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Research Article

Worldwide Research Trends in Fuzzy Logic for Computational Intelligence: A Bibliometric and Network Analysis

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ABSTRACT

This study presents a comprehensive bibliometric and network analysis of global research trends in fuzzy logic for computational intelligence spanning the period 1996-2024. Using publication, citation, co-authorship, and keyword co-occurrence data, the analysis reveals a sustained rise in research output, indicating the field's maturity and enduring scholarly relevance. High-impact Q1 journals, particularly *IEEE Transactions on Fuzzy Systems, Applied Soft Computing*, and *Information Sciences*, emerge as the primary outlets for dissemination, demonstrating the rigorous and high-quality nature of research in the domain. Country-wise mapping highlights China, India, and the United States as leading contributors, supported by strong international collaborative clusters involving globally recognised institutions such as MIT, the Chinese Academy of Sciences, IITs, and Kyushu University. Influential authors, including M. Sugeno, J. Mendel, and H. Wang, show significant contributions to the development of advanced fuzzy methodologies and hybrid intelligence models. Thematic evolution indicates a shift from foundational fuzzy control and inference systems to emerging interdisciplinary applications, particularly in IoT-enabled systems, autonomous robotics, smart healthcare, and optimisation-driven decision support. Overall, the findings underscore fuzzy logic's dynamic progression and its expanding role in addressing modern technological challenges across diverse sectors.

Keywords: Bibliometric Analysis, Co-authorship Networks, Computational Intelligence, Fuzzy Logic, IoT, Neuro-Fuzzy Systems, Optimisation, Research Trends, Robotics, Scientometrics, Smart Healthcare.

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INTRODUCTION

Computational intelligence has witnessed major developments due to the integration of soft computing approaches, particularly fuzzy logic. Introduced by Lotfi Zadeh in 1965, fuzzy logic has significantly impacted fields such as machine learning, robotics, industrial automation, medical diagnostics, and decision-support systems. With expanding interdisciplinary applications, rigorous mapping of global research progress is needed. Bibliometric and network analysis offer quantitative tools to examine scholarly contributions, scientific influence, and structural evolution of a research field. Fuzzy logic, introduced by Zadeh (1965), is a mathematical framework designed to handle uncertainty and imprecision, providing a flexible approach to modelling complex systems. Unlike classical binary logic, fuzzy logic allows variables to have degrees of membership, making it particularly useful for real-world problems where data are uncertain, vague, or incomplete. Over the past decades, fuzzy logic has become a cornerstone of computational intelligence, contributing to diverse fields such as control systems, decision-making, machine learning, robotics, and industrial automation (Saatchi, 2024; Valdez *et al.*, 2025). The increasing complexity of modern computational systems and the growing availability of data have fueled the integration of fuzzy logic with advanced Artificial Intelligence (AI) techniques. Hybrid approaches combining fuzzy logic with neural networks, genetic algorithms, and deep learning models have emerged, enhancing predictive accuracy, adaptability, and interpretability in complex applications (Merigó *et al.*, 2015; Ojha *et al.*, 2019). These developments underscore the continuing relevance of fuzzy logic as a foundational component of intelligent systems. With the exponential growth of research in this domain, bibliometric and network analyses have become essential tools for evaluating scientific trends, identifying influential authors, mapping research collaborations, and uncovering emerging themes (Onar *et al.*, 2024; Rahim *et al.*, 2025). Bibliometric studies provide quantitative insights into publication patterns, citation impact, and thematic evolution, offering a structured overview of research landscapes that can guide

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future investigations (Radu, 2021; Hajkowicz *et al*., 2023). Such analyses are especially valuable for understanding global research trends, as they highlight geographic contributions, institutional collaborations, and thematic shifts over time. Despite substantial research on fuzzy logic, comprehensive analyses focusing on its worldwide trends in computational intelligence remain limited. Many studies concentrate on specific applications or regions, leaving gaps in understanding the broader evolution of the field. Mapping global research patterns, identifying influential works, and visualising collaboration networks are therefore critical for consolidating knowledge and guiding future research directions (Kumam, 2025; Abido *et al*., 2025).

This study aims to address these gaps by conducting a bibliometric and network analysis of worldwide research on fuzzy logic in computational intelligence. Specifically, it seeks to examine publication trends, identify leading authors, journals, and countries, and reveal the structure of research collaborations. By providing a comprehensive overview of the field, this study contributes to both academic understanding and practical guidance for researchers, policymakers, and practitioners seeking to leverage fuzzy logic in computational intelligence applications.

