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Clustering Analysis: A Note on Methodologies and Trends

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Abstract

This study conducts a bibliometric analysis of clustering techniques in scientific research using VOSviewer and Gen-AI-based Consensus.app. The dataset was collected from Scopus and the Web of Science using predefined queries to filter articles published in 2024 and 2025. VOSviewer was utilized to visualize co-authorship networks, keyword co-occurrence, citation relationships, bibliographic coupling, and co-citation patterns, revealing key research clusters and influential studies. Additionally, Consensus.app was employed to generate AI-driven insights, summarizing key themes and emerging trends in clustering methodologies. The results indicate that clustering research is highly collaborative, with strong institutional networks and interdisciplinary applications. Machine learning, data mining, and network analysis emerge as dominant themes, with key publications shaping methodological advancements. The co-citation network highlights foundational studies that have influenced the field. By combining traditional bibliometric techniques and AI-based analysis, this study offers a comprehensive perspective on clustering research, identifying knowledge gaps and potential future directions. These findings provide valuable insights for researchers seeking to explore emerging topics, collaborate effectively, and contribute to the development of clustering methodologies. However, this study is limited to publications indexed in Scopus and Web of Science within the years 2024–2025, which may not fully capture longer-term developments. Future research could expand the scope to other databases and timeframes for a broader perspective.

Keywords: Bibliometric Analysis; Clustering; Co-Citation; Consensus.app; Machine Learning; VOSviewer

I. Introduction

In recent years, clustering analysis has gained significant attention in various research fields, ranging from machine learning and data science to bioinformatics and bibliometric studies. Clustering techniques are widely used to identify patterns, segment large datasets, and uncover hidden structures in data. As scientific literature continues to grow exponentially, bibliometric analysis has emerged as a crucial method for evaluating research trends, mapping intellectual landscapes, and identifying influential studies. By leveraging bibliometric tools such as VOSviewer, researchers can visualize and analyze co-authorship networks, keyword co-occurrences, citation relationships, and other scholarly interactions [1], [2]. Despite the extensive application of clustering methods in various domains, there is a need for a systematic analysis of how clustering has been studied and applied in bibliometric research. Understanding the development of this field can provide insights into emerging trends, dominant research clusters, and potential future directions. This study aims to bridge this gap by conducting a bibliometric analysis of clustering-related research, examining its evolution, key contributors, and thematic focus areas [3], [4].

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Previous bibliometric studies on clustering have primarily focused on analyzing keyword co-occurrence and co-authorship networks, mapping collaboration patterns, and identifying dominant research themes. While these approaches provide valuable insights into research trends, they often lack a deeper examination of how studies are interconnected at the citation level. This study extends beyond conventional bibliometric analyses by integrating bibliographic coupling and co-citation analysis, offering a more comprehensive perspective on the intellectual structure of clustering research. By incorporating these additional methodologies, we can identify not only the most frequently discussed topics but also the foundational studies that have shaped the field. This approach allows for a more nuanced understanding of clustering trends, uncovering influential works and emerging areas that may not be apparent through traditional co-authorship or keyword analyses alone [5], [6]. The main objective of this study is to explore the research landscape of clustering techniques through bibliometric analysis, using data extracted from high-impact journals. By analyzing co-authorship patterns, keyword associations, and citation networks, this study seeks to identify influential works, major research collaborations, and thematic clusters in the field. The findings are expected to contribute to a better understanding of the role of clustering methods in knowledge discovery and provide valuable insights for future research and collaboration opportunities [3], [7].

This study contributes to theory by extending bibliometric methodologies with the integration of AI-based literature synthesis, offering a hybrid approach that moves beyond conventional keyword or citation analyses. From a practical perspective, the study provides actionable insights for researchers to identify influential works, emerging themes, and collaboration opportunities in clustering research. The scientific novelty lies in combining VOSviewer with Consensus.app, which has rarely been applied in clustering-related bibliometric studies, thereby producing a richer and more interpretive mapping of the research landscape. Readers can benefit from this study as it not only maps the state-of-the-art but also highlights knowledge gaps and future directions that are crucial for advancing clustering methodologies across disciplines.

