ISSN: 2581-4311
DOI: doi.org/10.30967/IJCRSET/Altyeb-Ali-Abaker-Omer/208

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International Journal of Current Research in Science, Engineering & Technology

https://urfpublishers.com/journal/ijcrset

Vol: 8 & Iss: 4

Review

Evaluating the Use of VOSviewer in Bibliometric and Science-Mapping Studies: Trends, Current State and Future Directions

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Citation: Omer AAA, Issa IIM, Abuker YYA, Asad S. Evaluating the Use of VOSviewer in Bibliometric and Science-Mapping Studies: Trends, Current State and Future Directions. *Int J Cur Res Sci Eng Tech* 2025; 8(4), 483-497. DOI: doi.org/10.30967/IJCRSET/Altyeb-Ali-Abaker-Omer/208

Received: 12 December, 2025; **Accepted:** 18 December, 2025; **Published:** 19 December, 2025

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ABSTRACT

Over the last fifteen years, bibliometric and science-mapping methodologies have proliferated globally, with VOSviewer emerging as a prominent visualisation tool. Nonetheless, a thorough longitudinal evaluation of VOSviewer's application and interpretation in empirical studies remains absent. This study addresses this gap through a thematic and meta-bibliometric assessment of 10,333 VOSviewer-based publications indexed in Scopus between 2010 and 2024. Using a mixed-methods design, the analysis investigates publication growth, geographical and disciplinary diffusion, conceptual structures, methodological techniques, software interoperability with complementary tools (Bibliometrix, CiteSpace, Gephi, CitNetExplorer) and commonly reported methodological challenges. A stratified qualitative content analysis of 30 representative studies provides deeper insight into analytical preferences, patterns of tool integration and emerging standards of practice. The findings reveal exponential global adoption of VOSviewer, along with a stable methodological core centred on citation and keyword co-occurrence analysis, accompanied by a growing reliance on multi-tool workflows that enhance temporal intelligence, reproducibility and statistical depth. Five conceptual clusters illustrate a dual trajectory: consolidation of foundational bibliometric methods alongside diversification into technologically intensive domains such as artificial intelligence, Industry 4.0/5.0, smart cities and pandemic-related research. Persistent challenges remain, which include dependence on a single database, inconsistency in keyword metadata standards, sensitivity to thresholds and interpretation challenges. The research outlines paths that should be followed for future studies, including the combination of multiple databases, the openness and standardization of workflows, the integration of qualitative and quantitative approaches to bibliometrics and the interpretation that is more context aware. Generally, the synthesis presents the first disciplinary assessment of VOSviewer's methodological role, challenges and promise at the research level.

Keywords: VOSviewer; Bibliometric analysis; Science mapping; Citation networks; Keyword co-occurrence; Software integration; Methodological challenges; Bibliometrix; CiteSpace; Conceptual structures; Research trends

Introduction

Over the past fifteen years, research techniques within the realms of bibliometrics and science mapping studies have gained a prominent position in understanding knowledge structures, processes and developments. Such research utilises citational and publication data, along with quantifiable analyses, to identify influential authors and research fronts[1,2]. The expansion of large-scale scholarly databases, particularly Scopus and Web of Science, has transformed bibliometrics from a largely statistical tradition into a visual, data-intensive and interpretive research paradigm that supports evidence-based decision-making, research evaluation and innovation policy. This transition toward data-rich and visually oriented analysis has been driven by the emergence of dedicated software tools that can convert complex bibliographic metadata into intuitive knowledge maps[3]. Some of the most prominent tools within this area include CiteSpace[4], Bibliometrix/Biblioshiny[5] and VOSviewer[6]. These tools have enabled the development and growth of advanced science mapping tools, such as citation analysis, co-citation analysis, co-author analysis, keyword co-occurrence analysis and bibliographic coupling, thereby revealing intellectual, conceptual and social structures within research domains. A broader ecosystem of complementary tools, including Pajek, HistCite, Gephi and CitNetExplorer, has also emerged, each offering distinct analytical strengths and visualisation capabilities; a comparative overview of these primary tools is presented in **(Table 1)**.

Within this expanding ecosystem, VOSviewer has emerged as the most widely adopted and frequently cited visualisation tool. Its Visualisation of Similarities (VOS) algorithm[6], efficient clustering and user-friendly interface have made it the preferred choice for researchers conducting bibliometric and science-mapping studies across disciplines, including Medicine, the Social Sciences, Information Science, Environmental Science and Engineering (see Figure 4). Since its release in 2010, VOSviewer has been used in over 14,900 publications in the Scopus database, demonstrating its central role in shaping the practice of contemporary bibliometrics. Despite its ubiquity, however, there has been no comprehensive, long-term evaluation of how VOSviewer itself has been used. Existing bibliometric reviews often apply VOSviewer to domain-specific topics without examining the methodological choices, analytical preferences or integration strategies underlying its use. As a result, little is known about how VOSviewer-based research has evolved across regions or within disciplines, which techniques are most implemented, how researchers combine VOSviewer with complementary tools such as Bibliometrix or CiteSpace or what methodological challenges are frequently encountered.

A synthesis of prior methodological literature highlights this gap. Early bibliometric research primarily focused on citation counts as measures of influence[7,8]. However, the introduction of co-citation[9], co-word analysis[10] and bibliographic coupling laid the groundwork for modern relational science mapping. Through the 1980s and 1990s, digitisation of scholarly databases enabled large-scale analyses of scientific communication[11,12], while multidimensional scaling, force-directed layouts and clustering algorithms advanced the visual representation of scientific structures[6,13]. These developments set the stage for the emergence of specialised visualisation tools. Between 2004 and 2017, a series of primary tools significantly influenced the evolution of the field. Pajek and HistCite provided foundational computational capacities for network and historiographic analysis. CiteSpace introduced temporal burst detection and trend evolution mapping, while Gephi added powerful layouts and interactive network visualisation. The release of VOSviewer in 2010 marked a methodological leap, as its scalable clustering, intuitive display and compatibility with Scopus and Web of Science revolutionised the accessibility of bibliometric visualisation. CitNetExplorer[14] further strengthened historiographic and citation-path analysis. Meanwhile, Bibliometrix/Biblioshiny[5] integrated open, script-based and reproducible workflows, complementing visualisation tools like VOSviewer. Collectively, as summarised in **(Table 1)**, these tools trace a progression from foundational computational approaches to integrated, reproducible and visually rich ecosystems.

Despite substantial advances in bibliometric methodologies and the widespread adoption of VOSviewer across disciplines, the methodological literature still exhibits several enduring gaps that underscore the need for a systematic evaluation. First, there has been no longitudinal examination of how VOSviewer-based analytical techniques have evolved, leaving the temporal and methodological trajectory between 2010 and 2024 largely undocumented. Second, national and regional patterns of use remain insufficiently understood, limiting insights into the geographical and disciplinary diffusion of the software. Third, although VOSviewer is frequently used in conjunction with other tools, such as Bibliometrix, CiteSpace, Gephi and CitNetExplorer, evidence of how these platforms are integrated in practice is fragmented and often anecdotal. Fourth, existing studies rarely provide systematic accounts of methodological and technical challenges, including threshold sensitivity, data-cleaning inconsistencies and risks of interpretive bias despite their clear implications for transparency and reproducibility. Finally, no comprehensive effort has mapped the conceptual structures or emerging thematic patterns within VOSviewer-based research itself, leaving a significant gap in understanding the intellectual landscape shaped by this influential tool.

To address these gaps, this study conducts a meta-bibliometric and thematic evaluation of VOSviewer-based scholarship published between 2010 and 2024. It examines publication trends, geographic and disciplinary diffusion, dominant analytical techniques, conceptual and thematic structures, interoperability patterns and reported methodological challenges. The following research questions guide the analysis:

- **RQ1:** How has the use of VOSviewer evolved across bibliometric and science-mapping studies in terms of publication volume, geographical distribution and disciplinary coverage applications?
- **RQ2:** What conceptual structures and thematic patterns characterise VOSviewer-based research during this period?
- **RQ3:** Which bibliometric techniques (citation, co-citation, co-authorship, co-occurrence and bibliographic coupling) are most frequently applied?
- **RQ4:** How is VOSviewer integrated with other bibliometric tools, particularly Bibliometrix, CiteSpace, Gephi and CitNetExplorer?
- **RQ5:** What methodological, technical and interpretive challenges have been identified and what future research is proposed?

By addressing these questions, the study provides the first comprehensive evaluation of VOSviewer's methodological role in contemporary bibliometrics. The findings contribute to both the meta-science of bibliometric methodology and the ongoing refinement of integrated, reproducible and transparent science-mapping practices.

Table 1: Comparative Overview of primary bibliometric and science-mapping tools (approx. 2004-2017).