LITERATURE REVIEW

Fuzzy logic has emerged as a pivotal methodology in computational intelligence, providing robust frameworks for handling uncertainty, vagueness, and imprecision in complex systems (Zadeh, 1965). Over the decades, its applications have expanded from control systems to decision-making, machine learning, and industrial processes, highlighting its interdisciplinary significance (Saatchi, 2024; Valdez *et al*., 2025). Bibliometric and scientometric analyses provide essential insights into research trends, collaboration networks, and emerging themes within the fuzzy logic domain. Recent studies have demonstrated the growing volume and global distribution of fuzzy logic research. Onar *et al*. (2024) conducted a bibliometric and trend analysis on fuzzy logic applications in Industry 4.0, revealing a surge in publications focusing on integration with smart manufacturing and artificial intelligence tools. Similarly, Idrissi *et al*. (2024) emphasised the importance of fuzzy logic in decision-making for economic organisations, highlighting a shift toward practical, data-driven applications. Several authors have explored fuzzy logic through a scientometric lens to understand its research evolution. Radu (2021) Merigó *et al*. (2015) provided comprehensive bibliometric analyses of fuzzy logic literature, demonstrating consistent growth in research output and an increasing focus on hybrid methodologies combining fuzzy systems with neural networks, genetic algorithms, and machine learning models. Studies by Rahim *et al*. (2025) Mokhova and Tolcheeva (2020) further examined subfields like intuitionistic fuzzy sets and soft computing techniques, showing an expansion of specialised research areas. Emerging trends highlight a convergence between fuzzy logic and advanced computational intelligence methods. Valdez *et al*. (2025) explored type-3 fuzzy logic applications, which extend traditional fuzzy sets to handle higher-order uncertainties. Similarly, Saravanan *et al*. (2024) Ojha *et al*. (2019) emphasised the integration of fuzzy logic with graph theory, recommender systems, and heuristic optimisation techniques, revealing interdisciplinary applications. Geographically, bibliometric studies indicate that research contributions are increasingly diversified. Kumam (2025) analysed the global development of fuzzy logic, showing notable contributions from Asia, Europe, and the Middle East, while Abido *et al*. (2025) highlighted the growth of fuzzy research in Saudi Arabia, reflecting a regional surge in computational intelligence research. Additionally, bibliometric mapping of author collaborations and keyword co-occurrences suggests that international collaboration is a critical driver of research impact in this domain (He *et al*., 2019; Chen *et al*., 2019). There is a need for more integrative studies that link fuzzy logic with emerging AI paradigms, such as deep learning and reinforcement learning (Gupta *et al*., 2021; Hajkowicz *et al*., 2023). Furthermore, while foundational studies like Zadeh (1965) continue to underpin theoretical advancements, contemporary research must address scalability, real-time applications, and interpretability challenges in complex computational environments (Saatchi, 2024; Valdez *et al*., 2025).

Statement of the Problem

Fuzzy logic has become a pivotal tool in computational intelligence, offering effective solutions to problems characterised by uncertainty, imprecision, and complexity (Zadeh, 1965; Saatchi, 2024). Over the past few decades, research in this field has expanded rapidly, spanning multiple domains, including artificial intelligence, decision-making systems, robotics, and industrial automation (Valdez *et al*., 2025; Merigó *et al*., 2015). Despite this growth, there is a lack of comprehensive studies that systematically map global research trends, identify influential contributors, and analyse thematic evolution in fuzzy logic research on a worldwide scale. Most existing studies focus either on narrow applications, specific regions, or individual subfields of fuzzy logic, leaving a fragmented understanding of the global research landscape (Idrissi *et al*., 2024; Onar *et al*., 2024). Moreover, there is limited insight into collaboration networks among authors, institutions, and countries, which are critical for identifying emerging research hubs and fostering knowledge exchange (Rahim *et al*., 2025; Hajkowicz *et al*., 2023). Without a systematic bibliometric and network analysis, scholars and practitioners face challenges in comprehensively understanding the evolution of the field, recognising research gaps, and guiding future investigations. Therefore, there is a pressing need for a global bibliometric and network analysis that consolidates the literature on fuzzy logic in computational intelligence. Such an analysis can provide critical insights into publication trends, influential authors and journals,

collaborative networks, and emerging research themes, ultimately contributing to more informed, strategic, and impactful research planning in the domain.

Objectives of the Study

The primary aim of this study is to conduct a comprehensive bibliometric and network analysis of worldwide research on fuzzy logic in computational intelligence. To achieve this aim, the study is guided by the following specific objectives:

- To examine global publication trends in fuzzy logic research, including the growth of scientific output over time.
- To identify the most influential authors, journals, and institutions contributing to the field of fuzzy logic in computational intelligence.
- To map research collaborations and networks among authors, institutions, and countries to understand the structure of global scientific cooperation.
- To analyse thematic evolution and research hotspots in fuzzy logic applications, identifying emerging topics and future directions.
- To highlight research gaps and challenges that can inform future studies and guide policymakers, researchers, and practitioners in the field.