II. Methodology

This study employs a bibliometric analysis approach to examine research trends related to clustering and analysis methodologies. Data for this study were retrieved from Scopus and Web of Science, ensuring a comprehensive and high-quality dataset. The search query used for data collection included specific filters, such as publication type (articles only), publication stage (final), source type (journals), and language (English). Additionally, only publications from 2024 and 2025 were considered to capture the latest research developments in this field [8]. The selection criteria for the dataset involved several key parameters. First, documents had to include clustering and analysis-related terms in their title, abstract, or keywords to ensure relevance. Second, studies were filtered to exclude review papers, focusing solely on original research articles. Furthermore, publications with a minimum citation threshold were considered to highlight influential studies. By applying these selection parameters, we ensured that the dataset reflected cutting-edge research and key contributions to the domain [9], [10].

For the data analysis, we utilized VOSviewer, a widely used tool for bibliometric mapping and visualization. The analysis focused on multiple bibliometric aspects, including co-authorship networks, co-occurrence of keywords, citation analysis, bibliographic coupling, and co-citation analysis. These techniques enabled the identification of research clusters, collaboration patterns, and the most influential studies in clustering research. The findings were visualized through network maps, helping to uncover hidden structures and relationships within the selected publications [11], [12].

To enhance clarity, a research framework is provided in Figure 1, illustrating the overall process of this study. The workflow begins with data collection from Scopus, followed by data cleaning and preprocessing to ensure relevance and quality. Next, bibliometric mapping is conducted using VOSviewer to identify co-authorship, co-occurrence, and citation structures. The subsequent stage involves NLP and topic modeling, which in this study is supported by Gen-AI through Consensus.app to automatically synthesize and interpret insights from the retrieved literature. Finally, the outputs undergo visualization and interpretation, highlighting research trends, collaboration networks, and

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emerging themes in clustering methodologies. This process-oriented framework ensures that each stage is systematically connected, combining traditional bibliometric analysis with AI-driven approaches for deeper exploration.

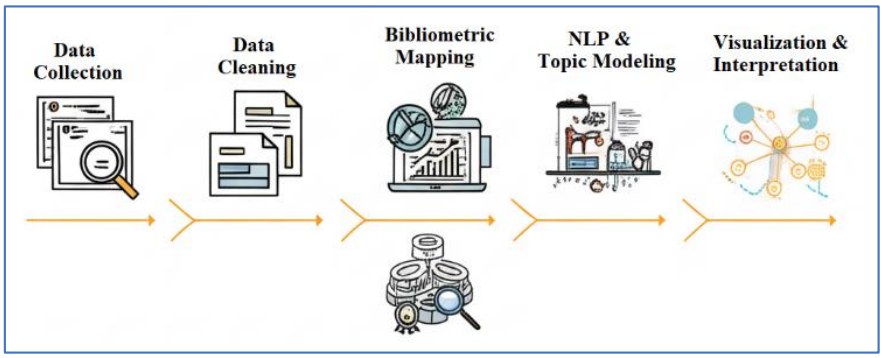


Figure 1. Methodological workflow

Figure 2 presents the front view of VOSviewer, a widely used software for bibliometric mapping. The interface provides an interactive visualization of relationships between research entities such as authors, keywords, or cited documents. Each node in the visualization represents an item (e.g., an author or keyword), while the size of the node reflects its frequency or level of influence in the dataset. The colors indicate clusters that group related items together, showing thematic patterns within the literature. Links between nodes represent co-authorship, co-occurrence, or citation connections, depending on the selected analysis type. This visualization enables researchers to intuitively explore collaboration networks, topic associations, and the structural organization of knowledge in the clustering research domain.