Tool/Year	Key reference	Developer/ Institution	**Core analytical functions**	**Interface and visualisation**	**Main strengths**	**Main limitations**	**License/Integration**
Pajek	[15,16]	Vladimir Batagelj & Andrej Mrvar, Univ. of Ljubljana	Analysis and visualisation of extensive networks; centrality and community metrics	Windows GUI; structural and basic graphical output	Handles extensive networks efficiently; mathematically robust; long tradition in social network analysis	Less user-friendly for non-experts; relatively simple visualisation compared with newer tools	Free for non-commercial/ academic use; exports to standard network formats that Gephi, CiteSpace, etc can read.
HistCite	[17]	Eugene Garfield, Institute for Scientific Information (ISI)	Historiographic mapping; citation lineage and local/ global citation scores	Windows GUI	Pioneering historiographic visualisation; easy tracking of citation chains	No longer maintained; limited modern visual and network functions	Legacy freeware (Windows); sometimes used as a precursor to later visualisation tools
CiteSpace	[4]	Chaomei Chen, Drexel University	Co-citation analysis; burst detection; cluster and timeline mapping	Java-based GUI; rich temporal and cluster visualisations	Excellent for detecting emerging topics and citation bursts; strong time-sliced analysis	Many parameters; relatively steep learning curve for beginners	Free; Java cross-platform; exports to Pajek/Gephi and interoperates with other tools
Gephi	[18]	Bastian, Heymann & Jacomy, WebAtlas / Médialab, Paris	General network analysis; modularity; dynamic and interactive graphs	Highly interactive GUI; advanced layout algorithms (e.g., ForceAtlas2)	Compelling, flexible network visualisation; real-time interaction with large graphs	Not bibliometric-specific; requires preprocessing of bibliometric data	Open-source (GPL); imports standard graph formats (GEXF, GraphML, etc.) produced from bibliometric data
VOSviewer	[6]	Nees Jan van Eck & Ludo Waltman, CWTS Leiden University	Construction and visualisation of bibliometric maps (co-authorship, co-citation, co-occurrence, bibliographic coupling and citation)	Dedicated GUI with network, overlay and density views	Extremely intuitive; optimised for large bibliometric networks; stable VOS mapping and clustering	Limited built-in statistical modelling; relies on external tools for advanced inferential analysis	Freeware; widely used in combination with CitNetExplorer and Bibliometrix/ Biblioshiny
CitNetExplorer	[14]	Nees Jan van Eck & Ludo Waltman, CWTS Leiden University	Analysis and visualisation of direct citation networks; citation-path and historiographic exploration	Combined graph and tabular interface	Very strong for exploring the development of research fields and citation paths; scalable to large networks	Focused on citation data only; limited functionality for keyword-based mapping.	Freeware; designed to interoperate seamlessly with VOSviewer
Bibliometri/ Biblioshiny	[5]	Massimo Aria & Corrado Cuccurullo, Univ. of Naples Parthenope	Comprehensive science-mapping and performance analysis; conceptual, intellectual and social structure mapping	R package (Bibliometrix) with web interface (Biblioshiny)	Fully reproducible workflows; strong statistical and modelling capabilities; open-source and extensible	Requires R environment; computation may be slower for massive datasets	Open-source (CRAN); exports networks that can be visualised in VOSviewer, Gephi and other tools

Methodology

Research design

This study adopts systematic bibliometric and thematic analysis to investigate how VOSviewer has been applied in bibliometric and science-mapping studies between 2010 and 2024. A mixed-methods design was employed, integrating quantitative bibliometric performance analysis, science-mapping visualisation and network analysis, alongside qualitative content synthesis of methodological practices, software integration and reported challenges, as well as proposed future research directions. This combination enables a comprehensive examination of publication patterns, conceptual structures, methodological trends and the thematic evolution of research using VOSviewer. Established bibliometric frameworks guide the workflow proposed[2,19,20], all of which emphasise transparency, reproducibility and interpretability. The analytical procedures comprised two complementary components: (1) Quantitative component (addressing RQs 1–2): Annual publication output, global research distribution and disciplinary spread. Keyword co-occurrence analysis to identify conceptual structures through VOSviewer clustering. (2) Qualitative component (addressing RQs 3-5): Evaluation of methodological techniques reported across studies; assessment of multi-tool Integration (e.g., Bibliometrix, CiteSpace, SciMAT, Gephi); and synthesis of reported limitations, technical challenges and proposed future

research directions. Together, these components provide a holistic assessment of the intellectual, methodological and thematic evolution of VOSviewer-related scholarship.

Data source and search strategy

The Scopus database was selected as the primary source due to its extensive disciplinary coverage and high-quality citation metadata. A targeted search strategy was designed to retrieve all publications explicitly referencing VOSviewer in the title, abstract or keywords. The final search was conducted on 14th November 2025. The applied search query was: TITLE-ABS-KEY("VOSviewer") AND PUBYEAR > 2009 AND PUBYEAR < 2025 AND (LIMIT-TO(DOCTYPE, "ar") OR LIMIT-TO(DOCTYPE, "re") OR LIMIT-TO(DOCTYPE, "cp")) AND (LIMIT-TO(LANGUAGE, "English")). The search strategy employed progressive filter criteria (year, document type and language), resulting in a count of 10,333 documents from an initial search of 16,076 documents. The data identification, screening and inclusion process followed a PRISMA flow diagram, as shown in **(Figure 1)**[21].

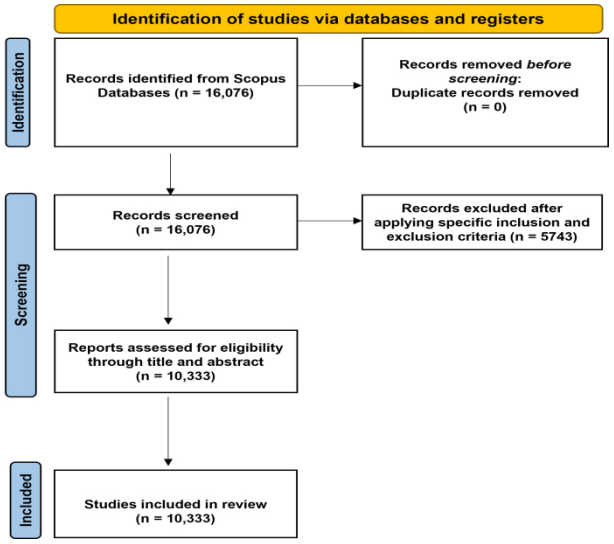

Figure 1: PRISMA flow diagram for data identification, screening and inclusion. This figure illustrates the stepwise filtering process used to obtain the final dataset. Starting with 16,076 Scopus records, successive screening by year (2010–2024), document type and language yielded a final set of 10,333 publications for bibliometric and thematic analysis.

Analytical workflow and tools

Performance analysis (RQ1): Performance analysis was conducted using Scopus' built-in analytical functions to examine annual publication trends (2010–2024), global and regional research distribution and disciplinary patterns in VOSviewer usage. These metrics provide an overview of the growth and diffusion of VOSviewer across scientific fields.

Conceptual and thematic analysis procedure (RQ2): To explore the conceptual structure and thematic evolution of VOSviewer-related research, author keywords were extracted from the 1000 most-cited studies and processed using VOSviewer version 1.6.20. A keyword co-occurrence analysis was performed using complete counting with a minimum threshold of three occurrences to ensure analytical significance. The resulting clusters were interpreted as conceptual themes and labelled according to the dominant keywords within each cluster.

Keyword cleaning and thesaurus construction

To enhance the consistency and interpretability of keyword networks, a structured thesaurus was developed and applied in VOSviewer. The cleaning and normalisation procedure followed five steps:

- **Extraction of author keywords:** All author keywords were exported and consolidated into a single list of unique terms, which formed the basis for normalisation.
- **Identification of variants and synonyms:** The list was systematically reviewed to identify: spelling and formatting variants (e.g., digitalisation vs. digitalization), singular–plural forms and hyphenation differences (e.g., smart city vs. smart cities), abbreviations and complete forms (e.g., AI vs. artificial intelligence), overlapping methodological terms (e.g., bibliometric vs. bibliometrics vs. bibliometric mapping, etc).
- **Definition of canonical terms:** For each group of related keywords, a single canonical term was assigned (e.g., bibliometric analysis, co-occurrence analysis, co-citation analysis, COVID-19, publication trend, VOSviewer, Web of Science, sustainable development). All variant forms were mapped to the canonical term.
- **Construction of the thesaurus file:** A two-column CSV file was generated with the headers "Label" and "Replace by". The "Label" column included all original keyword variants. "Replace by" contained their corresponding canonical forms. Canonical terms appeared only in the Replace by column to avoid conflicts with VOSviewer's rules.
- **Application of the thesaurus in VOSviewer:** The thesaurus was imported during network creation, merging all variants into their unified terms. This step reduced noise, eliminated redundant nodes, minimised artificial cluster fragmentation and strengthened the accuracy of the conceptual and thematic structure.

Content analysis sampling strategy for RQs 3 - 5

To address RQs 3-5, a qualitative content analysis was conducted using a stratified purposive sample of 30 studies. The sampling ensured methodological and temporal diversity. Most cited studies (n = 15) comprised highly cited papers published between 2010 and 2021, representing foundational methodological contributions. Most recent studies (n = 15): Publications from 2024 illustrating current practices and hybrid analytical workflows. Selection was facilitated through Scopus filters, sorting by Citations (highest) and Date (newest). Each study was manually coded for: analytical techniques (citation, co-citation, co-authorship, co-occurrence or bibliographic coupling); use of complementary tools (Bibliometrix, CiteSpace, Gephi, Pajek or CitNetExplorer); methodological or technical challenges (e.g., threshold sensitivity, data cleaning limitations, visualisation bias); and authors' recommendations and proposed directions for future research. Coded data were organised in an Excel template and thematic patterns were derived through open and axial coding. Higher-order categories included methodological consistency, interoperability, visualisation quality and reproducibility.