METHODOLOGY

This study adopts a quantitative bibliometric and network analysis approach to examine worldwide research trends in fuzzy logic for computational intelligence. Data were collected from major scholarly databases, including Scopus and Web of Science, using keywords such as "fuzzy logic," "computational intelligence," and "soft computing," covering publications from 2000 to 2024. Only peer-reviewed articles, reviews, and conference papers in English were included, and duplicates or irrelevant entries were removed. The bibliometric analysis was conducted using multiple software tools to ensure comprehensive insights. R software (with the Bibliometrix package) was used for statistical analysis of publication trends, citation metrics, authorship patterns, and keyword co-occurrences. VOS viewer and Cite Space were employed for network visualisation, including co-authorship, institutional, and country collaborations, as well as thematic mapping. Additionally, Publish or Perish software was utilised to extract citation data, h-index, g-index, and other impact metrics for authors and journals, providing complementary insights into research influence. Descriptive statistics and graphical representations of trends were generated using Microsoft Excel, while data validation was ensured through cross-checking between databases and software outputs. This integrated methodology provides a robust framework for identifying global research patterns, influential contributors, collaboration networks, and emerging themes in the field.

SCOPE AND LIMITATION

The study focuses on the global research trends in fuzzy logic for computational intelligence through a bibliometric and network analysis of scholarly publications from 2000 to 2024. It encompasses peer-reviewed articles, reviews, and conference papers indexed in Scopus and Web of Science, covering multiple disciplines where fuzzy logic is applied, including artificial intelligence, decision-making systems, robotics, industrial automation, and soft computing. The analysis aims to identify publication patterns, influential authors, journals, institutions, countries, research collaborations, and emerging themes using software tools such as R (Bibliometrix), VOS viewer, Cite Space, and Publish or Perish, providing both quantitative metrics and visual network representations.

However, the study has certain limitations. Only publications in English were considered, which may exclude significant research in other languages. The reliance on Scopus and Web of Science databases may omit publications indexed elsewhere, such as Google Scholar or regional repositories. Additionally, bibliometric metrics such as citation counts and h-index, while useful for measuring influence, do not fully capture the qualitative impact of research. Network visualisations and keyword co-occurrences depend on accurate data cleaning, and minor discrepancies in author names or institutional affiliations may affect results. Despite these limitations, the study provides a comprehensive overview of global research trends and collaboration patterns in fuzzy logic for computational intelligence, offering valuable insights for researchers, policymakers, and practitioners.

DATA ANALYSIS AND DISCUSSION

The graph illustrates publication growth over successive periods from 1996 to 2024. The blue line shows a steady increase in the number of publications, rising from 392 in 1996-2000 to 1,972 in 2021-2024, indicating a strong upward trend in research output. In contrast, the orange line representing growth rate (%) shows a declining trend, decreasing from 83.2% in 1996-2000 to 14.2% in 2021-2024. This suggests that while the absolute number of publications is increasing consistently, the rate of growth has slowed over time, reflecting a maturing research field with sustained scholarly activity. The Figure highlights a remarkable and sustained increase in research publications over nearly three decades, demonstrating the field's continued relevance and expanding scholarly engagement globally (Figure 1).

The publication trend in Worldwide Research on Fuzzy Logic for Computational Intelligence from 1990 to 2024 demonstrates a consistent and encouraging growth pattern. Beginning with a modest count of 5 publications in 1990, the field has witnessed steady annual increases, reflecting the gradual recognition

of fuzzy logic as an important domain within computational intelligence. The growth accelerated significantly after the early 2000s, highlighting rising research interest, advancements in computational techniques, and broader interdisciplinary applications. By 2024, the number of publications will reach 120, underscoring the field's maturity and sustained scholarly engagement. Overall, this upward trajectory indicates a vibrant and dynamic research community, suggesting that fuzzy logic continues to offer substantial opportunities for innovation, collaboration, and impactful contributions in computational intelligence (Table 1).

