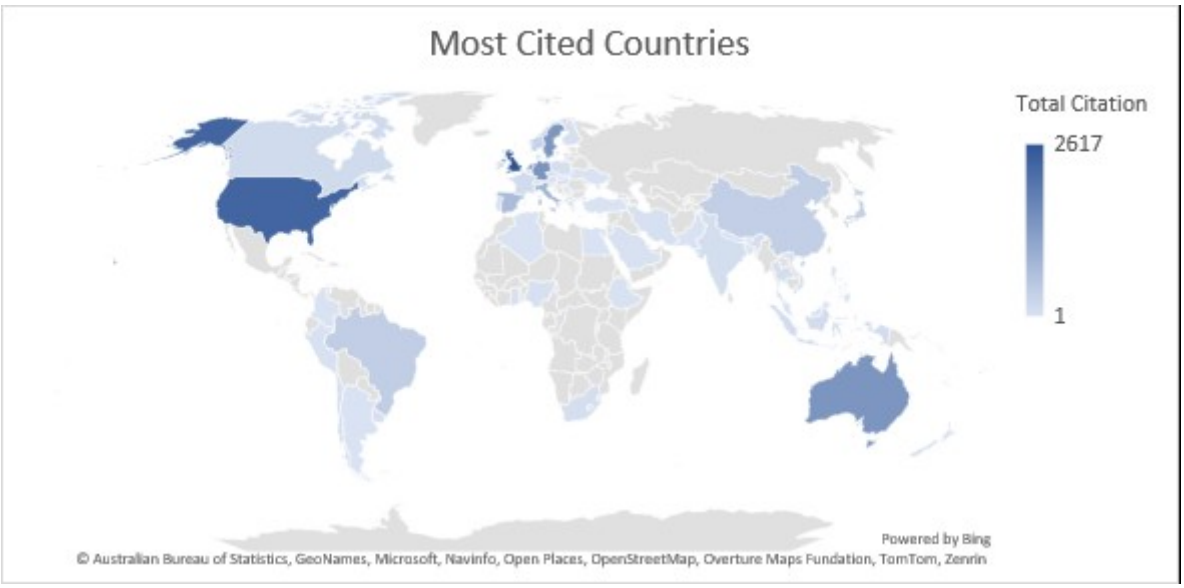

Fig. 6. Most cited countries.

urban planning, biodiversity conservation, and sustainable urban systems.

2.4.14 Most Frequent Words

The most frequent words in the field of NbS reflect key themes and research priorities. "Climate change" is the most common term with 203 occurrences, indicating the central role of climate-related challenges in disaster management research. "Biodiversity" and "Green infrastructure" follow with 81 and 70 occurrences respectively, highlighting the growing emphasis on NbS and ecosystem resilience.

Terms like "Adaptation" (64 occurrences) and "Cities" (63 occurrences) underscore the focus on urban resilience and adaptive strategies in response to climate threats. Additionally, "Ecosystem services" and "Management" appear frequently with 61 and 59 occurrences, reflecting the integration of ecological functions into disaster management frameworks.

The presence of "Ecosystem" (52 occurrences), "Climate-change" (48 occurrences), and "Adaptive management" (41 occurrences) further highlights the importance of ecological approaches, risk mitigation, and flexible management strategies in enhancing disaster resilience. These frequently used words offer insights into the primary research directions and the interdisciplinary nature of NbS studies.

2.4.15 Words' Frequency over Time

The cumulative frequency analysis of key terms over time highlights the growing prominence of "climate change" in NbS research, reflecting its increasing relevance since 2020. Other terms like "biodiversity", "green infrastructure", and "adaptation" also show a notable upward trend, suggesting a rising interest in NbS and resilience strategies. Similarly, "ecosystem services" and "management" exhibit consistent growth, underlining the importance of ecological approaches and governance frameworks in disaster management. The sharp increase in these terms post-2020 indicates a heightened focus on integrating environmental perspectives into this field.

2.4.16 Trending Topics

The trending topics analysis reveals that terms like "climate change," "mitigation," and "adaptation" have gained significant attention in recent years, reflecting a strong focus on addressing environmental challenges. "Green infrastructure," "governance," and "resilience" have also emerged as key topics, indicating the growing emphasis on sustainable urban planning and disaster management. The terms such as "remote sensing" and "carbon sequestration" highlight the increasing use of technological and NbS in research. The consistent presence of terms like "biodiversity" and "ecosystem services" further emphasizes the role of ecological considerations in current studies.