Results and Discussion

Publication growth and temporal evolution of VOSviewer-based research (RQ1)

The annual distribution of publications demonstrates a

clear and substantial expansion in the use of VOSviewer across bibliometric and science-mapping studies over the past fifteen years. As shown in **(Figure 2)**, the adoption of the software remained modest during the early phase (2010-2015), with annual outputs ranging from 1 to 19 publications. This initial period reflects the gradual recognition of VOSviewer as a reliable tool for visualising citation, co-occurrence and network structures; however, its use had not yet become mainstream within the bibliometric community. A notable upward shift emerges after 2016, when the number of studies increased to 34 publications, followed by a steady climb through 2017 (46) and 2018 (91). This phase corresponds to the broader diffusion of bibliometric techniques across interdisciplinary research domains and the increased availability of online datasets, such as Scopus and Web of Science, which facilitate the more frequent use of science-mapping tools.

The period between 2019 and 2021 marks a transformative acceleration. Publications rose from 203 in 2019 to 443 in 2020 and then more than doubled to 1007 in 2021. This surge reflects both methodological consolidation in bibliometric research and the global shift toward digital scholarship during the COVID-19 pandemic, which intensified researchers' reliance on automated visualisation software. The most dramatic growth occurred in the final three years of the study period. Annual outputs increased to 1773 publications in 2022, followed by 2835 in 2023 and culminating in an unprecedented 3859 publications in 2024. This exponential rise underscores VOSviewer's establishment as a standard and widely accepted instrument for mapping scientific knowledge structures. It also indicates the expansion of bibliometric practices into new domains, including environmental sciences, health research, social sciences, artificial intelligence and interdisciplinary policy studies, where VOSviewer is increasingly used to explore research trends, thematic clusters and intellectual foundations. Overall, the temporal evolution reveals a shift from limited, exploratory use in the early 2010s to widespread, methodologically sophisticated adoption in recent years. The pattern reflects both technological maturation and the growing importance of evidence-based, data-driven approaches to understanding the dynamics of scientific research across global academic communities **(Figure 2)**.

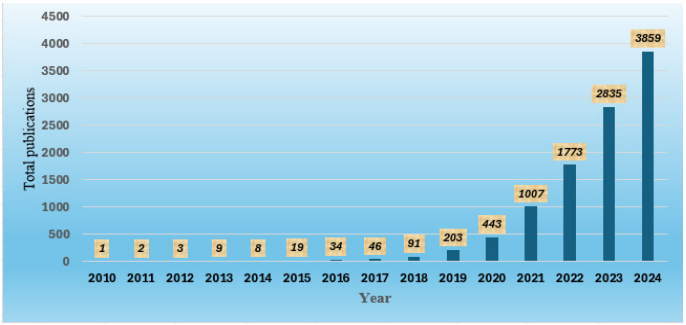

Figure 2: Annual growth of VOSviewer-based publications (2010–2024). This figure illustrates the year-by-year expansion in the number of studies employing VOSviewer. The results show a gradual rise during the early 2010s, followed by a sharp acceleration after 2016 and an exponential increase from 2020 onwards, indicating the software's widespread adoption across global research communities.

Geographical distribution and institutional contributions (RQ1)

The geographical distribution of publications reveals a highly uneven but increasingly diverse global landscape in the use of VOSviewer for bibliometric and science mapping research. As shown in **(Figure 3)**, China overwhelmingly dominates the field, producing 3769 publications, a figure that far exceeds that of all other countries. This leadership reflects China's expanding research output, substantial institutional investments in scient metrics and the widespread adoption of visual analytics tools in knowledge mapping studies across its universities and research institutes. Indonesia and India represent the second and third most significant contributors, with 1124 and 1080 publications, highlighting their rapid growth in bibliometric scholarship and the rising prominence of Indonesian and Indian institutions in global research analytics. Malaysia and the United States follow with 681 and 548 publications, respectively, indicating a stable but comparatively moderate level of engagement with VOSviewer, relative to China, Indonesia and India.

Other notable contributors include Brazil (347), Turkey (295) and Australia (240), each reflecting strong regional hubs for bibliometric and science-mapping applications. Several emerging research clusters are evident across Asia, Africa and Latin America, showcasing a growing yet still developing presence in the bibliometric landscape. Their increasing output suggests an expansion of academic capacity, a growing interest in evaluating quantitative research and the dissemination of scientometric methods across diverse disciplinary and institutional contexts. Notably, many regions, particularly in Central Africa, parts of the Middle East and small island states, show minimal engagement, often with fewer than five publications. This disparity highlights persistent global inequalities in research infrastructure, access to bibliometric training and participation in science mapping research.

Overall, the geographical distribution highlights three major patterns: (1) an intense concentration of output in Asia, driven primarily by China, Indonesia, India and Malaysia; (2) A secondary cluster of active producers in North America, Western Europe and parts of Latin America; and (3) A widening but uneven adoption across developing regions, where institutional contributions remain fragmented but are gradually increasing. The global spread of VOSviewer use thus reflects both the maturation of bibliometric practices and the emerging democratisation of scientometric tools across diverse academic systems.

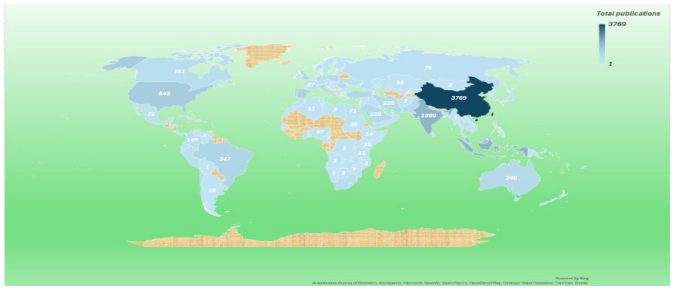

Figure 3: Global geographical distribution of VOSviewer-based publications. This map displays the spatial distribution of publications across countries, highlighting substantial disparities in research output.

Disciplinary and subject-area patterns in VOSviewer applications (RQ1)

The subject-area distribution of VOSviewer-based publications reveals a broad and rapidly expanding

interdisciplinary footprint, demonstrating that the software has become a central tool for knowledge-mapping across diverse scientific fields. As illustrated in **(Figure 4)**, Medicine accounts for the largest share of publications (15.7%), reflecting the notable rise of bibliometric studies in clinical sciences, public health and medical sub-specialities. The growing emphasis on evidence synthesis, research evaluation and knowledge visualisation within health-related disciplines has accelerated the adoption of VOSviewer as a tool for mapping research landscapes and identifying thematic clusters. Social Sciences represents the second most prominent field (12.8%), showcasing the increasing interest in bibliometric methods for policy analysis, education research, communication studies and various branches of sociology. This trend underscores the broader methodological shift in the social sciences toward data-driven insights, meta-research practices and scientometric evaluation.

Computer Science holds a significant share (9.5%), driven by the software's relevance for mapping research on machine learning, artificial intelligence, cybersecurity, digital transformation and information systems. Likewise, Environmental Science (7.5%), Engineering (7.4%) and Business, Management and Accounting (7.3%) also exhibit strong adoption, reflecting the widespread use of VOSviewer to analyse emerging technologies, sustainability research and industry-oriented academic trends. A substantial presence is also observed across specialised scientific domains such as Energy (4.1%), Biochemistry, Genetics and Molecular Biology (3.7%), Agricultural and Biological Sciences (3%), Decision Sciences (2.9%), Economics and Finance (2.8%), Mathematics (2.7%) and Arts and Humanities (2.4%). These fields increasingly rely on bibliometric tools to explore thematic evolutions, intellectual structures and cross-disciplinary linkages.

Even more minor but noteworthy contributions appear from Pharmacology, Immunology, Neuroscience, Earth and Planetary Sciences, Materials Science, Psychology, Chemical Engineering, Nursing and Chemistry, each illustrating the widening methodological acceptance of science-mapping techniques. While a small proportion of publications falls under the "Other" category (9.1%), the overall distribution demonstrates that VOSviewer is no longer confined to information science or scientometrics but has become a mainstream analytical tool in nearly all major academic sectors. Collectively, these disciplinary patterns highlight three key observations:

- A pronounced shift toward health, social sciences and digital-technology fields, where bibliometric synthesis is increasingly integral.
- Strong engagement from Science, Technology, Engineering and Mathematics (STEM) disciplines, particularly environmental science, engineering and computer science.
- Growing interdisciplinary convergence, with VOSviewer supporting hybrid analyses across scientific, social and applied research domains.

This broad distribution underscores VOSviewer's maturity as a versatile, cross-cutting methodological instrument used by diverse scholarly communities to map complex research ecosystems.