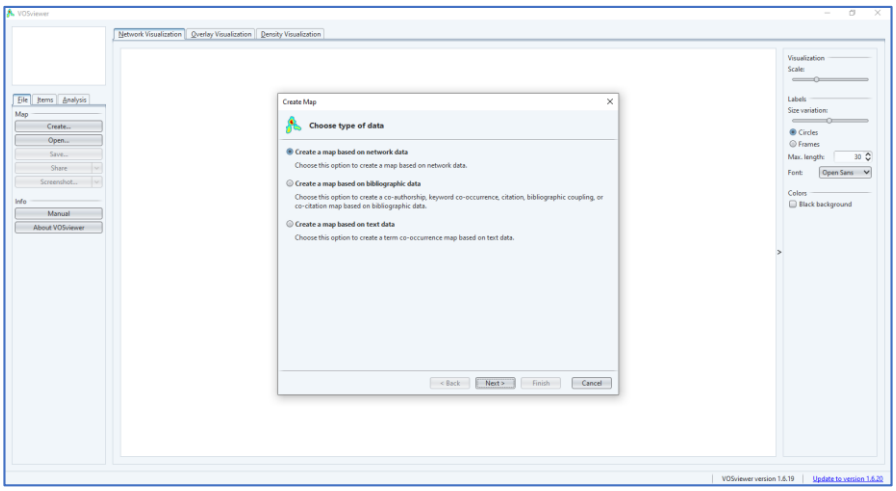


Figure 2. Vosviewer front view

Figure 3 presents the front view of Consensus.app, a Gen-AI-based platform utilized in this study to support NLP and topic modeling. The interface provides an AI-driven synthesis of literature by extracting, summarizing, and clustering relevant insights from scientific articles. Through its natural language processing capabilities, Consensus.app enables researchers to identify key themes, emerging topics, and consensus findings across large volumes of publications. This feature complements the bibliometric visualizations generated by VOSviewer, offering a more interpretive layer of analysis that bridges quantitative mapping with qualitative insights. The integration of this tool illustrates how Gen-AI can enhance the depth and clarity of bibliometric studies by automating the synthesis of textual data.

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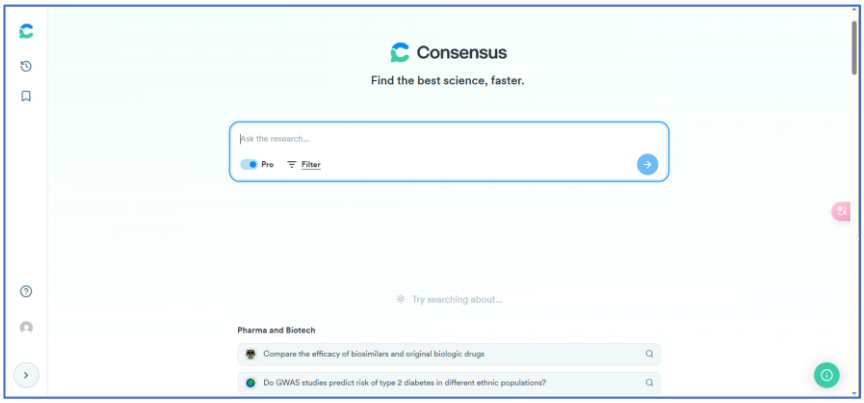


Figure 3. Consensus.app front view [13]

To ensure a comprehensive and high-quality dataset, this study retrieved bibliometric data from Scopus and Web of Science using the following query: TITLE-ABS-KEY (cluster AND analysis) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (EXACTKEYWORD , "Article")) AND (LIMIT-TO (PUBYEAR , 2024) OR LIMIT-TO (PUBYEAR , 2025)). This selection criterion ensures that only relevant, peer-reviewed journal articles from the latest research in 2024 and 2025 are included in the study. Unlike previous bibliometric analyses that primarily focus on co-authorship and keyword co-occurrence, this study integrates bibliographic coupling and co-citation analysis to provide a more comprehensive perspective on clustering research trends. Additionally, besides using VOSviewer, we also employed Gen-AI-based analysis using Consensus.app, which leverages AI-driven insights to summarize key findings from the retrieved literature. The integration of AI-assisted bibliometric tools enhances the accuracy and depth of the analysis, allowing for a more nuanced understanding of research clusters and emerging trends in clustering methodologies [14], [15].