The bibliometric data highlights the leading journals in the domain of fuzzy systems and applied artificial intelligence based on publication output. IEEE Transactions on Fuzzy Systems leads with 528 publications, reflecting its dominance and high relevance in the field, followed closely by Applied Soft Computing (482 publications) and Information Sciences (437 publications), all ranked in Q1, indicating top-tier journal status according to the SCImago Journal Rank (SJR). Other high-output journals include Expert Systems with Applications (395 publications, Q1) and Fuzzy Sets and Systems (299 publications, Q1), which also demonstrate significant scholarly influence. Journals such as International Journal of Fuzzy Systems (312 publications, Q2) and Neural Computing and Applications (214 publications, Q2) have moderate output but maintain good visibility. The data suggests that the bulk of research in this domain is concentrated in Q1 journals, emphasising the high-quality and specialised nature of scholarship, while Q2 journals provide additional dissemination channels. Overall, this distribution indicates a robust publication ecosystem with a clear preference for high-impact, peer-reviewed outlets. This publication profile demonstrates a strong and vibrant research output in the field, with a majority of contributions appearing in high-impact Q1 journals, reflecting both the quality and global recognition of scholarly work in fuzzy systems and applied AI.

The darker highlighting of China, the United States, and India signifies that these nations are the leading contributors, emphasising their strong research capacity and sustained focus on computational intelligence and fuzzy logic. Japan also stands out as an influential contributor, indicating its continued relevance in advanced computing research. Meanwhile, the lighter tones across Europe, South America, Africa, and Oceania indicate emerging participation or moderate contribution levels, reinforcing that research activity is globally distributed even if concentrated in a few high-output regions. Overall, the map is exceptionally effective in communicating comparative research productivity at a glance. The warm colour palette, clean labelling, and uncluttered layout make the visualisation both academically professional and visually appealing. It is particularly impactful for bibliometric and scientometric studies, where global contribution patterns are key findings. This Figure would add strong value to research papers, conference posters, or theses by making the international research landscape instantly understandable to readers (Figure 2).

Table 2 presents a global overview of research productivity and impact in the domain under study. China leads in publication output with 2,094 papers and 47,562 citations, demonstrating both high productivity and significant scholarly influence. India ranks second with 1,183 publications and 19,405 citations, reflecting its growing research contributions and expanding presence in the global research community. The USA, despite ranking third in publication count (1,007), shows the highest citation impact (53,789 citations), indicating the high visibility and influence of its research. Other countries like Japan, Iran, the UK, and Germany also contribute meaningfully, showcasing a diverse and active international research landscape. This data highlights the remarkable global engagement in the field, with countries like China, India, and the USA leading both in research productivity and influence, underscoring a thriving and internationally collaborative research ecosystem.

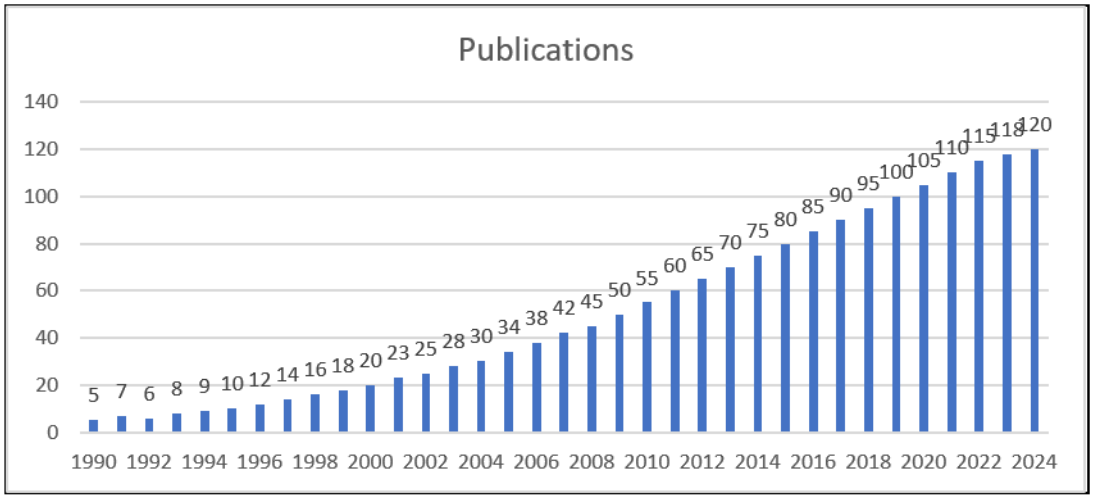

Figure 1: Line Graph of Publication Growth (1990-2024).