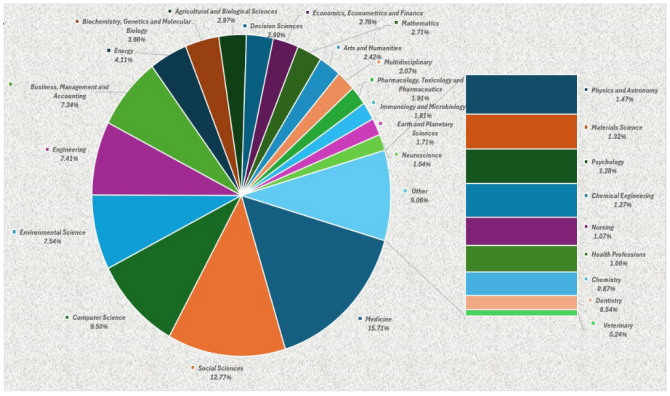

Figure 4: Subject-area distribution of VOSviewer-based research across disciplinary fields. This figure presents the proportional representation of major academic fields using VOSviewer between 2010 and 2024

Conceptual structures and thematic evolution of VOSviewer research (RQ2)

The keyword co-occurrence network **(Figure 5)** reveals a well-defined conceptual landscape comprising five major thematic clusters, derived from a cleaned set of 48 high-frequency keywords (from an initial pool of 244 terms following thesaurus normalisation). This refined structure offers a clearer understanding of how VOSviewer-related scholarship is intellectually organised and how methodological, technological and application-oriented themes intersect across the field. Two overarching patterns emerge from this clustered structure. First, VOSviewer research is anchored in a robust methodological core, represented by keywords such as bibliometric analysis, science mapping, co-citation analysis, co-occurrence analysis and network analysis. These terms form the conceptual backbone of the field, highlighting the persistent role of VOSviewer as a visualisation-driven analytical instrument in bibliometric research. Second, surrounding this methodological nucleus is an expanding ring of technology-driven and application-oriented themes, including artificial intelligence, big data, Industry 4.0/5.0, smart city, COVID-19, virtual reality and text mining. These domains illustrate the increasing integration of bibliometric methods with digital transformation, emerging technologies and evolving global challenges. **(Table 2)** synthesises the conceptual role of each cluster, its representative keywords and the emerging trends shaping the broader evolution of VOSviewer-based research.

Table 2: Conceptual themes and clustered structures in VOSviewer-based research (48 Keywords, 5 Clusters).

Cluster No.	Representative keywords	Emerging themes and trends	Conceptual structure
Cluster 1 (17 items)	artificial intelligence; augmented reality; big data; big data analytics; building information modeling; covid-19; data mining; industry 4.0; industry 5.0; internet of things; literature review; meta-analysis; publication trend; scientometrics analysis; smart city; text mining; virtual reality	Rapid expansion of VOSviewer use in digital and technological domains; strong links to automation, Industry 4.0/5.0 and AI-driven research; increased reliance on text mining and pandemic-related bibliometric evaluations	Represents the innovation-driven frontier of VOSviewer applications, emphasising technological transformation and fast-evolving interdisciplinary fields

Cluster 2 (9 items)	bibliometric analysis; blockchain; digitalization; network analysis; prisma; science mapping; supply chain management; sustainable development; systematic literature review	Integration of PRISMA-based review protocols; rising focus on sustainability, blockchain and supply chain resilience; convergence of systematic review methods with science-mapping techniques	Constitutes the methodological nucleus of the field, emphasising structured review practices and analytic rigour
Cluster 3 (8 items)	bibliometrix; citation analysis; citespace; diabetes; histcite; knowledge mapping; visualization; web of science	Increasing use of complementary bibliometric tools (Bibliometrix, CiteSpace, HistCite); diversification of data sources; expansion into Medicine and clinical science	Represents the multi-tool and data-source integration layer of VOSviewer research, highlighting interoperability and cross-platform validation
Cluster 4 (8 items)	bibliographic coupling; biblioshiny; co-authorship analysis; co-citation analysis; co-occurrence analysis; gephi; rstudio; scopus	Growing adoption of advanced network analysis techniques; expanding use of programming and visualisation environments (RStudio, Gephi); focus on high-quality databases (Scopus)	Forms the technical and analytical backbone of bibliometric studies, emphasising algorithmic sophistication and network construction
Cluster 5 (6 items)	citnetexplorer; cluster analysis; mapping; research trends; scimat; vosviewer	Increased emphasis on trend evolution, cluster detection and conceptual structure mapping; adoption of temporal bibliometrics	Represents the conceptual architecture and trend-detection cluster, shaping the intellectual structure and evolutionary patterns of VOSviewer research

Clustered conceptual structure and interrelationships in VOSviewer-based research: The keyword co-occurrence map **(Figure 5)** displays a dense and interconnected conceptual ecosystem organised into five colour-coded clusters: Cluster 1 (red), Cluster 2 (green), Cluster 3 (blue), Cluster 4 (yellow) and Cluster 5 (purple). Although each cluster has a distinct thematic identity, its strong interconnections demonstrate the field's high degree of methodological convergence and interdisciplinary integration.

Cluster 1 (red) represents the technology- and innovation-oriented frontier of VOSviewer research. Keywords such as artificial intelligence, the Internet of Things, big data and Industry 4.0/5.0 demonstrate the increasing application of bibliometric techniques in digitally intensive and rapidly evolving scientific domains. The presence of COVID-19, as well as meta-analysis and literature review, reflects VOSviewer's prominent role in synthesising rapidly growing research during the pandemic era. Cluster 2 (green) forms the methodological core, characterised by structured review approaches, including systematic literature reviews, PRISMA, science mapping and network analysis. Its proximity to Cluster 1 highlights how methodological rigour facilitates the expansion of bibliometric research into emerging technological fields. Cluster 3 (blue) represents the multi-tool integration environment, featuring tools such as CiteSpace, Bibliometrix and HistCite, as well as data sources like Web of Science. The cluster also encompasses knowledge mapping and visualisation, reflecting an increasing emphasis on cross-platform validation and more comprehensive analytic workflows. Its inclusion of diabetes indicates expanding use of VOSviewer in clinical and biomedical contexts. Cluster 4 (yellow) represents the technical and algorithmic foundations of bibliometric analysis. Keywords such as co-authorship analysis, co-citation analysis, Gephi, RStudio and Scopus highlight the computational and data-focused components that underpin science-mapping activities. Cluster 5 (purple) encompasses the conceptual and structural mapping cluster, which includes tools such as CitNetExplorer and SciMAT, as well as methodological concepts like cluster analysis, mapping and research trends. This cluster plays a central role in identifying intellectual structures, thematic evolution and longitudinal knowledge trajectories.

Collectively, these five clusters form a coherent conceptual architecture in which VOSviewer functions as both a foundational methodological tool and an adaptable platform for exploring dynamic scientific landscapes. Their interactions reveal a dual evolution, growing methodological sophistication alongside broadening thematic diversification, which highlights the increasing prominence of VOSviewer in contemporary research evaluation and science mapping.

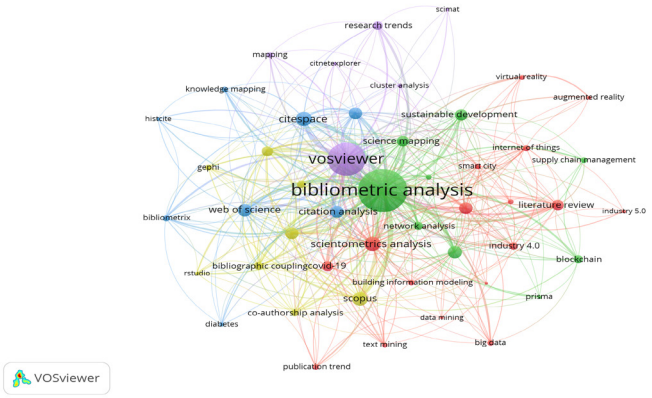

Figure 5: Keyword co-occurrence network of VOSviewer-based research (48 Keywords, 5 Clusters). A network visualisation showing five colour-coded thematic clusters derived from 48 high-frequency keywords (occurrence ≥ 3). The map illustrates the conceptual structure of VOSviewer-related research across methodological, technological and application-oriented domains

Thematic evolution over time: insights from the overlay visualisation: The overlay visualisation **(Figure 6)** offers a temporal perspective on the evolution of VOSviewer-related themes, assigning each keyword an average publication year, ranging from 2020 (purple/blue) to 2022 (yellow). This colour gradient reveals apparent shifts in research priorities, methodological practices and topical focus during the most recent phase of the field's development. The early period (approximately 2020), represented by cooler colours, emphasises foundational methodological concepts, including citation analysis, co-citation analysis, knowledge mapping, CiteSpace, HistCite and Web of Science. These themes reflect the period when bibliometric workflows were consolidating, particularly through increased use of multi-tool comparative analysis and high-quality database integration.

Entering 2021 (green), the visualisation shows a growing

emphasis on science mapping, network analysis, systematic literature reviews, scimat and cluster analysis. This middle period marks a methodological deepening, as researchers began employing more complex workflows that combine citation networks, temporal mapping and topic evolution techniques. VOSviewer increasingly operated not only as a visualisation tool but also as part of multi-stage analytical pipelines. The most recent period (≈ 2022) marked in yellow captures a decisive shift toward emerging technologies and real-world applications. Keywords such as big data, artificial intelligence, internet of things, virtual reality, Industry 4.0, Industry 5.0, smart city and blockchain signal the surging use of VOSviewer in technologically dynamic and data-intensive fields. The presence of COVID-19, publication trends and literature reviews underscore the central role of VOSviewer in synthesising the rapidly evolving post-pandemic scientific output.