2.4.17 Co-occurrence Network

The co-occurrence network visualizes the interconnectedness of key research topics, with "climate change" emerging as the most central and frequently occurring term. Closely linked themes include "ecosystem services," "green infrastructure," and "adaptation," indicating a strong focus on NbS and sustainability (Fig. 7).

On the one side, terms like "biodiversity," "resilience," and "mitigation" suggest emphasis on ecological protection and policy interventions. On the other side, connections with words like "urban planning," "flood control," and "water management" highlight the role of climate adaptation in urban environments. The network further illustrates how "carbon sequestration" and " Nature-Based Solutions" are gaining prominence in addressing environmental challenges.

2.4.18 Thematic Map

The thematic map provides a visual representation of research themes based on their development degree

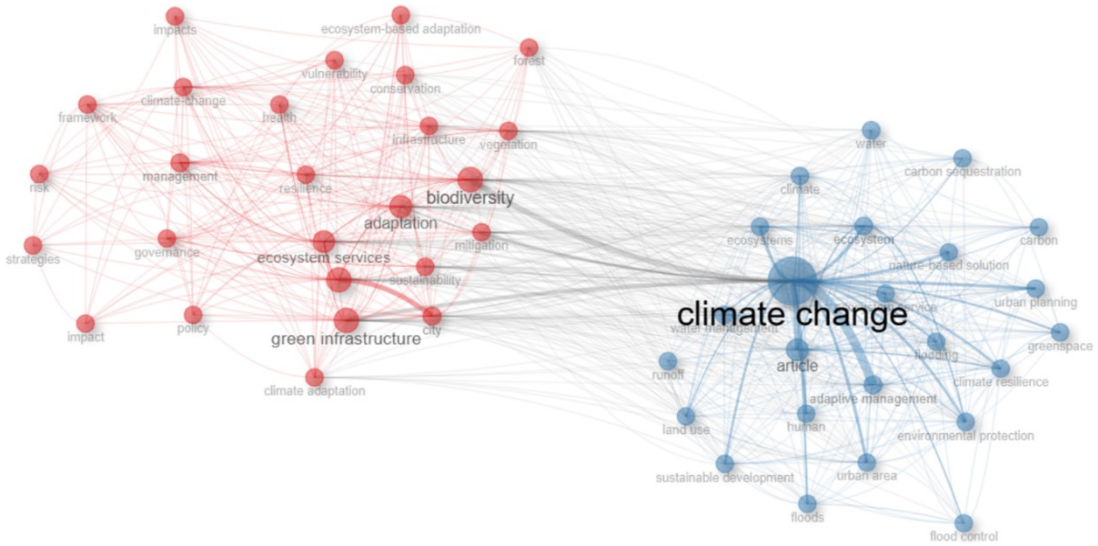

Fig. 7. Co-occurrence network.