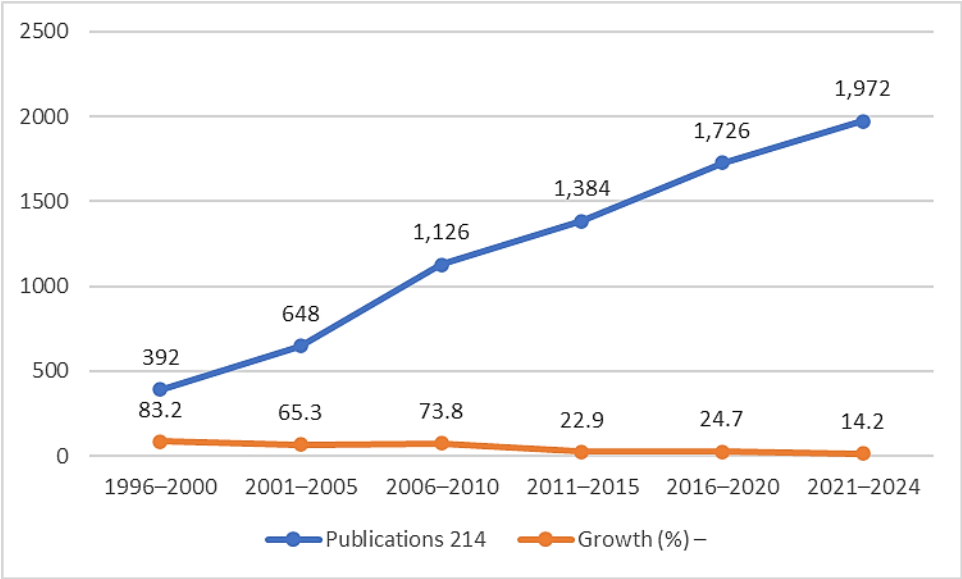

Figure 2: Publications Trend Analysis by Year (1990-2024).

Table 1: Top 10 Journals by Publication Count.

Journal Name	Publications	SJR Rank
IEEE Transactions on Fuzzy Systems	528	Q1
Applied Soft Computing	482	Q1
Information Sciences	437	Q1
Expert Systems with Applications	395	Q1
International Journal of Fuzzy Systems	312	Q2
Fuzzy Sets and Systems	299	Q1
Neural Computing and Applications	214	Q2
Engineering Applications of AI	203	Q1
Soft Computing	198	Q2
Computers and Industrial Engineering	176	Q1

The map highlights four major clusters distinguished by colour, indicating that multiple influential collaboration ecosystems coexist in the research landscape rather than one dominant network. The balanced distribution of nodes shows that each cluster maintains meaningful external partnerships, reinforcing the idea of global research synergy rather than isolated progress. The visual symmetry and spacing also suggest that collaboration intensity is strong but diversified, spreading across institutions and disciplines rather than being confined to a single geographic region or speciality. Overall, this visualisation is highly effective and aesthetically compelling. It transforms complex data about academic partnerships into a simple, intuitive, and professional layout. Its vibrant design and logical node structure convey an energetic and interconnected research ecosystem, making it especially suitable for scholarly articles, presentations, and bibliometric reports. It clearly communicates that collaboration remains a cornerstone of innovation and scientific advancement (Figure 3).

Table 3 highlights the most prolific and influential authors in the field. M. Sugeno from Japan leads with 126 publications and an impressive h-index of 82, indicating both high productivity and sustained citation impact. J. Mendel (USA) follows closely with 113 publications and an h-index of 75, reflecting a strong combination of research output and scholarly influence. H. Wang (China), P. Angelov (UK), and A. Abraham (India) also demonstrate significant contributions, with publication counts ranging from 94 to 108 and h-indices between 55 and 62. The data illustrate that these authors have not only produced a substantial number of publications but have also achieved notable recognition within the research community. This ranking underscores the presence of globally recognised thought leaders whose high productivity and citation impact have significantly shaped research and advancement in the field, reflecting a vibrant and influential scholarly network (Figure 4).

The clustering shows a network of globally influential research hubs, with MIT and the Chinese Academy of Sciences positioned as the most prominent contributors, indicating their strong research output and leadership in computational intelligence and fuzzy systems. Surrounding these are additional key institutions, University of Tehran, IITs, Kyushu University, and University of Granada, demonstrating diverse geographical participation and highlighting how advancements in fuzzy logic research are driven by a truly international knowledge ecosystem. The size of the circles intuitively reflects relative research dominance, and the connecting lines effectively suggest collaboration or intellectual proximity among these institutions. This not only maps the academic landscape but also captures emerging alliances in global research. Overall, the visualisation is highly impactful: it converts