While the methodology provides a systematic approach to data collection and analysis, some limitations remain. First, the reliance on a restricted timeframe (2024–2025) may overlook influential works published earlier. Second, the focus on English-language journal articles excludes potentially relevant non-English contributions. Additionally, AI-driven synthesis tools like Consensus.app, though powerful, may introduce biases depending on the coverage and interpretation of the indexed literature. These limitations open potential research problems such as extending the bibliometric dataset, integrating multilingual sources, and refining AI-assisted interpretations to reduce bias and increase reliability.

III. Results and Discussion

This study employs a bibliometric analysis approach to examine trends in missing value imputation research. The dataset used in this analysis was obtained from the Scopus database, covering publications from 2020 to 2024 [16].

This section presents the results of the bibliometric analysis, focusing on the visualizations generated using VOSviewer and the AI-assisted insights obtained from Consensus.app. First, we analyze the findings derived from VOSviewer, including co-authorship networks, keyword co-occurrence, citation patterns, bibliographic coupling, and co-citation relationships. These visualizations provide an overview of research clusters, key collaborations, and influential studies within the field of clustering analysis. Following this, we examine the results obtained from Consensus.app, which leverages Gen-AI to summarize key themes and emerging trends from the selected literature. By integrating both approaches, we gain a deeper understanding of the intellectual structure of clustering research and identify potential research gaps for future exploration [17], [18].

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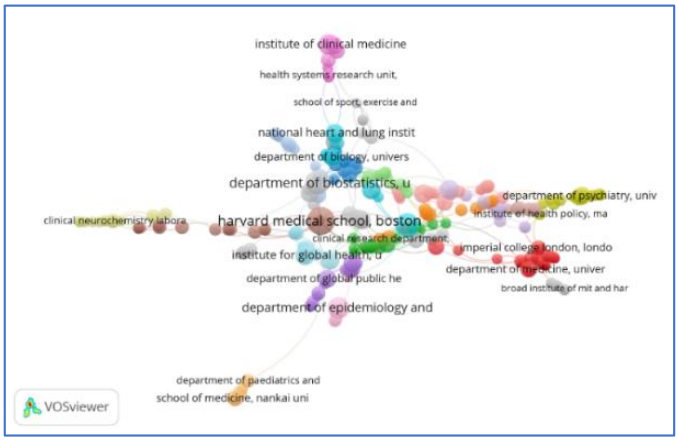


Figure 4. Visualization of Co-Authorship unit Organizations

The visualization in Figure 4 above shows a network of co-authorship at the organizational level, where each node represents an institution involved in a shared scientific publication. The size of the node describes the level of contribution, or the number of publications produced by the institution, while the line connecting the nodes indicates the collaborative relationship between institutions. The color of the node indicates an organizational cluster, which is a group of institutions that have a close cooperative relationship in a particular research topic; For example, red can represent institutions that focus on public health, green in neurochemistry, and blue in epidemiology or biostatistics. Thicker lines signify a more intense frequency of collaboration, indicating the degree of proximity and involvement between these institutions in scientific publications. These visualizations provide a clear picture of patterns of global collaboration between institutions as well as help identify key research groups in specific fields, reflecting how institutions work together in producing scientific knowledge across different disciplines [19], [20].

