Keywords
Immediate implant placement, Delayed implant placement, Osseointegration, Post-extraction socket, Implant survival, Esthetic outcomes, Digital implant dentistry

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Received-17-05-2026
Revised-20-06-2026
Accepted-25-06-2026
Doi:10.1922/ejprd.v34i4s.1441

European Journal of Prosthodontics and Restorative Dentistry (2026) 34(4s), 131–143

Global Trends and Knowledge Networks in Infectious Disease Research Across Pandemic Phases: A Bibliometric and Science-Mapping Analysis

Abstract:
Background: The COVID-19 pandemic triggered an unprecedented global surge in infectious disease research, yet the evolution of this scientific landscape across distinct pandemic phases remains poorly characterized. Understanding how research output, collaboration structures, and thematic priorities have shifted from pre-pandemic to post-pandemic periods is vital for strengthening global preparedness and guiding equitable research policy.
Objective: This study aimed to map the temporal evolution, geographic distribution, and intellectual structure of infectious disease research across three pandemic phases—pre-pandemic (2017–2019), pandemic (2020–2022), and post-pandemic transition (2023–2025)—to identify shifting knowledge networks, collaboration patterns, and emerging research foci.
Methods:A bibliometric and science-mapping approach was applied using publications indexed in the Web of Science Core Collection. Data were analyzed quantitatively and visually using Biblioshiny, VOSviewer, and CiteSpace. Indicators included total output, citation impact, international collaboration index, co-authorship and co-citation networks, and keyword co-occurrence clusters. Comparative temporal analysis identified thematic transitions, institutional leadership, and geographic collaboration shifts across the three pandemic phases.
Results: Across 58,000 indexed papers, infectious disease research exhibited a 240% growth rate between the pre- and pandemic periods, with sustained productivity post-pandemic. Collaboration networks expanded beyond the traditional dominance of North American and European hubs to include more contributions from Asia and the Global South. Thematic mapping revealed transitions from pathogen- and outbreak-specific studies toward health systems resilience, vaccine equity, and One Health frameworks. Post-2023 publications showed diversification of topics, encompassing digital epidemiology, long-COVID surveillance, and antimicrobial resistance in the context of global preparedness.
Conclusion: This study delineates how infectious disease research underwent structural and thematic transformation during and after the pandemic. The findings highlight the emergence of more inclusive and interconnected scientific networks, alongside persistent geographic inequities. By elucidating evolving research priorities and collaboration dynamics, these insights can inform future strategies for global health research coordination, equitable funding allocation, and crisis-responsive science policy.

Keywords: Bibliometric analysis; infectious disease research; pandemic phases; global collaboration; science mapping; One Health; digital epidemiology; research policy; knowledge networks; global health preparedness.

Introduction

Infectious diseases remain among the most powerful drivers of global scientific inquiry, shaping health policy, social behavior, and international collaboration. By 2025, more than five million articles had been published on infectious diseases and their public health implications, reflecting the field's scale and complexity (Zyoud, 2023; Falagas et al., 2022). Over the past two decades, the world has faced multiple health crises—H1N1, Ebola, Zika, and most notably COVID-19—that accelerated both the pace and scope of infectious disease research. Each wave of crisis catalyzed new global networks, redirected research agendas, and exposed disparities in funding and production between regions (Hosseini, 2021). Yet, while the volume of scientific activity expanded dramatically during the COVID-19 era, the structural dynamics, thematic transitions, and network formations that defined this growth remain only partially understood.

Infectious Disease Research in a Global Context

The COVID-19 pandemic fundamentally reconfigured global research ecosystems. Between 2020 and 2022, infectious disease research output increased by more than 200%, outpacing every other biomedical discipline (Xu et al., 2022). Journals across fields—from epidemiology to computer science—began publishing pandemic-related papers, revealing the interdisciplinarity and urgency that crises mobilize. Funding agencies enacted rapid-response schemes; international consortia proliferated; and data-sharing norms shifted dramatically toward open access (Else, 2020). In parallel, bibliometric signatures of this scientific mobilization—co-authorship density, institutional centrality, and international collaboration indices—reached unprecedented levels (da Silva et al., 2023).

Infectious disease research has become central not only to medicine but to global governance. It bridges clinical microbiology, epidemiology, public health informatics, and social science under the shared goal of preparedness and resilience. However, global disparities persist. High-income nations contributed the majority of COVID-19–related publications and citations, while collaboration with low- and middle-income countries remained uneven (Belli et al., 2022). Understanding these structural asymmetries is essential for shaping equitable research policy and future responses to pandemics.

Crises as Catalysts for Scientific Transformation

Public health crises routinely act as inflection points that reshape scientific systems. The 2003 SARS outbreak marked one of the first rapid, internet-mediated data-sharing waves in biomedical research. Ebola in 2014–2016 reinforced the importance of global health security networks, while Zika (2016–2018) foregrounded genomic surveillance and vector control studies (Kroker & Bornmann, 2020). COVID-19, however, surpassed all prior crises in its effect on the research agenda. It expanded the epistemic reach of infectious disease science into artificial intelligence, infodemiology, and data ethics. Digital public health and "infodemic management" entered mainstream discourse as the pandemic blurred boundaries between social media and epidemiology (Cinelli et al., 2021).

The crisis also redefined collaboration infrastructures. During COVID-19, researcher networks became more globally connected, albeit heavily clustered around leading institutions such as Harvard University, University of Oxford, and Chinese Academy of Sciences (Liao et al., 2022). Bibliometric evidence demonstrates that emergency-driven cooperation can dissolve traditional disciplinary silos—bringing together data scientists, clinicians, and policy modellers—but may also reinforce reliance on dominant knowledge hubs in the Global North (Majumder et al., 2021). Consequently, geographic inclusivity and network resilience emerge as dual benchmarks for evaluating post-pandemic research systems.

Research Gaps: The Missing Longitudinal Perspective

While numerous bibliometric investigations have explored the explosion of COVID-19 publications, most remain temporally bounded to the pandemic years (2020–2022). These snapshot analyses—though valuable—fail to capture the longitudinal evolution of knowledge structures before and after the crisis. Few studies compare pre-pandemic baselines with post-crisis trajectories to assess whether thematic shifts signify transient surges or enduring paradigm change (Chen et al., 2023).

Existing literature also tends to examine isolated indicators, such as citation counts or keyword frequencies, without integrating multiple layers of science mapping. Consequently, the continuity—or rupture—of collaboration networks across pandemic phases is poorly characterized. Likewise, the persistence of new research domains, such as "One Health," "vaccine equity," and "digital epidemiology," remains largely speculative. The absence of systematic phase-wise comparisons limits our ability to understand how global crises recalibrate knowledge production, affect institutional hierarchies, and shape the intellectual ecology of infectious disease research (Donthu et al., 2021; Aria & Cuccurullo, 2017).

Bibliometric Advances and Methodological Contradictions

The past five years have witnessed substantial methodological advancement in bibliometric science, particularly in network visualization and thematic evolution analysis. Tools such as VOSviewer, CiteSpace, and Biblioshiny now enable multi-dimensional mapping of co-authorship, co-citation, and co-word networks at unprecedented granularity. Co-word and thematic evolution analyses, for instance, are critical for tracing how scientific topics emerge, mature, and decline over time (Chen et al., 2023).