Overall, the overlay visualisation indicates a dual trajectory in the evolution of VOSviewer research: (1) methodological sophistication through advanced network metrics, temporal analyses and multi-tool validation; and (2) topical expansion driven by technological innovation and societal shifts. This evolution highlights VOSviewer's transformation from a specialised bibliometric tool into a versatile analytical platform increasingly used across disciplinary boundaries.

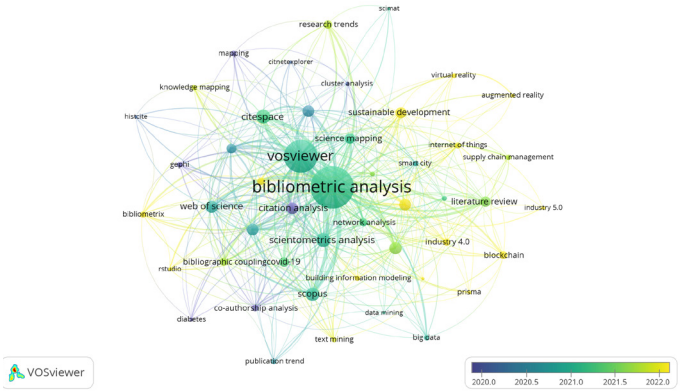

Figure 6: Overlay visualisation of author keyword co-occurrences, highlighting temporal thematic evolution (2020–2022). An overlay visualisation showing the temporal progression of key themes in VOSviewer-based research. Colours indicate the average publication year of each keyword, highlighting emerging research trends linked to digital technologies, intelligent systems and post-pandemic scientific growth

Analytical techniques applied in VOSviewer-based studies (RQ3)

This subsection synthesises the methodological patterns observed across the 30-study sample, drawing upon both the most cited foundational studies and the most recent publications. The analysis integrates performance data from the binary technique matrix (Table 3). It provides an interpretive discussion of the prevalence, purpose and disciplinary alignment of the five core bibliometric techniques: citation analysis, co-citation analysis, co-authorship analysis, keyword co-occurrence and bibliographic coupling.

Overview of technique usage across the dataset: The integrated dataset demonstrates a clear methodological hierarchy. Citation analysis (26/30 studies) and keyword co-occurrence analysis (26/30) are by far the most frequently applied techniques, followed by co-citation analysis (18/30) and co-authorship analysis (17/30). Bibliographic coupling is used least often, appearing explicitly in only 8 of the 30 studies **(Table 3)**. This distribution reflects both the evolution of bibliometric methodologies and the shifting analytical priorities of researchers. Foundational studies tend to emphasise citation-based and co-citation approaches[22-24], whereas contemporary research increasingly privileges co-occurrence mapping for conceptual exploration[25-27].

Dominance of citation analysis

Citation analysis is the most consistently used technique across both early influential studies and the more recent datasets. This universality reflects its role in establishing foundational performance metrics, identifying influential documents and guiding subsequent mapping of intellectual structure. The approach is central[22], normalisation processes[23] and citation-based clustering and is routinely embedded in applied studies[24,28-30]. The recent studies maintain this emphasis[31-35], all relying heavily on citation counts for performance assessment.

Expansion of keyword co-occurrence as a conceptual mapping tool: Keyword co-occurrence analysis, used in 26 of the 30 studies, has become the preferred method for mapping conceptual structures and identifying thematic clusters. Its rise is especially pronounced in the 2024 sample, where nearly all studies employ co-occurrence networks[25,26,36,37]. The technique's interpretive flexibility makes it particularly attractive for exploring emerging research frontiers, interdisciplinary topics and semantic relationships. In foundational work, co-occurrence is central[22]. It forms a core element of studies[38-40], underscoring its methodological longevity.

Co-citation analysis: stable but declining in recent usage: Co-citation analysis is used in 18 studies, dominating earlier work but appearing less frequently in recent publications. Early studies employ co-citation to reveal intellectual foundations and map scholarly traditions[29,30,39,41]. In contrast, fewer 2024 studies employ co-citation analysis, with notable exceptions including[31,33,34,42]. This shift suggests that contemporary researchers increasingly favour forward-looking, conceptually oriented techniques (such as co-occurrence) over historically grounded intellectual mapping.

Co-authorship analysis: identifying collaborative structures: Co-authorship networks appear in 17 studies, with usage patterns influenced by domain-specific interests in collaboration, institutional connectivity and international research dynamics. In foundational literature, co-authorship is used[24,28,38,41]. The studies have expanded this trend to examine collaboration patt erns[24,28,32,33,35,37,41-43]. The technique's moderate but steady usage reflects increasing scholarly attention to social and institutional research structures.

Limited application of bibliographic coupling: Bibliographic coupling is the least implemented technique across the dataset, appearing in only eight studies. Its use is explicitly mentioned[24,29,38,44]. In recent 2024 studies, bibliographic coupling appears only sporadically, sometimes expressly[33,45] and sometimes implied through citation link analysis[32,34]. The limited adoption may stem from researchers' preference for conceptually intuitive mapping tools and the additional interpretive complexity associated with coupling-based networks.

Table 3: Summary of bibliometric techniques used across the 30-study sample. (✓ = technique used; — = not used; "implied" = indicated but not explicitly operationalized).

Study	Citation analysis	Co-citation analysis	Co-authorship analysis	Co-occurrence analysis	Bibliographic coupling
Most cited studies					
[22]	✓	✓	—	✓	—
[23]	✓	(acknowledged)	—	—	(acknowledged, not used)
[24]	✓	—	✓	✓	✓
[46]	—	—	—	✓	—
[47]	✓	—	—	✓	—
[44]	✓	✓	✓	✓	✓
[41]	✓	✓	✓	—	—
[28]	✓	—	✓	—	—
[38]	—	✓	✓	✓	✓
[29]	✓	✓	—	✓	✓
[39]	✓	✓	—	✓	✓
[30]	✓	✓	—	✓	—
[40]	✓	✓	—	✓	—
[48]	✓	(implied)	✓	✓	—
[49]	✓	✓	✓	✓	✓
Most recent studies					
[26]	—	—	—	✓	—
[31]	✓	✓	—	✓	—
[25]	✓	—	✓	✓	—
[27]	✓	—	—	✓	—
[32]	✓	—	✓	✓	(implied)
[50]	—	—	✓	✓	—
[36]	✓	—	—	✓	—
[42]	✓	✓	✓	✓	(mentioned as a future method)
[51]	✓	✓	—	—	(implied)
[33]	✓	✓	✓	✓	✓
[34]	✓	✓	✓	✓	(implied)
[43]	✓	✓	✓	✓	—
[45]	✓	✓	✓	✓	✓
[35]	✓	—	✓	✓	—
[37]	✓	—	✓	✓	—

The methodological profile of VOSviewer scholarship illustrates a clear evolution:

- Citation analysis and co-occurrence analysis now constitute the primary dual framework for most studies, reflecting a balance between performance metrics and conceptual mapping.
- Co-citation analysis, once foundational, is now less prominent, suggesting a shift toward forward-looking thematic exploration rather than retrospective mapping of intellectual lineage.
- Co-authorship analysis is increasingly used to understand the social structure of research fields.
- Bibliographic coupling remains marginal despite its potential for identifying cutting-edge research fronts.

Collectively, the findings suggest that contemporary bibliometric practice has shifted toward concept-driven, collaboration-aware and trend-oriented analytic approaches, reflecting broader trends in research evaluation, interdisciplinarity and digital scholarship.

Integration of VOSviewer with other bibliometric tools (RQ4)

This subsection assesses the integration of VOSviewer with complementary bibliometric and visualisation tools across the 30-study corpus. The assessment draws on both foundational methodological literature and recent applied studies, allowing for the identification of longitudinal shifts in software usage and workflow design. The findings show that although VOSviewer remains the central visualisation tool, its application is increasingly embedded within multiphase analytical workflows that incorporate additional platforms-most notably Bibliometrix/Biblioshiny and CiteSpace, with Gephi and CitNetExplorer used less frequently.

Overview of integration patterns: The analysis shows considerable variation in how VOSviewer is employed across studies. Foundational methodological works tend to emphasise complementary tools that address citation-path exploration, network scalability and reference standardisation, such as Pajek, CitNetExplorer, CRExplorer and Publish or Perish. Studies from

2010 to 2020 frequently position VOSviewer as one component of a broader methodological ecosystem, rather than as a standalone tool. In contrast, more recent studies increasingly integrate VOSviewer with Bibliometrix/Biblioshiny and CiteSpace, tools that enhance reproducibility, statistical depth and temporal mapping. This stage-wise evolution highlights a maturation in bibliometric workflows, reflecting both technological advancements and the growing emphasis on transparent and replicable research design.

Integration with bibliometrix and biblioshiny: Integration with Bibliometrix/Biblioshiny appears primarily in the 2024 dataset and has become one of the most consistent multi-tool configurations. Studies utilise Biblioshiny for performance indicators, thematic evolution and statistical modelling, while relying on VOSviewer for visual network mapping[25,27,33,37,42]. This combination leverages Bibliometrix's analytical breadth and VOSviewer's strengths in cluster visualisation and interactive exploration. Earlier work also validates the compatibility of Bibliometrix and VOSviewer, indicating that hybrid workflows are not only widespread but increasingly normative[49].