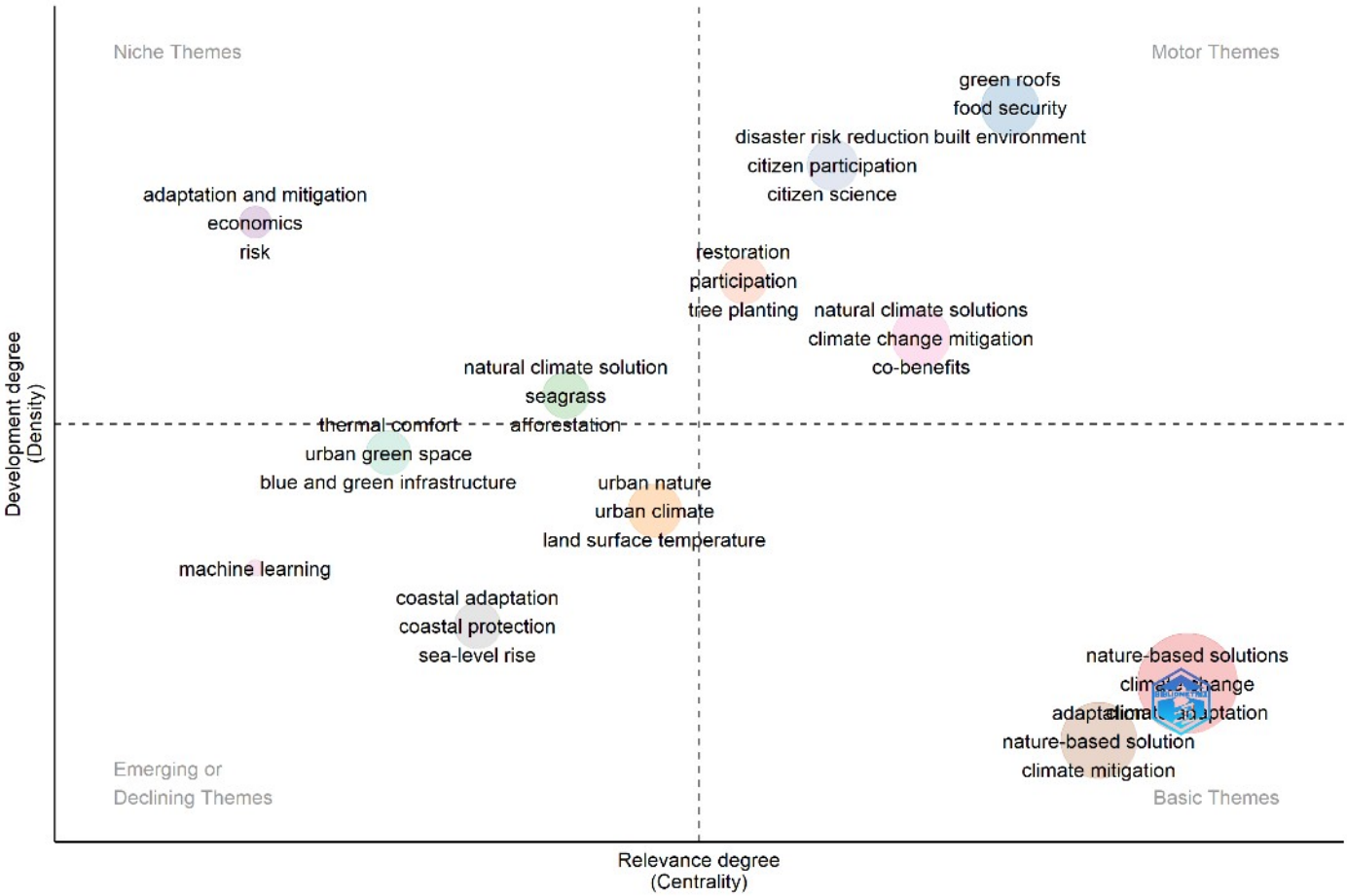

Fig. 8. Thematic Map.

(density) and relevance degree (centrality) (Fig. 8). The Basic Themes quadrant contains fundamental topics such as "Nature-Based Solutions," "climate adaptation," and "climate mitigation," which have high relevance but moderate development. The Motor Themes quadrant, indicating well-developed and significant areas, features topics like "green roofs," "food security," and "built environment," highlighting practical applications and sustainability initiatives. In the Niche Themes quadrant, topics like "adaptation and mitigation," "economics," and "risk" are specialized and highly developed but have limited cross-disciplinary connections. On the other hand, "machine learning" and "coastal