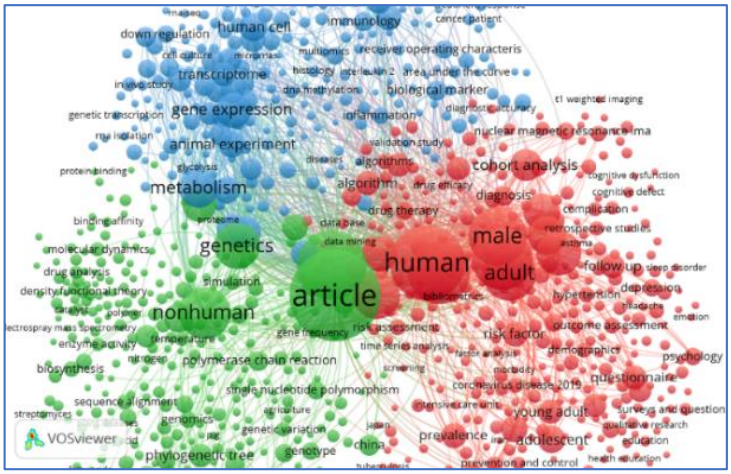


Figure 5. Visualization of Co-Occurrence unit All Keywords

Figure 5 that consist of VOSviewer's visualization with co-occurrence units of all keywords shows the relationship between various terms that often appear together in scientific literature, with different colors representing clusters of interrelated topics. The green cluster deals with genetics and molecular biology research, covering topics such as metabolism, enzymes, and polymerase chain reactions, which form the basis of biological analysis. The blue cluster refers to the study of gene expression and immunology, including terms such as gene expression, transcriptome, and human cell, which are widely used in biomolecular research and immune system-related diseases. Meanwhile, the red cluster focuses on clinical research and human health, with terms such as human, male, adult, diagnosis, and risk factors,

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which are often found in epidemiological studies and disease risk factors. The relationship between clusters is indicated by a connecting line that reflects the interconnectedness between concepts in the analyzed research, describing how various aspects of science interact with each other in the development of scientific research [21], [22].

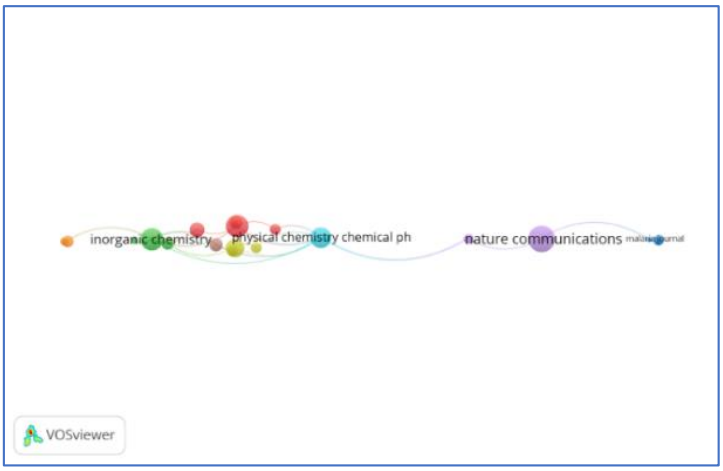


Figure 6. Visualization of Citation unit Sources

Based on VOSviewer visualization from citation unit sources, in Figure 6, the different colors on the nodes indicate clusters of journals or publication sources that have citations in the academic network. The orange cluster, which includes journals such as Inorganic Chemistry, as well as the green cluster with associated nodes, represents the first group of sources that have a close citation relationship in the field of inorganic chemistry. The pink to red cluster, which includes journals such as Physical Chemistry and Chemical Physics, signifies a second group of sources with strong linkages in physicochemical research. Meanwhile, the light blue cluster, which also includes Chemical Physics, serves as a transition area connecting various disciplines. The purple cluster, which includes journals such as Nature Communications, as well as the dark blue cluster, with examples such as the Malaria Journal, indicate a more specific group of publications and separate from the main cluster. Overall, this visualization structure illustrates the relationship between citations between journals in an academic network, helping to identify patterns of collaboration and influence of various sources within a research area [23], [24].