Integration with CiteSpace: CiteSpace is frequently used in studies requiring temporal, evolutionary or burst detection analyses, functions not available in VOSviewer. Foundational integration occurs, where CiteSpace is referenced as an essential tool for trend analysis[22]. Operationalise CiteSpace more systematically, applying it to identify citation bursts, detect emerging themes and generate timeline views[30,41]. In contrast, VOSviewer is used for visualising co-occurrence and co-citation networks. Recent studies continue to employ this dual-method approach, confirming that CiteSpace remains a crucial complement when longitudinal or temporal intelligence is required[27,34].

Integration with gephi: Gephi appears selectively across the dataset, applied only where advanced network manipulation or interactive layouts are required. A clear example is those who utilise VOSviewer for initial visualisation but rely on Gephi for more in-depth network analysis and refinement[44]. This pattern suggests that while VOSviewer excels in generating ready-made, interpretable networks, some researchers turn to Gephi for algorithmic flexibility (e.g., ForceAtlas2) and enhanced visual customizability. In recent studies, however, supplementary visualisation is achieved using lighter graphical tools, such as RAWGraphs or Photoshop, rather than Gephi, indicating a shift toward accessibility over complexity.

Integration with CitNetExplorer: CitNetExplorer is primarily used in foundational methodological studies, as its role serves as a citation-path and clustering engine[23]. The software's integration with VOSviewer is intentional and seamless, given that both tools share the same developers and conceptual frameworks. Incorporate CitNetExplorer for citation-based exploration[24]. Despite its utility, CitNetExplorer is rarely used in the 2024 dataset, indicating a shift in disciplinary preference toward more versatile platforms, such as Bibliometrix and CiteSpace. Nevertheless, CitNetExplorer remains valuable for historiographic analyses and fine-grained examination of citation lineages.

Additional tools supporting VOSviewer workflows: Both foundational and contemporary studies employ secondary tools to enhance bibliometric outputs. Examples include Pajek, SPSS and Network Workbench[22]. CRExplorer and Publish or Perish[24]. GraphPad Prism[41]. RAWGraphs, MapChart, WordClouds and Adobe Photoshop[43,51]. These tools demonstrate the methodological flexibility of bibliometric research, wherein VOSviewer often coexists with auxiliary platforms for statistical modelling, preprocessing or enhanced visualisation. **(Table 4)** presents a consolidated overview of how each study integrates VOSviewer with other bibliometric tools. This matrix illustrates software co-use patterns and highlights the extent to which VOSviewer is embedded in multi-tool analytical ecosystems.

Table 4: Software integration patterns across the 30-study sample. (✓ = used; — = not used; "mentioned" = referenced but not actively used; "recommended" = suggested for future work).

Study	VOSviewer	Bibliometrix / Biblioshiny	CiteSpace	Gephi	CitNetExplorer	Other tools
Most cited studies						
[22]	✓	—	mentioned	—	mentioned	SPSS, Pajek, Network Workbench
[23]	✓	—	—	—	✓	—
[24]	✓	—	—	—	✓	CRExplorer, Publish or Perish, ScientoPyUI
[46]	✓	—	—	—	—	—
[47]	✓	—	—	—	—	—
[44]	✓	—	—	✓	—	—
[41]	✓	—	✓	—	—	GraphPad Prism
[28]	✓	—	—	—	—	—
[38]	✓	—	—	—	—	—
[29]	✓	—	—	—	—	—
[39]	✓	—	—	—	—	—
[30]	✓	—	✓	—	—	—
[40]	✓	—	—	—	—	—
[48]	✓	—	—	—	—	—
[49]	✓	✓	—	—	—	—
Most recent studies						
[26]	✓	—	—	—	—	—

31	✓	—	—	—	—	—
25	✓	✓	—	—	—	—
27	✓	✓	✓	—	—	—
32	✓	—	—	—	—	R software
50	✓	—	—	—	—	(ScientoPy (recommended
36	✓	—	—	—	—	—
42	✓	✓	—	—	—	—
51	✓	—	—	—	—	RAWGraphs, Scimago Graphical Tool, Adobe Photoshop
33	✓	✓	—	—	—	—
34	✓	—	✓	—	—	—
43	✓	—	—	—	—	Sankey software, MapChart, Wordclouds
45	✓	—	—	—	—	MS Excel
35	✓	—	—	—	—	—
37	✓	✓	—	—	—	—

Methodological, technical and interpretive challenges and future research directions (RQ5)

The 30-study corpus reveals a diverse yet convergent set of methodological, technical and interpretive challenges, along with a rich agenda for future research that is highly relevant to VOSviewer-based bibliometric work. While several papers focus primarily on domain-specific issues (e.g., SDGs, digital transformation, circular economy, health sciences), their reflections on data, indicators, software and interpretation highlight recurring constraints in how bibliometric mapping is currently designed and utilised.

Methodological limitations and risks of bias: A first cluster of issues concerns study design, data selection and indicator bias. Several studies highlight the limitations of relying on single databases (usually Scopus or Web of Science), which constrain coverage and can bias the representation of a field. This concern is explicit[30,39,47,49] and is echoed in recent work[37,42,45,50,51], all of which note that using a single index or language (English only) risks omitting significant contributions and distorting impact patterns. Bibliometric indicator bias is another recurring theme. Question the h-index, arguing that it disadvantages highly cited but less prolific authors[40]. In contrast, the emphasis is that total citations systematically favour older publications and that normalised citations provide only a partial remedy[39]. The caution that citation counts fluctuate over time and can disadvantage recent work, particularly when analyses are limited to "most cited" subsets, is noted[30,34].

Methodological subjectivity and incompleteness arise at multiple levels. The studies note that the literature selection, inclusion criteria and coding decisions can introduce subjective bias, particularly in the "manual" or narrative components of the review[32,44,47,48]. Additionally, it is emphasised that interpreting clustering solutions primarily for large publication sets requires substantive expert knowledge and a basic understanding of clustering techniques to avoid misinterpretation[23]. Acknowledge that relying solely on author keywords, without a critical appraisal of the included studies, limits the depth of conceptual and methodological insight[27]. In recent studies, additional design issues have emerged, including the restriction of analyses to English publications[32,33,50], which focus only on a narrow subset, such as the "top 10" cited articles[45] or neglecting systematic critical appraisal of evidence[27,32]. These patterns show that while bibliometric techniques are becoming more sophisticated, basic safeguards of systematic review methodology (transparent criteria, sensitivity analysis, multi-database triangulation) are not yet consistently implemented.

Technical and data-related challenges: A second group of challenges is technical, relating to the nature of large bibliometric datasets and the capabilities of existing tools. Underline the difficulty of handling large, heterogeneous and distributed "big data", particularly in medical domains, where storage architectures, integration of disparate sources and sampling bias pose significant barriers[41]. It is emphasised that researchers require theoretical and practical tools explicitly designed for bibliometrics, rather than repurposed generic software[24]. They also note that bibliometric databases have uneven coverage across fields, thereby compounding bias in any analysis.

From a software perspective, the study highlights the complexity of clustering large publication sets and the limitations of CitNetExplorer for aggregate-level analysis[23]. Additionally, it is worth noting the technical difficulty of combining metadata from multiple sources and arguing that users often require capabilities beyond what a single tool (including VOSviewer) can deliver, especially when integrating multi-country or multi-institutional data[49]. In the 2024 corpus, technical constraints are often tied to data architecture and coverage rather than to VOSviewer itself. The studies emphasise the consequences of database choice, keyword selection and document-type filters for the completeness and robustness of their maps[31,33,37,42,50,51]. Furthermore, note that emerging methodological approaches, such as autoethnography, particularly when intersecting with digital technologies and religious practices, create additional challenges for integrating qualitative and quantitative evidence within a coherent analytical framework[26].

Interpretive challenges and conceptual blind spots: Beyond design and data, several studies emphasise interpretive risks of how maps and metrics are read and what they leave out. Explicitly warn that interpreting clustering and network visualisations requires expert domain knowledge and an understanding of how algorithms work; otherwise, users risk overinterpreting cluster boundaries or mistaking technical artefacts for substantive patterns[23]. Acknowledge that very detailed networks can overwhelm interpretation and obscure rather than clarify key terms[48]. In contrast, caution is warranted that the choice of tools

and models can shape theoretical conclusions, sometimes in unexamined ways[44,47].

Several studies highlight blind spots in terms of what bibliometric analysis tends not to capture. Argue that traditional frameworks struggle to reflect the complexity of phenomena such as the SDGs and digitalisation; bibliometric maps alone cannot fully represent institutional, country-level or sectoral heterogeneity[29,39]. Stress that static bibliometric snapshots fail to capture the dynamic evolution of sustainability practices[25], while noting that bibliometric analyses often overlook the societal or clinical impact, instead focusing on scholarly outputs[27,37].

Language and database restrictions also have interpretive implications. Explicitly note that focusing on English-language literature, specific Web of Science categories or a narrow set of document types can systematically exclude relevant work and skew perceived research frontiers[34,43,45,51]. Demonstrate that, in the context of Sudanese clinical health and medical care research, bibliometric mapping can reveal the underrepresentation of local challenges and collaboration needs; however, it cannot, by itself, diagnose the deeper structural constraints within health systems[35].

Future research directions: towards more robust and integrative VOSviewer-based workflows

Despite these challenges, the corpus offers a rich set of future research directions that collectively outline an agenda for improving VOSviewer-based bibliometrics.