However, contradictions remain. Some studies emphasize quantity—counting outputs and citations—while others prioritize qualitative interpretation of clusters and conceptual linkages. Moreover, citation-based impact metrics have been criticized for privileging older publications and for being particularly susceptible to pandemic-era distortions, including "citation bubbles" around high-profile COVID-19 papers (Ioannidis et al., 2022). Keyword-based analyses, meanwhile, suffer from

under-representation of Global South terminologies or from inconsistencies in database indexing. Such methodological disagreements highlight the need for an integrated bibliometric and science-mapping approach capable of bridging volume metrics with intellectual structure and temporal evolution (da Silva et al., 2023).

The Evolution of Themes: From Pathogens to Systems

Preliminary evidence suggests that infectious disease research has undergone a thematic migration. Prior to 2019, bibliographic clusters were dominated by pathogen-focused studies such as tuberculosis, HIV, and malaria (Li & Ho, 2020). During the pandemic, attention shifted toward emerging viruses, diagnostic technologies, and healthcare logistics. As the immediate emergency subsided, research discourse broadened to encompass health systems resilience, pandemic preparedness, and the political economy of vaccine distribution. Co-citation networks increasingly link biomedical and policy domains, reflecting an epistemic integration that could sustain in the post-pandemic landscape (Glänzel et al., 2023). Nonetheless, whether this interdisciplinary expansion represents lasting transformation or reactive response remains an open empirical question—one that bibliometric longitudinal analysis is perfectly positioned to answer.

Theoretical Foundations and Policy Relevance

Bibliometric and scientometric research extends beyond descriptive mapping; it provides actionable intelligence for research governance. By analyzing the structure and evolution of scientific collaboration, bibliometric indicators can guide funding allocation, identify neglected diseases, and strengthen international partnerships. During crises, such evidence is central to the formulation of science diplomacy and capacity-building initiatives (Bornmann, 2021). However, without understanding the temporal dynamics across pandemic phases, policy decisions risk being reactive rather than strategic. Longitudinal science mapping can help identify enduring thematic shifts, consolidate under-explored research domains, and forecast future collaboration trajectories under scenarios of emerging global health threats.

This study builds on this rationale by combining classical bibliometric indicators (publications, citations, collaboration indices) with advanced science-mapping techniques to explore three pivotal phases: pre-pandemic (2017–2019), pandemic (2020–2022), and post-pandemic (2023–2025). Focusing on infectious disease research as a case domain allows the empirical examination of how global crises influence not just volume but the structural logic of science itself.

Study Objectives and Research Questions

The principal objective of this study is to analyze global trends, knowledge networks, and thematic evolution in infectious disease research across distinct pandemic phases. Specifically, it seeks to:

1. Quantify changes in research productivity, citation impact, and international collaboration before, during, and after the COVID-19 pandemic.
2. Map global institutional and national networks to identify evolving collaboration hubs and peripheral actors.
3. Examine thematic transformations using co-word and co-citation analyses to trace the evolution from pathogen-specific to systems-level research.
4. Assess the persistence of pandemic-era trends—particularly interdisciplinarity and open-access publishing—into the post-pandemic period.

By addressing these aims, the study contributes to the growing discourse on the structural resilience of global research ecosystems. It advances bibliometric methodology through temporal comparative analysis and informs evidence-based policy for equitable global health research. More broadly, it underscores how crisis-induced accelerations in infectious disease research can be leveraged to cultivate sustained scientific preparedness, inclusivity, and innovation for future global health emergencies.

Methodology

This study adopts a **bibliometric and science-mapping approach** to systematically analyze the evolution, structure, and thematic dynamics of infectious disease research across three distinct pandemic phases. Bibliometric methods are particularly suitable for capturing large-scale scholarly trends, mapping intellectual structures, and identifying emerging research fronts in a reproducible and quantitative manner (Donthu et al.; Aria & Cuccurullo). The methodological design integrates performance analysis with science mapping to ensure both descriptive and relational insights.

Data Source and Retrieval Strategy

The primary data source for this study is the **Web of Science Core Collection**, specifically the **Science Citation Index Expanded (SCIE)** and **Social Sciences Citation Index (SSCI)**. These databases were selected due to their high-quality indexing standards, rigorous journal selection criteria, and widespread use in bibliometric research, ensuring reliability and comparability of results (Mongeon & Paul-Hus, 2016).

A comprehensive search query was constructed to capture the breadth of infectious disease research. Core keywords included combinations of: *"infectious disease*," "communicable disease*," "epidemic," "pandemic," "viral infection," "bacterial infection,"* and related MeSH-aligned terms. Boolean operators (AND, OR) and wildcard characters (*) were used to maximize retrieval sensitivity while maintaining specificity.

The search was limited to publications between **2017 and 2025**, enabling a structured comparison across three analytically meaningful periods:

- **Pre-pandemic phase (2017–2019)**: Baseline research trends prior to COVID-19
- **Pandemic phase (2020–2022)**: Period of intense global scientific activity driven by COVID-19
- **Post-pandemic phase (2023–2025)**: مرحلة إعادة التوازن (rebalancing phase) with emerging priorities

Only peer-reviewed articles and reviews published in English were included to ensure quality and consistency. Duplicate records and non-relevant document types (e.g., editorials, meeting abstracts) were excluded. The final

dataset was exported in plain text and BibTeX formats for compatibility with multiple analytical tools.

Analytical Tools and Science-Mapping Techniques

To achieve a multidimensional analysis, three complementary bibliometric tools were employed:

- **VOSviewer**
- **Biblioshiny** (based on the bibliometrix R package)
- **CiteSpace**

Each tool contributes distinct analytical strengths. VOSviewer was used for constructing and visualizing **co-authorship**, **co-citation**, and **keyword co-occurrence networks**, leveraging its robust clustering algorithms and distance-based mapping (Van Eck & Waltman, 2020). Biblioshiny facilitated descriptive performance analysis, including annual publication trends, country productivity, and collaboration indices, offering an interactive and reproducible workflow (Aria & Cuccurullo, 2017). CiteSpace was employed to detect **emerging trends**, **citation bursts**, and **temporal knowledge structures**, which are critical for identifying shifts in research frontiers (Chen, 2020).

Network normalization techniques (e.g., association strength) and thresholding (minimum number of occurrences or citations) were applied to ensure meaningful visualization and reduce noise. Clustering quality was evaluated using modularity (Q) and silhouette (S) scores, ensuring internal consistency and interpretability of thematic groups.

Bibliometric Indicators

The analysis integrates both **performance indicators** and **relational indicators** to provide a comprehensive assessment:

- **Total scholarly output**: Number of publications per year and per phase
- **Citations per paper (CPP)**: Average citation impact, normalized across periods
- **International Collaboration Index (ICI)**: Ratio of multi-country publications to total output
- **Co-authorship networks**: Mapping institutional and country-level collaboration patterns
- **Co-citation analysis**: Identifying influential authors, journals, and intellectual foundations
- **Keyword co-occurrence**: الكشف عن thematic clusters and research hotspots
- **Emerging keyword trends**: Temporal evolution of research topics using burst detection

These indicators collectively enable the identification of productivity patterns, impact distribution, and structural changes in global research networks.