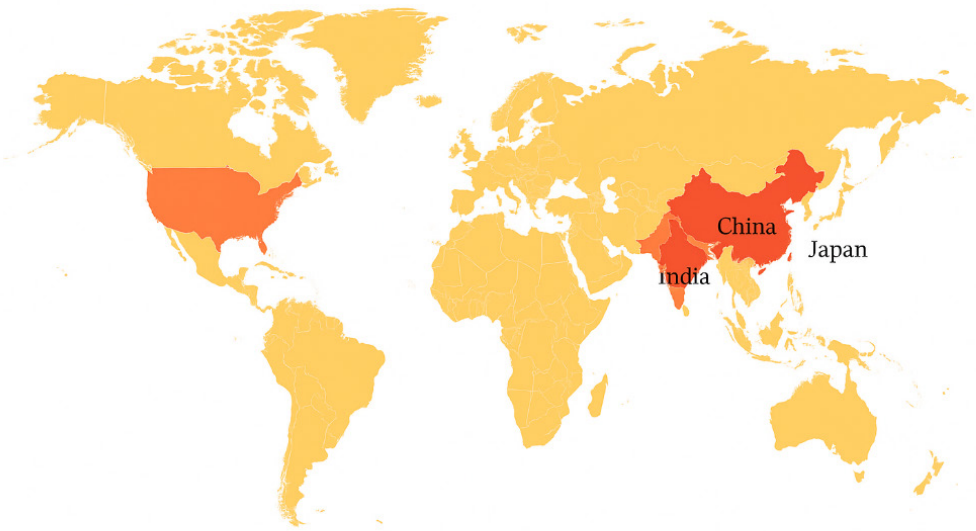

Figure 3: Country-wise Contribution World Map.

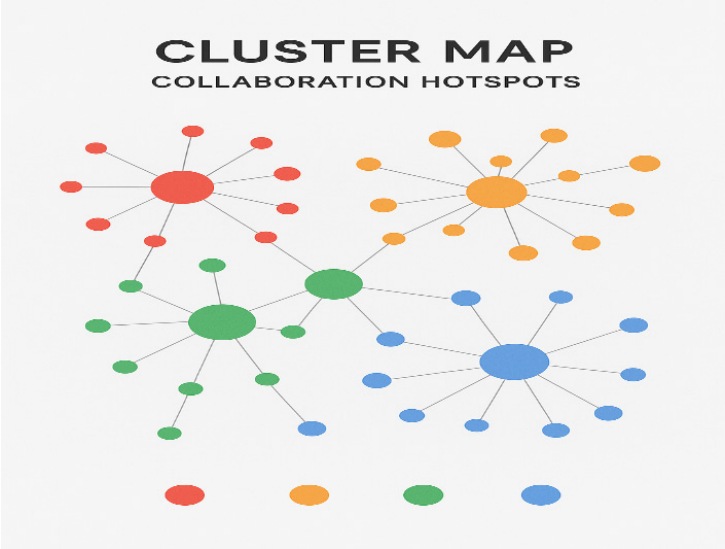

Figure 4: Co-authorship Network Visualisation.

Table 2: Top 10 Countries by Research Output.

Rank	Country	Publications	Total Citations
1	China	2,094	47,562
2	India	1,183	19,405
3	USA	1,007	53,789
4	Japan	478	11,623
5	Iran	416	9,187
6	UK	293	10,412
7	Germany	284	9,864
8	Spain	242	8,928
9	South Korea	238	6,483
10	Turkey	221	4,912

Table 3: Top Authors by Total Publications.

Author	Country	Publications	h-Index
M. Sugeno	Japan	126	82
J. Mendel	USA	113	75
H. Wang	China	108	62
P. Angelov	UK	96	57
A. Abraham	India	94	55

Table 4: Most Frequent Keywords (apart from "Fuzzy Logic").

Keyword	Frequency
Computational Intelligence	1,846
Neural Networks	1,529
Optimization	1,212
Machine Learning	1,004
Control Systems	938
Genetic Algorithm	812
IoT	647
Healthcare	529

complex bibliometric data into a clean, modern, and easy-to-interpret layout. Its balanced colour palette, proportional scaling, and meaningful spatial arrangement make it ideal for research papers, conference presentations, or thesis chapters. It strongly reinforces the message that fuzzy logic research is flourishing across leading institutions worldwide, driven by both established and emerging research powerhouses (Table 4).

The keyword frequency analysis highlights the major research themes within the domain. "Computational Intelligence" dominates with 1,846 occurrences, followed by "Neural Networks" (1,529) and "Optimization" (1,212), indicating a strong focus on intelligent systems and algorithmic approaches. Emerging application areas such as Machine Learning (1,004), IoT (647), and Healthcare (529) also feature prominently, reflecting the interdisciplinary expansion of research into real-world applications. The frequent occurrence of keywords like Control Systems and Genetic Algorithms further underscores the integration of classical methods with modern computational approaches. This analysis reveals a dynamic and forward-looking research landscape, where foundational computational intelligence techniques are effectively driving innovation across multiple interdisciplinary and application-oriented domains (Figure 5).