- **Integrated and advanced software environments:** It explicitly proposes the development of an integrated tool that combines CitNetExplorer and VOSviewer, enabling interactive exploration, multi-level clustering and flexible aggregation of citation relations[23]. Similarly, argue for tools that can better handle multi-source metadata and support international, multi-country studies[49]. In contrast, a call is for more specialised, bibliometrics-oriented software that can handle experimental and domain-specific data structures[24].
- **Multi-database, multi-method and longitudinal designs:** A strong theme across both older and recent studies is the recommendation to move beyond single-database, cross-sectional designs. The studies suggest using multiple databases (e.g. Scopus, Web of Science, Google Scholar) and broader query strategies, as well as incorporating non-English literature where possible[25,30,37-39,42,45,49-51]. It is also recommended to adopt longitudinal and mixed-method approaches, integrating bibliometric mapping with empirical, case-based and survey data to capture the dynamics and real-world impacts of sustainability and resilience practices[25].
- **Stronger links between bibliometric patterns and substantive theory:** Emphasise that bibliometric work should not remain purely descriptive[29,39,44]. They call for theory-building and theory-testing frameworks that connect cluster structures and thematic maps to conceptual models in digital transformation, marketing, SDGs and business models. Similarly, advocates are developing standardised metrics and conceptual frameworks in the virtual word-of-mouth literature[33]. At the same time, encourage future research on competitiveness and knowledge management in emerging countries, guided by insights from science mapping[40].
- **Better treatment of uncertainty, quality and context:** Several studies suggest that future bibliometric research should place greater emphasis on uncertainty, quality appraisal and context. Discuss the misrepresentation of measurement uncertainty and overconfident reporting of significant figures in the context of BET methods, illustrating how quantitative techniques can be misused if underlying assumptions are not scrutinised[46]. Argue that systematic reviews should incorporate comprehensive quality assessment and synthesis of evidence rather than relying solely on bibliometric metrics[32]. Suggest that future work should include a critical appraisal of the included studies and assess their broader societal or clinical impact, rather than citation-based influence[25,27].
- **Thematic and domain-specific research agendas informed by bibliometrics:** Finally, many future research suggestions are domain-specific but still shaped by bibliometric insights. Examples include: advancing platform research and digital innovation[30], exploring new business model archetypes[39], deepening research on circular economy practices and eco-design[48], expanding SDG-related work in business and policy[29,38], investigating non-exhaust emissions and brake-pad wear mechanisms[32], refining accounting methods for the circular economy[50] and exploring microbiome-based biomarkers and therapies in IgAN[34]. Even where the agenda is substantive rather than methodological, bibliometric mapping is used as a launchpad for targeted, hypothesis-driven research. Overall, the evidence from RQ5 indicates that VOSviewer-based studies are becoming increasingly aware of their own limitations and blind spots and are actively proposing ways to address them. The emerging consensus points toward integrated, multi-tool workflows; multi-database and multi-method designs; stronger theoretical grounding; and explicit attention to data quality, uncertainty and societal relevance as key priorities for the next generation of bibliometric and science-mapping research.

Key findings, Limitations of this study and Future Directions

Key findings

This study provides the first longitudinal and meta-analytical evaluation of VOSviewer-based scholarship from 2010 to 2024, analysing publication trends, conceptual structures, methodological techniques, interoperability patterns and reported challenges. Four overarching findings emerge.

- First, VOSviewer has undergone exponential global adoption, with the number of annual publications increasing from fewer than 20 between 2010 and 2015 to nearly 4000 in 2024. This growth reflects not only wider access to bibliometric methods but also the mainstreaming of science mapping across various disciplines, particularly Medicine, the social sciences, computer science, environmental studies and business research.
- Second, the conceptual landscape of VOSviewer research comprises five tightly interlinked thematic clusters: (1) technology- and innovation-driven fields (AI, IoT, Industry 4.0/5.0), (2) methodological and review-oriented scholarship, (3) multi-tool integration and database diversification, (4) advanced network-analytic and algorithmic techniques and (5) conceptual architecture and trend-evolution mapping.

Together, these clusters reveal both methodological consolidation and thematic diversification, with VOSviewer positioned as a central tool linking traditional bibliometrics to emerging digital-science domains.

- Third, VOSviewer-based research exhibits a stable methodological core. Citation analysis and keyword co-occurrence analysis dominate contemporary workflows, while co-citation and co-authorship networks remain important but less consistently applied. Bibliographic coupling is the least used technique, indicating that researchers prefer more interpretable forward- or backwards-looking approaches over structurally complex coupling-based networks.
- Fourth, the integration of VOSviewer with other platforms is now widespread. Bibliometrix/Biblioshiny and CiteSpace serve as the most common complements, offering statistical modelling and temporal intelligence, respectively. Foundational studies draw more heavily on CitNetExplorer, Pajek and HistCite, while a subset of recent studies incorporates Gephi, RAWGraphs and other visualisation tools. This confirms that VOSviewer increasingly operates within multi-method, multi-tool analytical ecosystems, rather than as a standalone environment.

Limitations of this study

Although the study offers a comprehensive evaluation, several limitations should be acknowledged.

- Firstly, database coverage. The analysis relies exclusively on Scopus-indexed publications, which, although broad, still excludes non-indexed regional outputs, grey literature, non-English publications and works archived in WoS, Google Scholar, Dimensions or national repositories. This may introduce geographical and disciplinary bias.
- Secondly, methodological sampling. The qualitative component (RQ3–RQ5) is based on a purposive sample of 30 studies. While selected to maximise temporal and methodological diversity, this sample cannot encompass the full heterogeneity of over 10,000 VOSviewer-related publications.
- Thirdly, keyword-based conceptual mapping. Conceptual structures (RQ2) rely on author-supplied keywords, which can be inconsistent, incomplete or strategically chosen. Although thesaurus-based cleaning minimised noise, the results remain sensitive to author practices and metadata quality.
- Fourthly, tool-specific constraints. VOSviewer's own design influences what can be visualised and how clusters form. Its lack of built-in temporal analytics limited statistical modelling and reliance on user-selected thresholds may shape interpretations in ways not fully controlled for in this review.
- Finally, interpretive subjectivity. As with all bibliometric syntheses, cluster labelling, theme interpretation and identification of emerging trends involve human judgement informed by contextual reading. Alternative interpretations of the same networks are possible.
- Together, these limitations suggest that while the findings offer strong methodological insights, they should be understood within the epistemic boundaries inherent to database-driven bibliometric research.

Future research directions

The synthesis of methodological challenges across the 30-study corpus highlights several priorities for advancing VOSviewer-based bibliometrics.

- Multi-database, multi-language and cross-platform workflows. Future studies should integrate Scopus, Web of Science, Dimensions, PubMed and regional databases to reduce geographical bias and increase robustness. Expanding beyond English-language corpora is essential for capturing global scholarship more inclusively.
- Integrated analytical ecosystems. There is a strong need for improved interoperability between VOSviewer and complementary platforms such as Bibliometrix, CiteSpace, Gephi and CitNetExplorer. Open APIs or unified interfaces could support reproducible workflows, temporal analyses and cross-validation of clusters.
- Methodological transparency and standardisation. Threshold settings, cleaning protocols, clustering parameters and bibliometric indicators should be documented more explicitly, enabling reproducibility and comparability across studies. Standard reporting frameworks analogous to PRISMA could help structure bibliometric methodology.
- Development of hybrid quantitative–qualitative bibliometrics. Combining science mapping with content analysis, critical appraisal, machine learning and natural language processing would enhance interpretive depth. Hybrid approaches are particularly promising for rapidly evolving fields such as biomedical research, AI and sustainability sciences.
- Addressing interpretive and contextual blind spots. Future research should investigate methods to integrate societal impact, clinical relevance, policy influence and equity considerations into bibliometric frameworks. Bibliometrics should complement, rather than substitute for, expert knowledge and substantive theorisation.
- Advancing frontier techniques. Bibliographic coupling, thematic evolution modelling and dynamic topic mapping remain underutilised. Their wider adoption could reveal emergent research fronts and enhance strategic research planning across disciplines.

Collectively, these directions point toward an emerging paradigm of integrated, transparent, context-aware and theory-informed bibliometrics.

Conclusions

This study provides the first comprehensive, meta-level evaluation of VOSviewer's methodological role within contemporary bibliometrics. Over the past fifteen years, VOSviewer has evolved from a specialised mapping tool into a widely adopted platform that underpins global science-mapping practices. Its exponential growth reflects both technical strengths, such as scalable clustering and intuitive visualisation, as well as database compatibility and the increasing demand for visual, data-driven research synthesis across disciplines.

The findings show that VOSviewer-based studies share a methodological centre of gravity, including citation analysis, co-occurrence analysis and cluster-based conceptual mapping, while exhibiting growing heterogeneity in thematic focus and software integration. The conceptual structure of the field reveals

a dynamic interplay between methodological consolidation and topical expansion, particularly in the areas of digital technologies, health sciences and sustainability.

At the same time, the study identifies persistent methodological, technical and interpretive challenges. These include reliance on single databases, inconsistencies in keyword metadata, subjective thresholding, limited temporal analytics and restricted interoperability. Addressing these challenges will require more sophisticated multi-tool workflows, stronger methodological standardisation, cross-database integration and more nuanced interpretive frameworks.