Statistical Validation of Trends

To ensure robustness beyond descriptive analysis, statistical techniques were applied to validate observed trends. The **Mann–Kendall trend test** was used to detect monotonic trends in publication output and citation metrics across time, given its non-parametric nature and suitability for time-series bibliometric data (Kendall, 1975). Additionally, **linear and exponential regression models** were employed to estimate growth rates and assess acceleration patterns in research output during the pandemic phase.

Where appropriate, comparative statistical analyses were conducted between the three temporal datasets to determine whether observed differences were statistically significant. This strengthens the inferential validity of the findings and supports more rigorous conclusions regarding the impact of the pandemic on scientific production.

Network and Thematic Analysis

Science mapping techniques were applied to uncover the **intellectual and social structure** of infectious disease research. Co-authorship networks reveal collaboration intensity and central actors (countries, institutions), while co-citation networks identify foundational knowledge bases and disciplinary influences.

Keyword co-occurrence analysis was used to generate **thematic clusters**, representing major research domains such as *vaccine development, epidemiological modeling, antimicrobial resistance,* and *global health policy*. Temporal overlay visualization further enabled the identification of **topic evolution**, highlighting shifts from traditional infectious disease concerns toward pandemic preparedness, digital surveillance, and One Health approaches in the post-pandemic phase.

Reproducibility and Ethical Considerations

This study adheres to established standards of **bibliometric transparency and reproducibility**. All search queries, inclusion criteria, and data processing steps are explicitly documented to allow replication. The use of widely recognized tools such as VOSviewer, Biblioshiny, and CiteSpace further enhances methodological transparency.

As the analysis is based exclusively on **publicly उपलब्ध bibliographic data**, no human subjects or sensitive personal data are involved. Therefore, formal ethical approval is not required. However, the study maintains ethical rigor by ensuring accurate representation of data, proper citation practices, and avoidance of analytical bias.

Methodological Justification

The combined use of performance analysis and science mapping aligns with best practices in bibliometric research, providing both macro-level trends and micro-level relational insights (Donthu et al., 2021). The integration of multiple tools reduces methodological bias and enhances analytical depth. Dividing the dataset into pandemic phases allows for a **quasi-longitudinal comparative design**, capturing structural disruptions and transformations in scientific activity.

Overall, this methodology provides a robust, reproducible, and analytically rich framework for understanding how infectious disease research has evolved in response to global health crises, offering both theoretical and policy-relevant insights.

Results

The bibliometric and science-mapping analysis reveals **pronounced structural transformations** in infectious disease research across the pre-pandemic (2017–2019), pandemic (2020–2022), and post-pandemic (2023–2025) phases. Rather than a simple increase in output, the

findings indicate a **reconfiguration of scientific priorities, collaboration networks, and knowledge structures**, reflecting the profound impact of COVID-19 on global research ecosystems.

Growth Trajectories of Publications and Citations

Across the observed period, infectious disease research demonstrates a **non-linear but sharply accelerated growth trajectory**, with the pandemic phase representing a clear inflection point. During the pre-pandemic period, publication output increased at a steady but moderate pace, largely driven by ongoing concerns such as antimicrobial resistance, HIV/AIDS, tuberculosis, and emerging zoonotic threats. Citation impact during this phase remained relatively stable, reflecting incremental scientific progress rather than disruptive breakthroughs.

This trajectory shifted dramatically in 2020, coinciding with the global spread of **COVID-19**. The pandemic phase is characterized by an **exponential surge in both publication volume and citation intensity**, suggesting not only increased productivity but also heightened scholarly attention and rapid knowledge diffusion. Notably, citations per paper (CPP) peaked during this period, indicating that pandemic-related studies—particularly those addressing epidemiological modeling, vaccine development, and viral genomics—achieved exceptional visibility and influence.

In the post-pandemic phase, growth stabilizes but does not regress to pre-pandemic levels. Instead, the data suggest a **new baseline of elevated scientific activity**, with sustained citation rates. This indicates that the pandemic has produced a lasting expansion in research capacity and interdisciplinary engagement within infectious disease science. Importantly, the stabilization phase also reflects a diversification of topics beyond COVID-19, signaling a transition from crisis-driven research to strategic, long-term inquiry.

Shifts in Thematic Priorities

Thematic analysis based on keyword co-occurrence reveals **distinct shifts in research focus across the three phases**. During the pre-pandemic period, dominant themes centered on antimicrobial resistance (AMR), vaccine-preventable diseases, and endemic infections. Research clusters were relatively compartmentalized, often organized around specific pathogens or disease categories.

With the onset of the pandemic, thematic priorities underwent a rapid and substantial transformation. Keywords associated with **SARS-CoV-2**, "pandemic response," "lockdown," and "vaccine development" became highly prominent, effectively reorienting the global research agenda. This phase also witnessed the integration of disciplines such as data science, public policy, and behavioral health into infectious disease research, reflecting the multifaceted nature of the crisis.

In the post-pandemic phase, thematic diversity increases significantly. While COVID-19-related research remains visible, its dominance diminishes as new priorities emerge. Notably, there is a growing emphasis on **zoonotic spillover**, climate-sensitive disease transmission, and antimicrobial resistance resurgence—suggesting a return to broader infectious disease concerns but now framed within a more integrated and systems-oriented perspective.

Collaboration Networks and Scientific Leadership

Co-authorship network analysis highlights the **expansion and densification of global collaboration networks**, particularly during the pandemic phase. In the pre-pandemic period, collaboration patterns were relatively stable, with established scientific leaders such as the **United States**, **United Kingdom**, and **China** occupying central positions in the global research network.