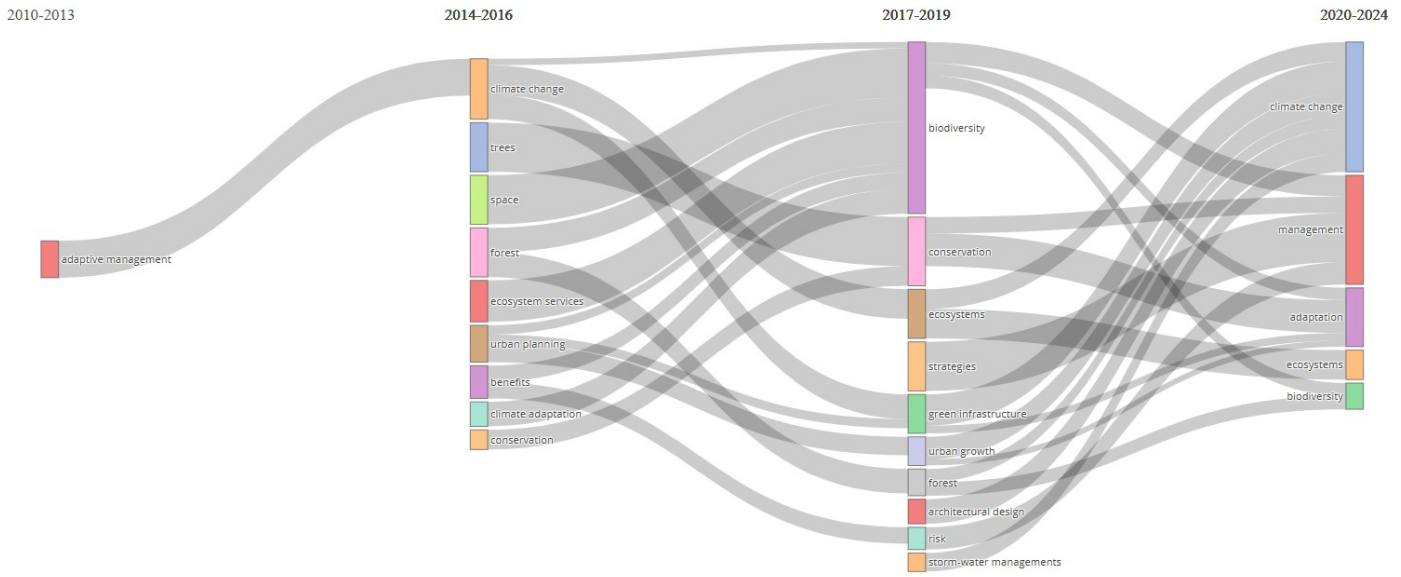

Fig. 9. Thematic evolution.

adaptation" in the Emerging or Declining Themes quadrant suggest growing areas of interest or fields requiring further research. Additionally, themes like "citizen participation," "disaster risk reduction," and "restoration" show increasing importance in collaborative environmental efforts.

2.4.19 Thematic Evolution

This chart shows how research themes have developed and transitioned over time from 2010 to 2024. Initially, the field was dominated by the concept of adaptive management (Fig. 9). During the 2014–2016 period, key themes like climate change, ecosystem services, urban planning, and conservation emerged, reflecting growing interest in environmental management and urban sustainability.

In the 2017–2019 phase, the focus expanded further to include biodiversity, green infrastructure, urban growth, and storm-water management, suggesting an increasing emphasis on NbS and urban resilience. From 2020 to 2024, the themes became more specialized and interconnected. Climate change remained a dominant topic, while management, adaptation, ecosystems, and biodiversity gained prominence. This evolution indicates a more comprehensive and applied approach to addressing climate challenges, emphasizing both ecological conservation and urban management strategies.

2.4.20 Factorial Analysis

The factorial analysis map presents a conceptual structure of research themes using Multiple Correspondence Analysis (MCA) (Fig. 10). The horizontal axis (Dim 1) represents the primary dimension explaining most of the variance in the data, while the vertical axis (Dim 2) captures additional variation. On the left side, themes like NbS, environmental protection, and carbon sequestration are positioned, indicating a focus on ecological management and sustainability. The top region is dominated by terms like floods, flood control, and adaptive management, reflecting concerns about disaster management and urban resilience. Towards the right, themes like climate adaptation, green infrastructure, and resilience are prominent, highlighting adaptive strategies and urban planning efforts. The bottom section contains concepts like health, cities, and framework, representing urban-focused studies and governance frameworks. This map provides an overview of how different concepts are interconnected and which themes are most relevant in the research landscape.

2.4.21 Collaboration Network of Countries

The collaboration network visualizes the research partnerships between countries, with the size of the nodes representing the volume of research output and the thickness of the connecting lines indicating the strength of collaboration (Fig. 11). The USA and the United Kingdom are the most prominent nodes, reflecting their leading roles in international research collaboration. European countries like Germany, the Netherlands, and France form a tightly connected cluster, demonstrating strong regional partnerships. In contrast, countries like China, India, and Brazil are more loosely connected, engaging in fewer but significant collaborations, particularly with the USA. The red and blue colour scheme further distinguishes the regional collaboration patterns, with the USA dominating the red cluster, while the United Kingdom leads the blue cluster. This network highlights the prominence of Western countries in global research and the growing participation of emerging economies.