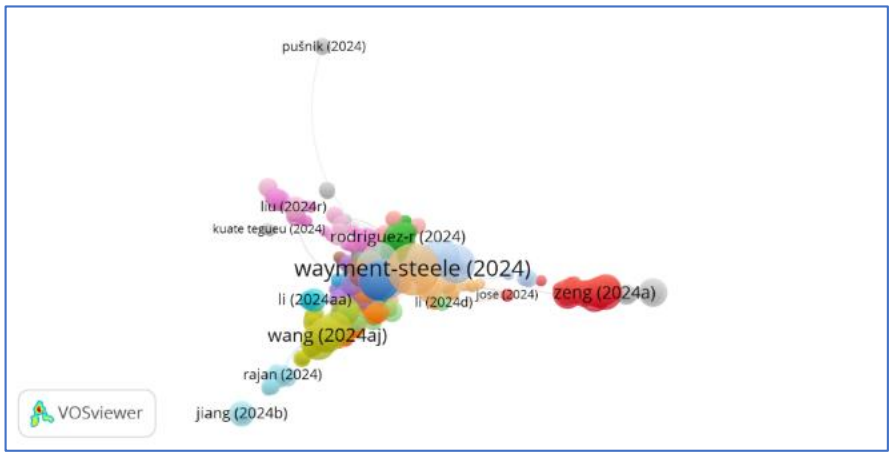


Figure 7. Visualization of Bibliographic Coupling unit Documents

Based on VOSviewer's visualization of bibliographic coupling unit documents in Figure 7, different colors show clusters and patterns of relationships between publications in the research network,

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reflecting the intellectual structure and citation linkages between documents. The light blue cluster, with Wayment-Steele (2024) as the central node, has the most connections, pointing to the main role of this document in establishing bibliographic relationships with other publications. The orange and red clusters, which include Jose (2024) and Zeng (2024a), form additional groups with strong citation linkages in their specific fields. Meanwhile, the green and yellow clusters, with documents such as Li (2024aa) and Wang (2024aj), signify groups of documents that have close citation relationships, indicating interconnected research themes. Overall, this visualization provides an overview of how documents in the research network are connected through shared references, helping to identify publications with significant influence and patterns of scientific development in a particular field [25], [26].