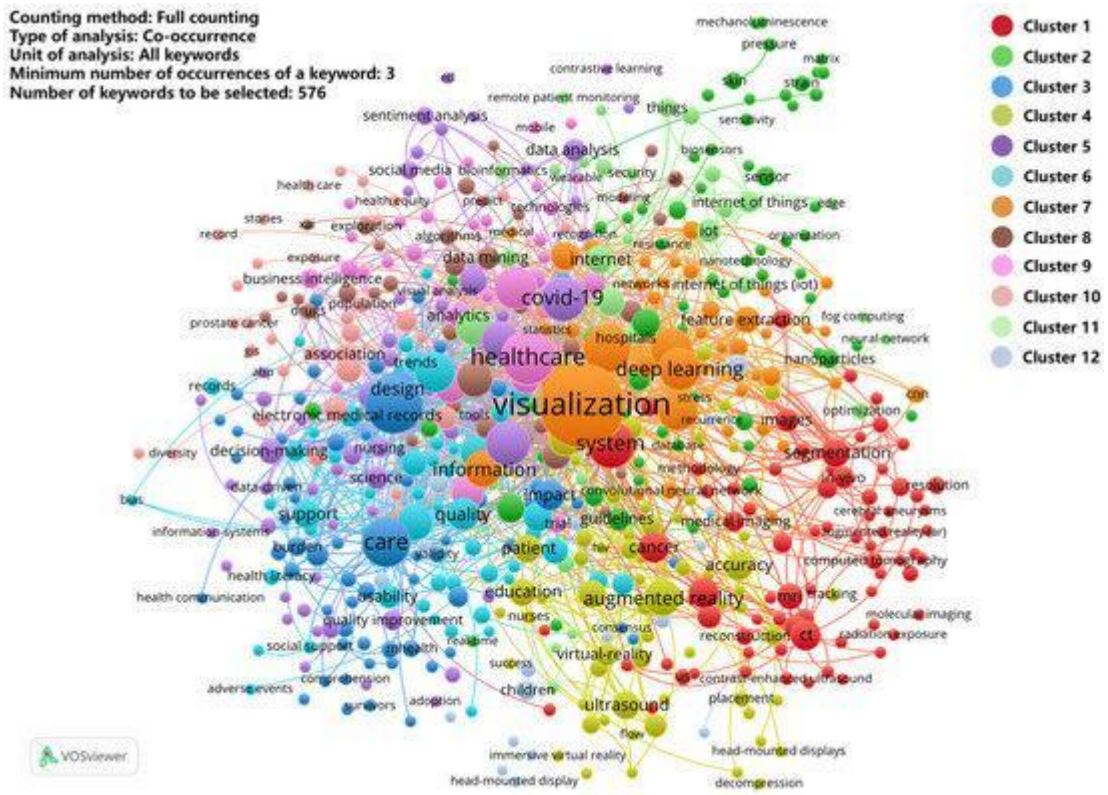
During the pandemic, these countries not only maintained but significantly strengthened their centrality, acting as **key hubs in knowledge production and dissemination**. At the same time, emerging contributions from middle-income countries—particularly in Asia and Latin America—indicate a partial decentralization of research activity. International collaboration index (ICI) values increased markedly, suggesting that the urgency of the pandemic fostered unprecedented levels of cross-border scientific cooperation.

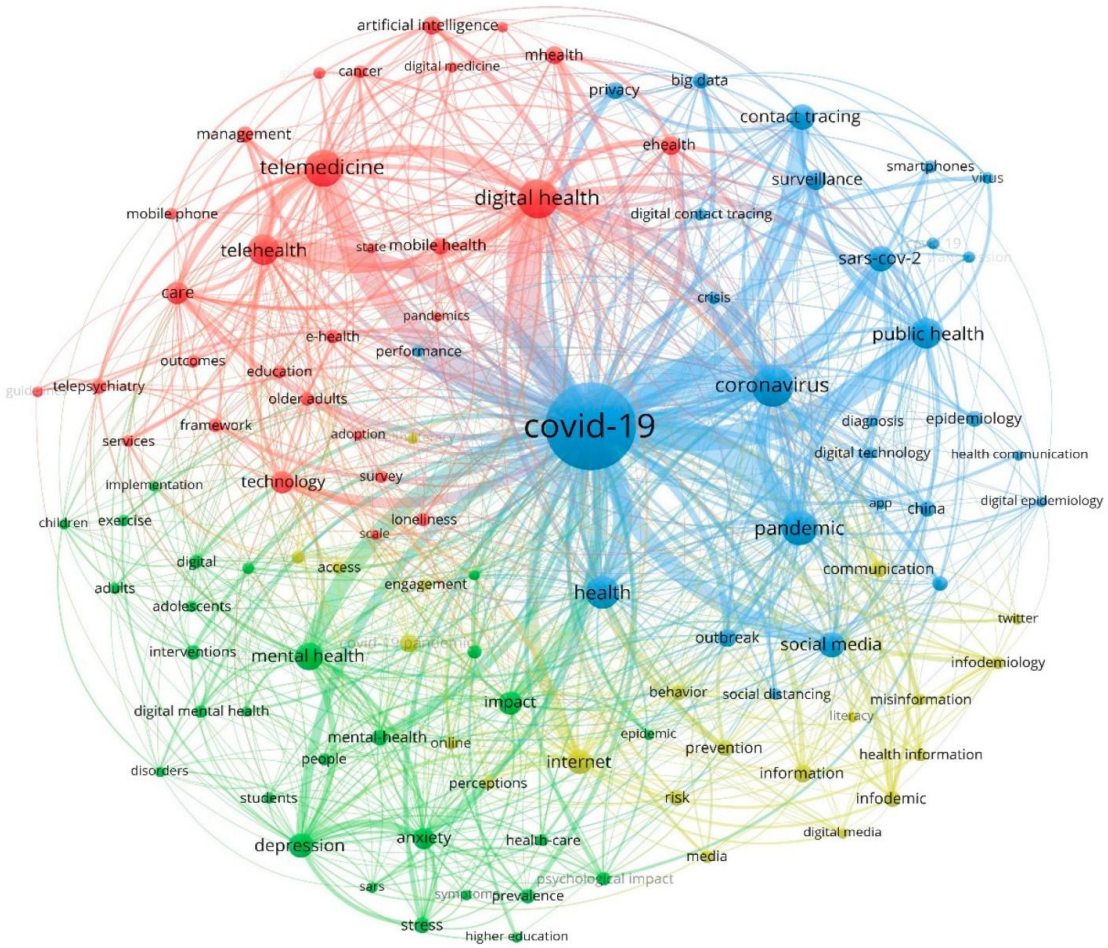
Institutional analysis further reveals the prominence of leading research centers such as **Harvard University**, **University of Oxford**, and the **World Health Organization**, which played pivotal roles in coordinating research efforts and shaping global health responses. Author-level centrality measures similarly indicate the emergence of highly influential scholars whose work bridged multiple thematic and geographic clusters.