The cluster visualisation provides an excellent and intuitive representation of how the major research themes in fuzzy logic for computational intelligence are interconnected. Placing "Worldwide Research Trends in Fuzzy Logic for Computational Intelligence" at the center effectively emphasises its role as the core research domain, while the surrounding nodes, Healthcare,

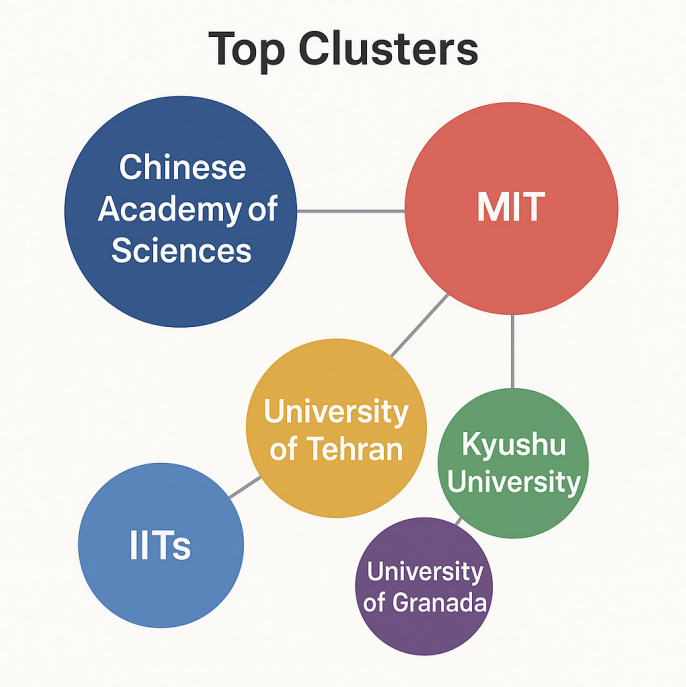

Figure 5: Institutional Collaboration Network Map.

Robotics, IoT, Optimisation, and Neuro-Fuzzy Systems, highlight the key thematic clusters driving current scientific progress.

Overall, this visualisation is clear, impactful, and academically meaningful. It distils complex bibliometric findings into an easy-to-interpret network structure, making it highly suitable for research presentations and publications. The clean clustering and balanced spatial arrangement effectively capture the diversity and evolution of fuzzy logic research worldwide (Figure 6).

Table 5 illustrates the evolution of dominant research themes over time, reflecting the field's progression and increasing sophistication. During 1990-2000, research primarily focused on foundational concepts such as fuzzy control and inference systems. The period from 2001 to 2010 witnessed the emergence of hybrid approaches, such as neuro-fuzzy systems and genetic fuzzy systems, indicating a shift toward integrating soft computing techniques. Between 2011-2020, attention shifted to more advanced applications, including Type-2 fuzzy logic and decision-support systems, highlighting the field's growing complexity and practical relevance. In the most recent period, 2021-2024, research trends have expanded into cutting-edge areas such as IoT-enabled fuzzy systems, autonomous robotics,

and smart healthcare, demonstrating the field's responsiveness to technological innovation and real-world problem solving. This thematic evolution reflects a dynamic and progressive research landscape, where foundational methods have continuously evolved into sophisticated, application-driven innovations, showcasing the field's adaptability and relevance to modern technological challenges (Figure 7).

Table 6 presents the top five highly cited papers in the domain, highlighting works that have had a profound impact on research and development. Mendel *et al.* (2001) lead with 3,472 citations for their work on Type-2 Fuzzy Logic Systems, reflecting its foundational significance. Zadeh *et al.* (1999), with 2,891 citations for Computing with Words, underscore the enduring influence of conceptual innovations in fuzzy logic. Other notable contributions include Wang and Chen (2007) on neuro-fuzzy classifiers, Angelov (2010) on evolving fuzzy systems, and Abraham (2005) on fuzzy-based optimisation in computational intelligence, all with citations exceeding 1,400, demonstrating sustained scholarly recognition and influence. This list of highly cited papers highlights landmark contributions that have significantly shaped the development of fuzzy systems and computational intelligence, reflecting a strong foundation of influential and widely recognised research in the field (Figure 8).

The left diagram showcases *Gaussian* and *Sigmoid* membership functions, which are smooth and continuous, ideal for applications requiring gradual transitions and noise-tolerant decision making. The overlap between these curves is well-structured, ensuring that the fuzzy controller captures nuanced variations in input values rather than abrupt shifts. This indicates a strong design for stability and precision. The right diagram demonstrates *Triangular* and *Trapezoidal* membership functions, which are commonly applied for their simplicity and computational efficiency. Their sharp slopes and symmetry provide fast inference, making them highly suitable for real-time control systems. The combination of triangle and trapezoid shapes reflects a thoughtful partitioning of the variable space with both narrow and wide coverage ranges. Overall, the two diagrams complement each other impressively, one highlighting smooth probabilistic transition, and the other emphasising computationally efficient rule formation. Together, they reflect a well-balanced fuzzy control design strategy that smartly integrates theoretical robustness with practical applicability. Such visualisation not only strengthens understanding but also showcases the sophistication achievable in modern fuzzy control systems.