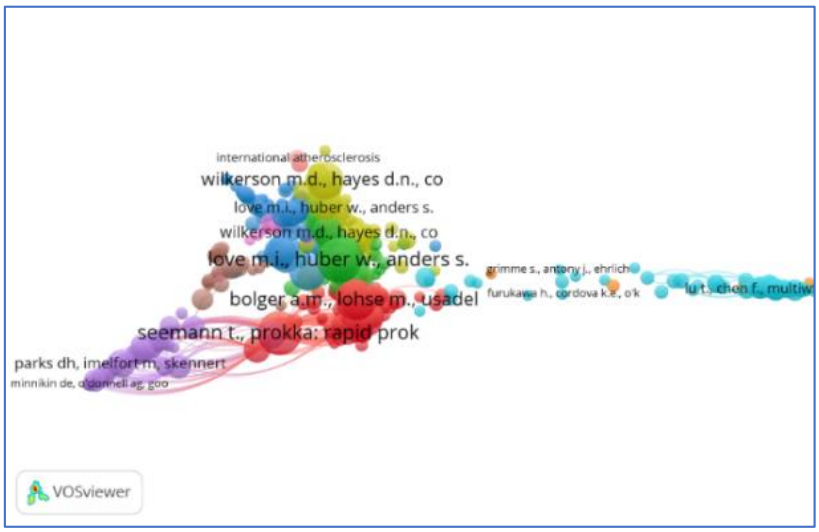


Figure 8. Visualization of Co-Citation unit Cited References

The visualization of co-citations using VOSviewer in Figure 8 shows clustering based on co-cited references in scientific literature, with colors reflecting groups of references that are frequently cited together. The red cluster reflects a major reference pool in bioinformatics methodologies, with sources such as Prokka and Rapid being the main references in genomic analysis. The green cluster groups reference focuses on biological data analysis, including the works of Bolger, Lohse, and Usadel which are often cited in the context of sequencing data processing. The blue cluster shows a strong link in the fields of bioinformatics and biotechnology, with references such as Wilkerson and Hayes, researchersve a strong relationship with other research through the number of shared citations. The purple cluster consists of references that contribute to microbiome analysis and environmental science, while the orange and light blue clusters represent more specific groups of references, such as material analysis and experimental methods. This network structure reveals how scientific references are interconnected through shared citation patterns, helping in identifying key literature that influences the development of a research field [27], [28].

The bibliometric analysis reveals significant trends in clustering research, highlighting key institutions, influential journals, and dominant research themes. The co-authorship network indicates strong collaborations among top-tier universities and research centers, particularly in the fields of bioinformatics and artificial intelligence. Compared to previous studies, which primarily focused on keyword-based clustering, this study expands the perspective by integrating co-citation and bibliographic coupling analysis, providing a more comprehensive view of research linkages. The implications of these findings suggest that clustering techniques continue to evolve, with increasing interdisciplinary collaborations and applications in emerging domains such as healthcare analytics and environmental monitoring. These insights can guide researchers in identifying potential collaborators and emerging research gaps, ultimately shaping future directions in clustering-related studies [29], [30].

All insights in the next study were obtained from Consensus.app, an AI-powered literature synthesis tool. Cluster analysis is a fundamental technique in data analysis used to classify multivariate data into subgroups, revealing patterns and structures within the data. It is widely applied across various fields such as medicine, psychology, and market research. Cluster analysis encompasses a variety of methods, each with its own strengths and weaknesses. Traditional methods like K-means and K-medoids require the number of clusters to be specified beforehand, which can be a limitation when the number of clusters is unknown. Other widely used techniques include hierarchical, partitioning, sequential, and additive clustering, with solution approaches based on dynamic programming and graph-theoretical algorithms. More recent advancements incorporate neural network-based clustering methods, such as self-organizing maps and learning vector quantization, which leverage competitive learning mechanisms for improved clustering performance [31]. One of the primary challenges in cluster analysis is determining the optimal number of clusters. Traditional approaches often rely on parametric assumptions or complex calculations, while recent developments propose nonparametric methods based on distortion measures, offering computational efficiency and ease of implementation. Additionally, the high dimensionality and density of real-world datasets require more sophisticated automatic clustering techniques. Advances in clustering techniques include model-based clustering, which provides a statistical framework for addressing key issues such as cluster determination and outlier handling. Nature-inspired metaheuristic clustering approaches have also gained traction, offering greater flexibility in managing complex datasets. Furthermore, methods like local gravitation clustering introduce innovative concepts, such as local resultant forces, to enhance clustering performance. Ensuring the reliability of clustering results remains crucial, with validation techniques ranging from internal and external validation to stability analysis and visual evaluation. Despite persistent challenges, the continuous evolution of clustering techniques improves their applicability across diverse scientific domains [32], [33].

IV. Conclusion

This bibliometric analysis of clustering research has provided valuable insights into the collaboration networks, keyword co-occurrence, citation patterns, bibliographic coupling, and co-citation relationships within the field. The findings highlight key research trends, influential institutions, and dominant topics shaping the study of clustering techniques. By utilizing VOSviewer, this study effectively maps the intellectual structure of the domain, identifying major contributions and knowledge gaps. The results contribute to a deeper understanding of clustering research and its interdisciplinary applications. Future research should focus on expanding the analysis to include emerging methodologies, integrating machine learning advancements, and examining the impact of clustering techniques across various scientific disciplines.

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