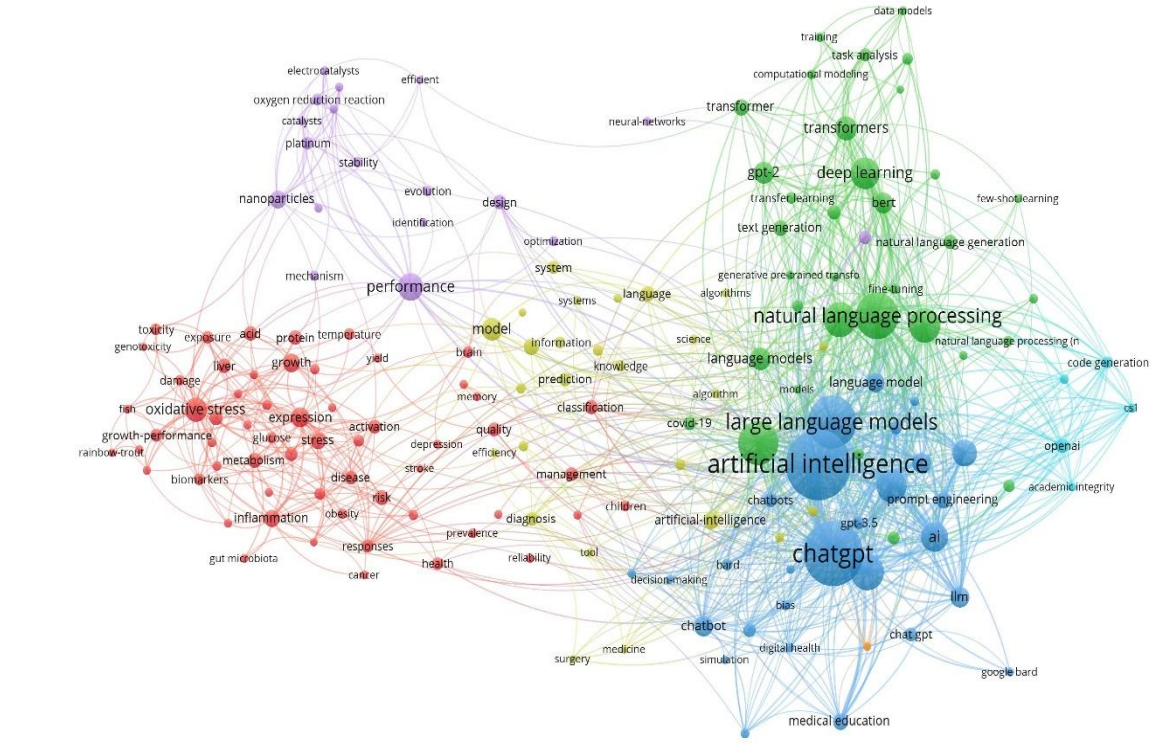
In the post-pandemic phase, collaboration networks remain dense but exhibit signs of **regional clustering**, with increased intra-regional partnerships alongside sustained global ties. This suggests a hybrid model of collaboration combining global coordination with localized research priorities.