3 Conclusion

This bibliometric analysis of NbS for climate resilience from 2010 to 2024 highlights the rapid expansion of research in this field. The study examined 765 publications indexed in Scopus and Web of Science, revealing a 46.61% annual growth rate, reflecting the increasing global interest in NbS as a sustainable approach to climate adaptation.

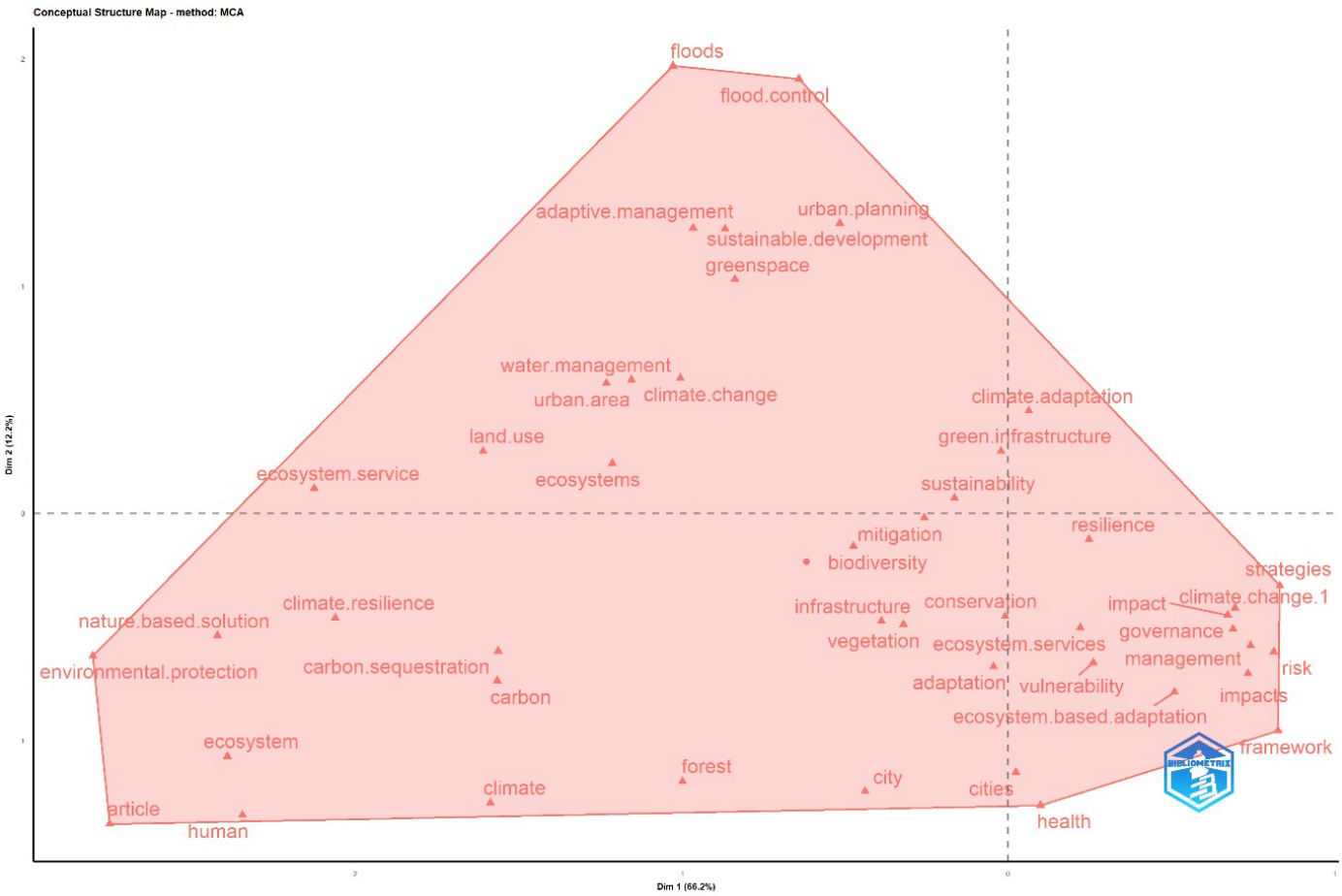

Fig. 10. Factorial analysis.