Ultimately, this study highlights that VOSviewer is not merely a visualisation tool, but a central methodological node within an evolving ecosystem of bibliometric and science-mapping practices. By clarifying its uses, limitations and future potential, the analysis contributes to the development of robust, transparent and contextually meaningful bibliometric research in the years ahead.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

This research did not receive any specific funding from public, commercial, or not-for-profit funding agencies. Institutional support was provided by the School of Coffee and Tea and the Yunnan International Joint Laboratory of Digital Conservation and Germplasm Innovation, Puer University. We also acknowledge the developers of VOSviewer for providing an open and accessible tool that supports bibliometric and science-mapping research.

References

1. Zupic I, Čater T. Bibliometric methods in management and organization. Organ Res Methods 2015;18(3):429-472.
2. Donthu N, Kumar S, Mukherjee D, et al. How to conduct a bibliometric analysis: An overview and guidelines. J Bus Res 2021;133:285-296.
3. Ali Abaker Omer A, Dong Y. Mapping the Use of Bibliometric Software and Methodological Transparency in Literature Review Studies: A Comparative Analysis of China-Affiliated and Non-China-Affiliated Research Communities (2015-2024). Publications 2025;13(3).
4. Chen C. CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. J Am Soc Inf Sci Technol 2006;57(3):359-377.
5. Aria M, Cuccurullo C. Bibliometrix: An R-tool for comprehensive science mapping analysis. J Informetr 2017;11(4):959-975.
6. van Eck NJ, Waltman L. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 2010;84(2):523-538.
7. Price DJ de S. Little Science, Big Science. Columbia University Press 1963.
8. Garfield E. Citation indexes for science. Science 1956;123(3184):61-62.
9. Small H. Co-citation in the scientific literature: A new measure of the relationship between two documents. J Am Soc Inf Sci 1973;24(4):265-269.
10. Callon M, Courtial JP, Turner WA, Bauin S. From translations to problematic networks: An introduction to co-word analysis. Soc Sci Inf 1983;22(2):191-235.
11. Persson O, Glänzel W, Danell R. Inflationary bibliometric values: The role of scientific collaboration and the need for relative indicators in evaluative studies. Scientometrics 2004;60(3):421-432.
12. Noyons ECM, Moed HF, Luwel M. Combining mapping and citation analysis for evaluative bibliometric purposes: A bibliometric study. J Am Soc Inf Sci 1999;50(2):115-131.
13. Chen C. Science Mapping: A Systematic Review of the Literature. J Data Inf Sci 2017;2(2):1-40.
14. van Eck NJ, Waltman L. CitNetExplorer: A new software tool for analyzing and visualizing citation networks. J Informetr 2014;8(4):802-823.
15. Batagelj V, Mrvar A. Pajek: Analysis and visualization of large networks. In: Freeman J, ed. Graph Drawing Software. Springer 2004:77-103.
16. Mrvar A, Batagelj V. Analysis and visualization of large networks with program package Pajek. Complex Adapt Syst Model 2016;4(1).
17. Garfield E. Historiographic mapping of knowledge domains literature. J Inf Sci 2004;30(2):119-145.
18. Bastian M, Heymann S, Jacomy M. Gephi: An open source software for exploring and manipulating networks. In: Proceedings of the International AAAI Conference on Web and Social Media 2009;3:361-362.
19. Marzi G, Balzano M, Caputo A, Pellegrini MM. Guidelines for Bibliometric-Systematic Literature Reviews: 10 steps to combine analysis, synthesis and theory development. Int J Manag Rev 2025;27(1):81-103.
20. Öztürk O, Kocaman R, Kanbach DK. How to design bibliometric research: an overview and a framework proposal. Rev Manag Sci 2024.
21. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372(71).
22. Jan N, Ludo VE. Software survey : VOSviewer , a computer program for bibliometric mapping. Published online 2010:523-538.
23. Eck NJ, Waltman L. Citation-based clustering of publications using CitNetExplorer and VOSviewer. Scientometrics 2017;111(2):1053-1070.
24. Moral-muñoz JA, Herrera-viedma E, Santisteban-espejo A, et al. Software tools for conducting bibliometric analysis in science: An upto-date review. El Prof la informa- ción 2020;29:1-20.
25. Abdelaziz S, Munawaroh M. Mitigating Supply Chain Vulnerabilities: A Bibliometric Analysis of Sustainable Logistics for Resilience and Risk Management with Perspectives on the Automotive Industry. Int J Automot Sci Technol 2024;8(4):544-588.
26. Au-Yong-Oliveira M, Bampoori M, Grassos T. Religious Tourism and Pilgrimage Tourism. J Tour Dev 2024;47:547-566.
27. Li C, He A, Hu J, Xia Y, He C, Zhuang W. Mapping the evolution and frontiers of Translational Lung Cancer Research: a bibliometric analysis and literature review. Transl Lung Cancer Res 2024;13(12):3764-3777.
28. Sarkodie SA, Strezov V. A review on Environmental Kuznets Curve hypothesis using bibliometric and meta-analysis. Sci Total Environ 2019;649:128-145.
29. Pizzi S, Caputo A, Corvino A, Venturelli A. Management research and the UN sustainable development goals (SDGs): A bibliometric investigation and systematic review. J Clean Prod 2020;276:124033.

30. Ding X, Yang Z. Knowledge mapping of platform research: a visual analysis using VOSviewer and CiteSpace. Electron Commer Res 2022;22(3):787-809.

31. Norgren E, Stankeviciene J. Systematic Literature Review on the Methodological Approaches of the Efficiency of Green Investment in Renewable Energy-Based Development. Forum Sci Oeconomia 2024;12(4):30-46.

32. Unaldi M, Uyaroğlu A. A Systematic Review of Brake Pad. Int J Automot Sci Technol 2024;8(4):404-418.

33. Jyoti N, Kumar J. Mapping the landscape of virtual word of mouth (v-WOM) in the tourism sector: A bibliometric review. Turyzm/Tourism 2024;34(2):155-169.

34. Li X, Li C, Wu P, et al. Recent status and trends of innate immunity and the gut-kidney aixs in IgAN: A systematic review and bibliometric analysis. Int Immunopharmacol 2024;143.

35. Omer F, Vo O, Care H. Bibliometric Analysis of Clinical Health and Medical Care Research: The Case of Sudan from 1991 to 2021 2024;36(3):98-116.

36. Damayanti FN, Wiyanti Z, Istiana S, Kusumawati E, Pranata S. Medical Crimes in Midwifery Cases: Bibliometrics Analysis. Babcock Univ Med J 2024;7(2):42-50.

37. Chen J, Sun L, Shilko TA, et al. Exploring exercise interventions in substance abuse treatment: A comprehensive bibliometric analysis. Medicine (Baltimore) 2024;103(51):41018.

38. Belmonte-ure LJ, Joaquín F, Camacho-ferre F. Agricultural waste : Review of the evolution , approaches and perspectives on alternative uses 2020;22.

39. Caputo A, Pizzi S, Pellegrini MM, Dabi M. Digitalization and business models : Where are we going ? A science map of the field 2021;123:489-501.

40. Gaviria-marin M, Merigó JM, Baier-fuentes H. Knowledge management: A global examination based on bibliometric analysis 2019;140:194-220.

41. Liao H, Tang M, Luo L, et al. A Bibliometric Analysis and Visualization of Medical Big Data Research. Published online 2018:1-18.

42. Kaith A, Sachdeva G. Bibliometric insights into green human resource management: A connection with business ethics and values. Purushartha 2024;17(1):51-63.

43. Esmer Y, Dertli Ş. Bibliometric Analysis of Sport Entrepreneurship Literature: The Case of Web of Science. Res Sport Educ Sci 2024;26(4):159-176.

44. Donthu N, Kumar S, Pattnaik D. Forty- fi ve years of Journal of Business Research : A bibliometric analysis 2020;109:1-14.

45. Tokgöz Kaplan T. Evidence-Based Bibliometric and Scientometric Analysis of Research on Casein Phosphopeptide Amorphous Calcium Phosphate. Selcuk Dent J 2024;11(3):303-308.

46. Bardestani R, Patience GS. Experimental methods in chemical engineering : specific surface area and pore size distribution measurements - BET 2019:2781-2791.

47. Kraus S, Jones P, Kailer N, Weinmann A, Chaparro-banegas N. Digital Transformation : An Overview of the Current State of the Art of Research 2021.

48. Ferasso M, Beliaeva T, Ribeiro-soriano D, Kraus S, Clauss T. Circular economy business models : The state of research and avenues ahead 2020:3006-3024.

49. Arruda H, Silva ER, Lessa M, Proença Jr D, Bartholo R. VOSviewer and bibliometrix. J Med Libr Assoc JMLA 2022;110(3):392.

50. Maksymiv Y, Shkromyda N, Urbančič J. Accounting And Reporting In Supporting The Transition To A Circular Economy: A Bibliometric Analysis. J Vasyl Stefanyk Precarpathian Natl Univ 2024;11(4):101-110.

51. Yan Y, Lee J. Research Status, Hotspots And Evolution In The Field Of Online Music Education: A Bibliometric Review. Yegah Musicol J 2024;7(4):1161-1190.