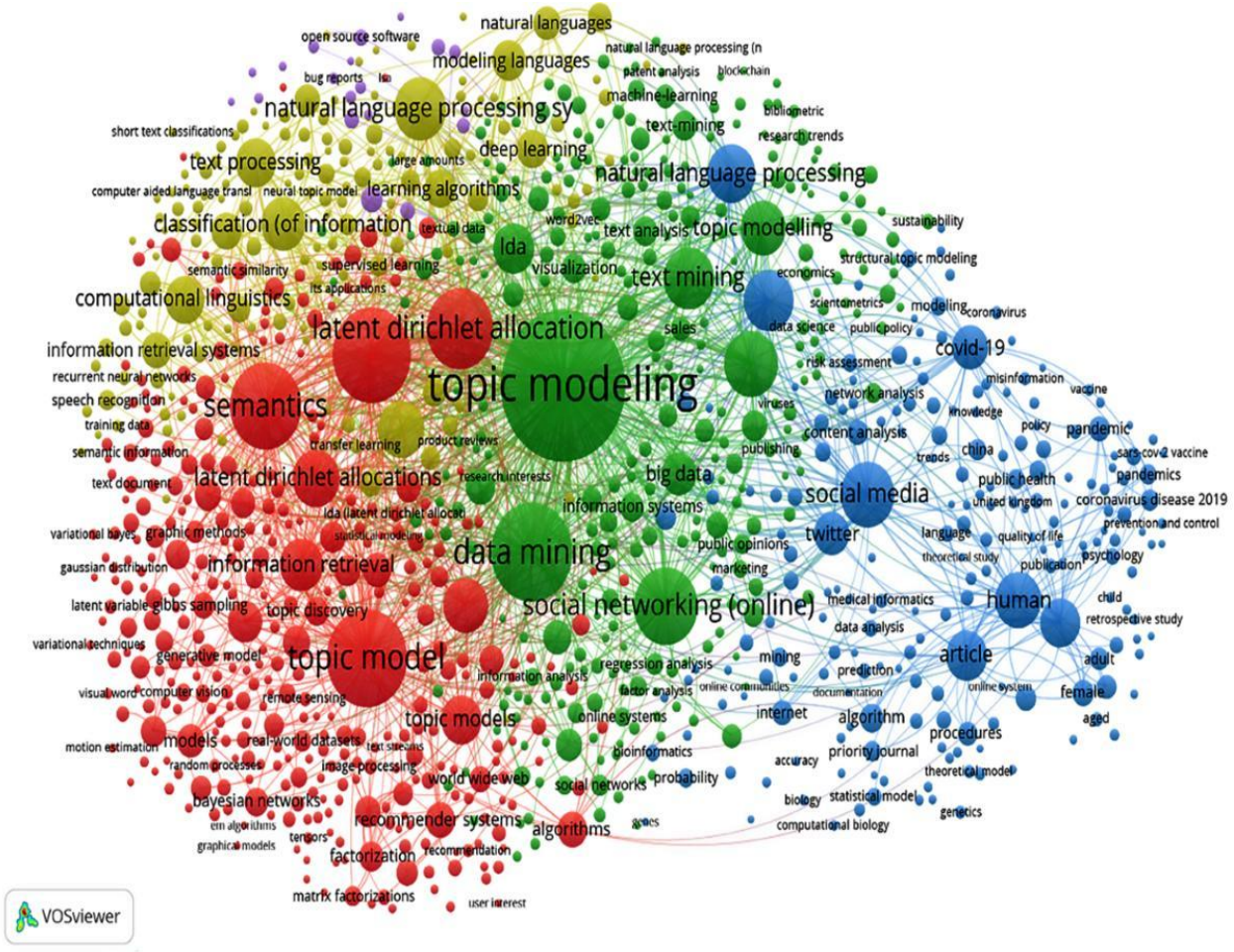
Co-Word Mapping and Thematic Clusters

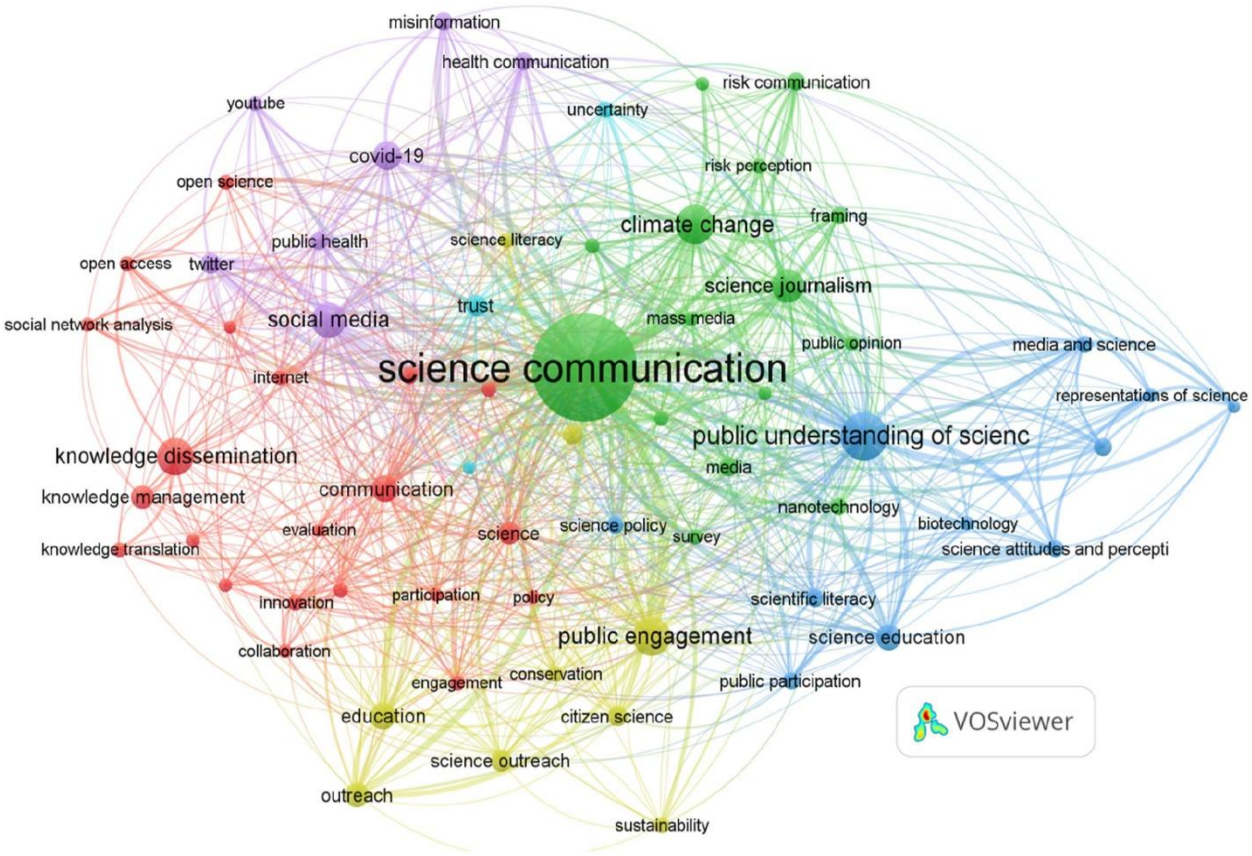
Co-word analysis using **VOSviewer** reveals the **evolution of thematic clusters and knowledge structures** over time.

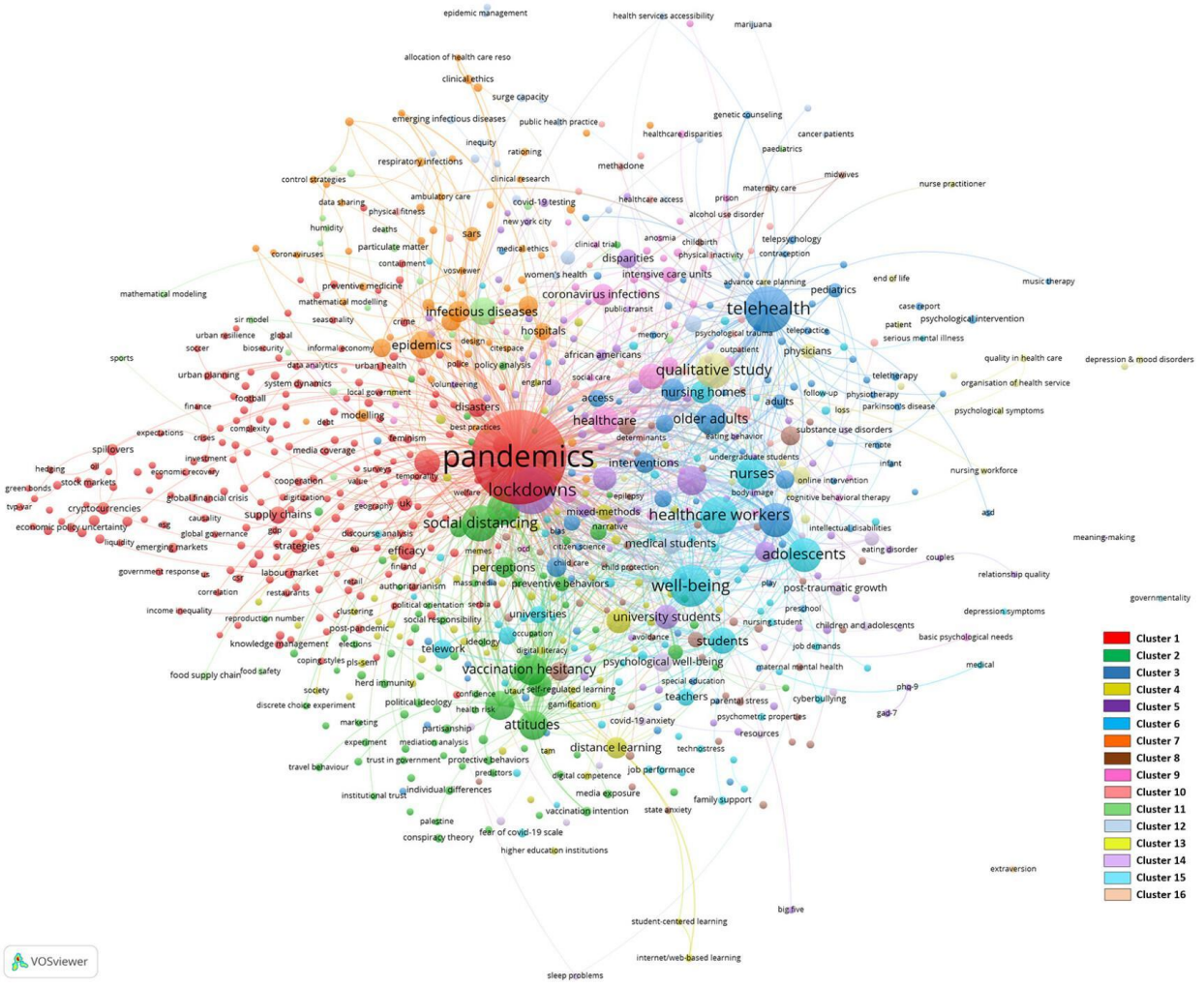












In the pre-pandemic phase, clusters are relatively discrete, with clear boundaries between domains such as "antimicrobial resistance," "viral infections," and "public health surveillance." These clusters reflect a **pathogen-specific and discipline-bound research structure**.

The pandemic phase introduces a high degree of **cluster overlap and network density**, indicating the convergence of previously distinct research areas. For example, keywords related to virology, epidemiology, digital health, and policy appear within interconnected clusters, reflecting the interdisciplinary nature of pandemic research. Terms such as "contact tracing," "mobility data," and "infodemic" emerge as bridging concepts linking health science with technology and social science domains.

In the post-pandemic phase, co-word mapping reveals a transition toward **integrative frameworks**, particularly the **One Health** paradigm. This shift is evidenced by the co-occurrence of terms related to human health, animal reservoirs, environmental change, and global policy within unified clusters. Thematic boundaries become more fluid, suggesting a maturation of the field toward systems-level thinking.

Emerging Post-Pandemic Research Frontiers

One of the most significant findings of this study is the identification of **emerging research areas in the post-pandemic phase**, as indicated by keyword burst analysis and temporal overlay mapping.