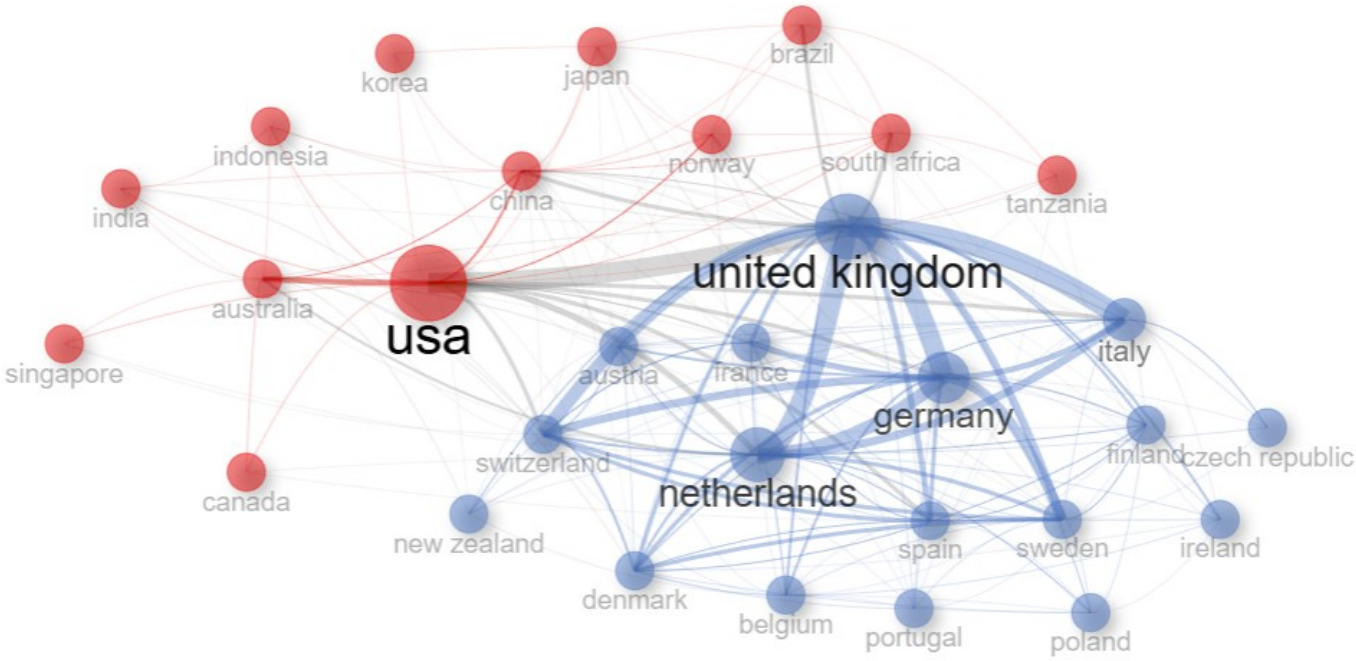

Fig. 11. Collaboration network of countries.

With an average citation impact of 21.99 citations per document, the findings underscore the growing academic influence of NbS research. The analysis identifies 385 publication sources, with key contributors from leading institu-

tions and universities across the world. Collaborative research is prominent, with 3,214 authors contributing to the field at a co-authorship rate of 4.87 authors per document, although single-author publications remain relatively low (only 65 documents). International collaboration accounts for 18.56% of the total publications, indicating moderate but expanding global partnerships in NbS research. The thematic analysis reveals that NbS research is increasingly focused on disaster risk reduction, ecosystem-based adaptation, sustainable urban planning, and biodiversity conservation. The study also highlights the growing integration of NbS into climate policy, environmental governance, and green infrastructure development.

Despite the promising growth, challenges remain in bridging the gap between research and real-world implementation, enhancing interdisciplinary collaboration, and aligning policy frameworks with scientific advancements. Strengthening these areas will be crucial for scaling up NbS initiatives effectively. This study provides valuable insights that can guide future research, policy formulation, and practical applications of NbS. By fostering global collaboration and aligning research with real-world challenges, NbS can be effectively used to enhance climate resilience, environmental sustainability, and societal well-being in the face of ongoing climate change.

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