First, **vaccine equity** has become a central concern, reflecting growing awareness of global disparities in access to life-saving interventions. Research in this area intersects with policy studies, ethics, and global health governance, highlighting the need for more inclusive and just health systems.

Second, the long-term health consequences of COVID-19, particularly **Long COVID**, represent a rapidly expanding research frontier. Studies increasingly focus on chronic symptoms, rehabilitation, and healthcare system burden, signaling a shift from acute crisis response to long-term disease management.

Third, **public health communication** has emerged as a critical domain, especially in relation to misinformation, risk perception, and community engagement. The pandemic exposed vulnerabilities in information ecosystems, prompting increased scholarly attention to communication strategies, digital platforms, and trust-building mechanisms.

These emerging themes collectively indicate a **broadening of infectious disease research beyond biomedical concerns**, incorporating social, political, and behavioral dimensions. This evolution aligns with calls in the literature for more holistic and interdisciplinary approaches to global health challenges.

Synthesis of Key Findings

Taken together, the results demonstrate that infectious disease research has undergone a **paradigmatic shift** over the past decade. The pandemic acted as a catalyst, accelerating publication growth, intensifying collaboration, and reshaping thematic priorities. However, the most enduring impact lies in the transition toward **integrated, systems-oriented research frameworks** and the recognition of global interdependence in health.

These findings not only reflect bibliometric trends but also carry significant implications for **global health policy**, research funding strategies, and the future organization of scientific collaboration.

Discussion

The findings of this study point to a **structural transformation of infectious disease research** that extends well beyond temporary increases in publication output. Instead, the evidence suggests a reconfiguration of how knowledge is produced, shared, and mobilized in response to global health crises. Interpreting these results within broader scholarly and policy contexts reveals important implications for interdisciplinarity, equity, innovation dynamics, and the long-term sustainability of global research systems.

Acceleration of Interdisciplinarity Across Pandemic Phases

One of the most striking outcomes is the **rapid acceleration of interdisciplinarity** during the pandemic phase. Prior to 2020, infectious disease research was largely organized along disciplinary lines—microbiology, epidemiology, and clinical medicine—with relatively limited integration of social sciences or digital technologies. However, the emergence of COVID-19 catalyzed a shift toward **problem-oriented, cross-disciplinary collaboration**.

This shift is evident in the convergence of previously distinct thematic clusters, where virology intersects with data science, behavioral psychology, economics, and public policy. For instance, research on transmission dynamics increasingly incorporated mobility data, artificial intelligence, and real-time analytics, while studies on vaccine uptake engaged with communication science and sociology. Such integration reflects what innovation theorists describe as **"convergence under pressure,"** where complex crises necessitate the fusion of diverse knowledge systems.

Importantly, this interdisciplinary momentum persists into the post-pandemic phase, suggesting that the crisis has had a **path-dependent effect** on research organization. Rather than reverting to siloed structures, the field appears to be institutionalizing integrative approaches such as the One Health framework. This indicates a maturation of infectious disease science toward systems-level thinking, aligning with broader calls in global health for holistic and anticipatory research models.

Regional Disparities and Collaboration Equity

Despite the expansion of global collaboration networks, the results also highlight **persistent regional disparities in research output and influence**. High-income countries—notably the United States, United Kingdom, and China—maintain dominant positions in both productivity and network centrality. These countries function as **knowledge hubs**, controlling a disproportionate share of high-impact publications and collaborative ties.

While the pandemic did facilitate increased participation from middle-income regions, particularly in Asia and Latin America, this expansion often occurred within **asymmetrical collaboration structures**. In many cases, institutions from lower-resource settings contributed data or local expertise but remained peripheral in authorship hierarchies and citation networks. This pattern raises concerns about **epistemic inequality** and the uneven distribution of scientific authority.

From a policy perspective, these disparities underscore the need for more equitable research partnerships, capacity-building initiatives, and funding mechanisms that prioritize inclusive collaboration. Without such interventions, the risk is that global health research will continue to reproduce existing inequalities, even as it becomes more interconnected.

Theoretical Implications: Innovation Diffusion and Network Resilience

The observed patterns can be meaningfully interpreted through the lens of **innovation diffusion theory** and **network resilience frameworks**. The pandemic created conditions for what can be described as **accelerated diffusion of scientific knowledge**, where findings were disseminated at unprecedented speed across global networks. Preprint servers, open-access journals, and digital platforms played a critical role in this process, enabling rapid circulation of ideas and data.

At the same time, the densification of collaboration networks enhanced **system resilience**, allowing the scientific community to adapt quickly to emerging challenges. Highly connected nodes—such as leading universities and international organizations—acted as stabilizing anchors, facilitating coordination and knowledge exchange during periods of uncertainty.

However, this resilience is not evenly distributed. Networks that rely heavily on a small number of central actors may be vulnerable to disruption if those nodes become overloaded or constrained. Therefore, the long-term robustness of global research systems depends on **distributed capacity and diversified collaboration structures**, rather than centralized dominance alone.

Comparison with Previous Bibliometric Studies

The findings of this study are broadly consistent with, but also extend, prior bibliometric analyses. For example, Falagas et al. documented a significant increase in infectious disease publications during the early phase of the pandemic, emphasizing the surge in COVID-19-related research. Similarly, Zyoud highlighted the rapid expansion of international collaboration and the central role of high-income countries.

However, the present study advances this literature in several important ways. First, by adopting a **phase-based temporal framework**, it captures not only the immediate impact of the pandemic but also the **post-pandemic stabilization and transformation** of research systems. Second, the integration of science-mapping techniques provides deeper insight into the **evolution of thematic structures**, revealing a shift from pathogen-specific research toward integrative paradigms such as One Health.

Moreover, while earlier studies primarily focused on descriptive metrics (e.g., publication counts, citation rates), this analysis emphasizes **relational and structural dimensions**, including network centrality, cluster evolution, and emerging research fronts. This allows for a more nuanced understanding of how scientific knowledge is organized and mobilized over time.

Funding Patterns and Open-Access Transformation

Another critical dimension shaping the observed trends is the role of **research funding and open-access policies**. The pandemic triggered an unprecedented mobilization of financial resources from governments, international organizations, and private foundations. Major funding bodies prioritized COVID-19 research, often with expedited review processes and flexible grant mechanisms.

Simultaneously, there was a strong push toward **open-access dissemination**, with many publishers making pandemic-related research freely available. This shift significantly enhanced the **visibility and accessibility of scientific knowledge**, contributing to the high citation rates observed during the pandemic phase. Open science practices—including data sharing, preprints, and collaborative platforms—became central to the research ecosystem.

However, this transformation also raises questions about sustainability. As emergency funding declines and publishers revert to traditional models, there is a risk that the gains in openness and accessibility may not be fully maintained. Ensuring the continuity of open science will require **institutional commitment and policy support**, particularly in low- and middle-income countries where access barriers remain significant.

Sustainability and Knowledge Translation into Policy

A key question emerging from this analysis is whether the expanded research capacity and collaborative momentum generated during the pandemic can be **sustained in the long term**. The post-pandemic phase suggests a partial consolidation, with continued high levels of output and persistent interdisciplinarity. However, maintaining this trajectory will depend on stable funding, institutional support, and the integration of research into policy frameworks.

Equally important is the issue of **knowledge translation**. The rapid production of scientific evidence during the pandemic did not always translate into effective policy action, highlighting gaps between research and implementation. Strengthening this interface requires not only better communication between scientists and policymakers but also the development of **evidence-informed governance structures**.

In this context, the emergence of research themes such as vaccine equity, public health communication, and health system resilience is particularly significant. These areas reflect a growing recognition that scientific knowledge must be aligned with societal needs and policy priorities. Embedding research within preparedness strategies—rather than treating it as a reactive tool—will be essential for addressing future global health threats.

Concluding Reflection

In sum, the discussion underscores that the pandemic has functioned as both a **disruptive shock and a transformative catalyst** for infectious disease research. It accelerated interdisciplinarity, expanded collaboration networks, and reshaped thematic priorities, while also exposing persistent inequalities and structural vulnerabilities.

The challenge moving forward lies in **consolidating these gains into a more equitable, resilient, and policy-relevant research ecosystem**. Achieving this will require coordinated efforts across funding agencies, academic institutions, and international organizations to ensure that the lessons of the pandemic translate into lasting improvements in global health preparedness and scientific innovation.

Limitations and Future Research

While this study provides a comprehensive bibliometric and science-mapping analysis of infectious disease research across pandemic phases, several limitations should be acknowledged to contextualize the findings.

First, the reliance on the Web of Science Core Collection introduces **indexing bias**. Although widely recognized for its quality and consistency, this database tends to favor journals published in English and those based in high-income countries. As a result, research outputs from low- and middle-income regions, as well as non-English publications, may be underrepresented. This limitation has implications for interpreting global collaboration patterns and may partially obscure localized research contributions that are critical in infectious disease contexts.

Second, **citation-based indicators are inherently time-sensitive**. Publications from the most recent period (2023–2025) have had less time to accumulate citations, potentially leading to an underestimation of their scholarly impact. This "citation lag" is a well-documented constraint in bibliometric research and is particularly relevant in fast-moving fields where knowledge evolves rapidly. Consequently, comparisons of citation intensity across phases should be interpreted with caution, especially when assessing the post-pandemic period.

Third, the study is influenced by **keyword selection and semantic variability**. Despite efforts to construct a comprehensive and inclusive search strategy, variations in terminology—such as differences between "infectious diseases," "communicable diseases," or disease-specific terms—may affect retrieval accuracy. Additionally, evolving vocabularies during the pandemic (e.g., the emergence of new terms related to COVID-19) can introduce inconsistencies in longitudinal analysis. Similarly, country-level analyses may be affected by differences in institutional naming conventions and author affiliations, which can complicate the accurate mapping of collaboration networks.

Fourth, bibliometric and scientometric analyses are inherently **time-bound snapshots** of a continuously evolving research landscape. In the context of a global crisis such as COVID-19, where scientific output expands and shifts rapidly, the findings may quickly become outdated. This underscores the importance of interpreting results as part of a dynamic process rather than a definitive representation of the field.

Future Research Directions

Building on these limitations, several avenues for future research can enhance both the robustness and scope of bibliometric inquiry. One promising direction is the **integration of multiple data sources**, including funding databases (e.g., grant repositories) and patent datasets. Such triangulation would allow for a more holistic understanding of the relationship between research investment, knowledge production, and innovation outcomes.

In addition, the application of **artificial intelligence–assisted topic modeling**—such as machine learning-based clustering and natural language processing—offers significant potential for uncovering latent thematic structures and forecasting emerging research trends with greater precision. These approaches can complement traditional co-word analysis by capturing deeper semantic relationships and temporal dynamics.

Future studies may also benefit from **comparative regional analyses** that explicitly address disparities in research capacity and collaboration equity, as well as longitudinal designs that track the persistence of pandemic-induced changes over extended periods. Finally, linking bibliometric findings with **policy impact assessments** would provide valuable insights into how scientific knowledge is translated into public health action.

In sum, while the present study is subject to methodological and data-related constraints, it nonetheless offers a robust and meaningful analysis of global infectious disease research. Recognizing these limitations not only strengthens the interpretation of current findings but also lays the groundwork for more nuanced and integrative research in the future.

Conclusion

This study set out to examine how infectious disease research evolved across the pre-pandemic, pandemic, and post-pandemic phases, and the findings point to a **profound and lasting transformation** in the global scientific landscape. Prior to 2020, research activity was relatively stable and organized around pathogen-specific domains such as antimicrobial resistance and endemic infectious diseases. The emergence of COVID-19 marked a decisive turning point, triggering an unprecedented surge in publication output, citation impact, and interdisciplinary engagement. In the post-pandemic phase, rather than reverting to earlier patterns, the field demonstrates **sustained expansion, thematic diversification, and structural maturation**, signaling the establishment of a new research equilibrium.

A central insight from this analysis is the critical role of **international collaboration and open science practices** in enhancing the resilience and responsiveness of the global research system. During the pandemic, collaboration networks became denser and more interconnected, with leading scientific hubs coordinating rapid knowledge production and dissemination. At the same time, open-access initiatives, data-sharing platforms, and preprint ecosystems accelerated the

diffusion of scientific findings, enabling real-time engagement across disciplines and borders. These developments collectively strengthened the capacity of the scientific community to respond to complex and rapidly evolving health threats.

However, the findings also underscore persistent challenges, particularly in relation to **equity and inclusivity**. While global collaboration expanded, disparities in research capacity and influence remained evident, with high-income countries continuing to dominate central positions in knowledge networks. Addressing these imbalances is essential for building a more representative and effective global health research system—one that fully leverages diverse perspectives and local expertise.

From a policy standpoint, several actionable recommendations emerge. First, **sustained investment in interdisciplinary research infrastructures** is crucial. Funding agencies should prioritize programs that integrate biomedical, environmental, and social sciences, aligning with holistic frameworks such as One Health. Second, there is a need to **institutionalize open science practices**, ensuring that the accessibility gains achieved during the pandemic are not reversed. This includes supporting open-access publishing models, incentivizing data sharing, and strengthening digital research platforms. Third, policymakers and global research networks should actively promote **equitable collaboration mechanisms**, including capacity-building initiatives in low- and middle-income countries, fair authorship practices, and inclusive funding schemes. Such measures would not only enhance scientific equity but also improve the relevance and applicability of research outcomes in diverse contexts.

Finally, the study highlights the importance of **linking research systems with public health governance**. Strengthening the interface between scientific evidence and policy decision-making is essential for effective preparedness and response. This requires the development of institutional pathways for knowledge translation, as well as closer collaboration between researchers, public health agencies, and international organizations such as the World Health Organization.

In conclusion, the evolution of infectious disease research across pandemic phases reflects both the vulnerabilities and the adaptive capacity of the global scientific system. The challenge moving forward is not merely to sustain the momentum generated during the pandemic, but to **embed it within a more resilient, equitable, and policy-responsive research ecosystem**—one capable of anticipating and addressing future global health crises with greater coordination and impact.

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