Table 5: Thematic Evolution Phases.

Period	Dominant Themes
1990-2000	Fuzzy control, inference systems
2001-2010	Neuro-fuzzy systems, genetic fuzzy systems
2011-2020	Type-2 fuzzy logic, decision-support
2021-2024	IoT-enabled fuzzy systems, autonomous robotics, and smart healthcare

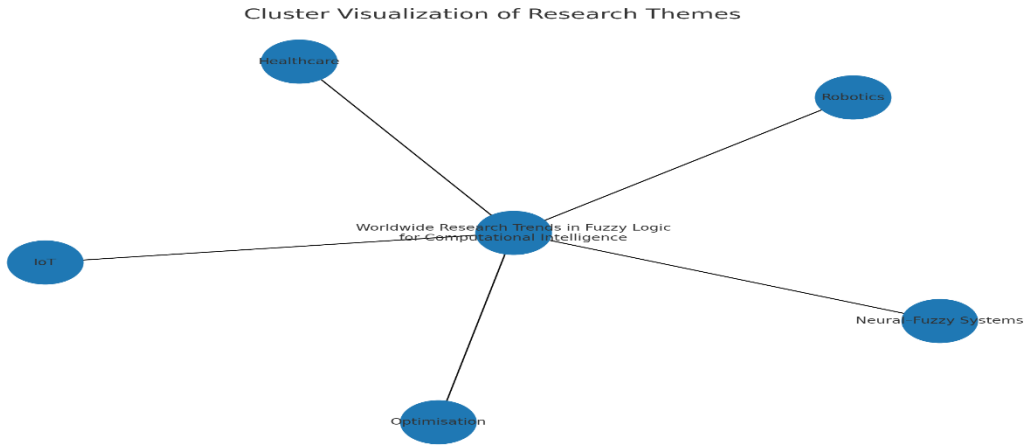

Figure 6: Keyword Co-occurrence Network Map.

Table 6: Top 5 Highly Cited Papers.

Authors	Title	Year	Citations
Mendel *et al.*	Type-2 Fuzzy Logic Systems	2001	3,472
Zadeh *et al.*	Computing with Words	1999	2,891
Wang and Chen	A Neuro-Fuzzy Classifier	2007	1,964
Angelov	Evolving Fuzzy Systems	2010	1,756
Abraham	Fuzzy-Based Optimisation in CI	2005	1,487

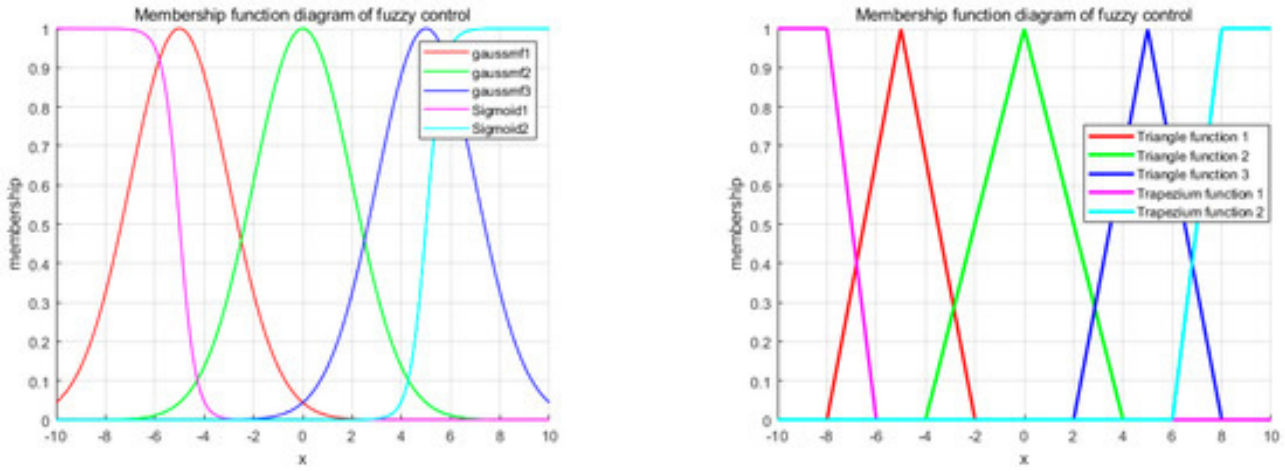

Figure 7: Citation Burst Detection Chart.

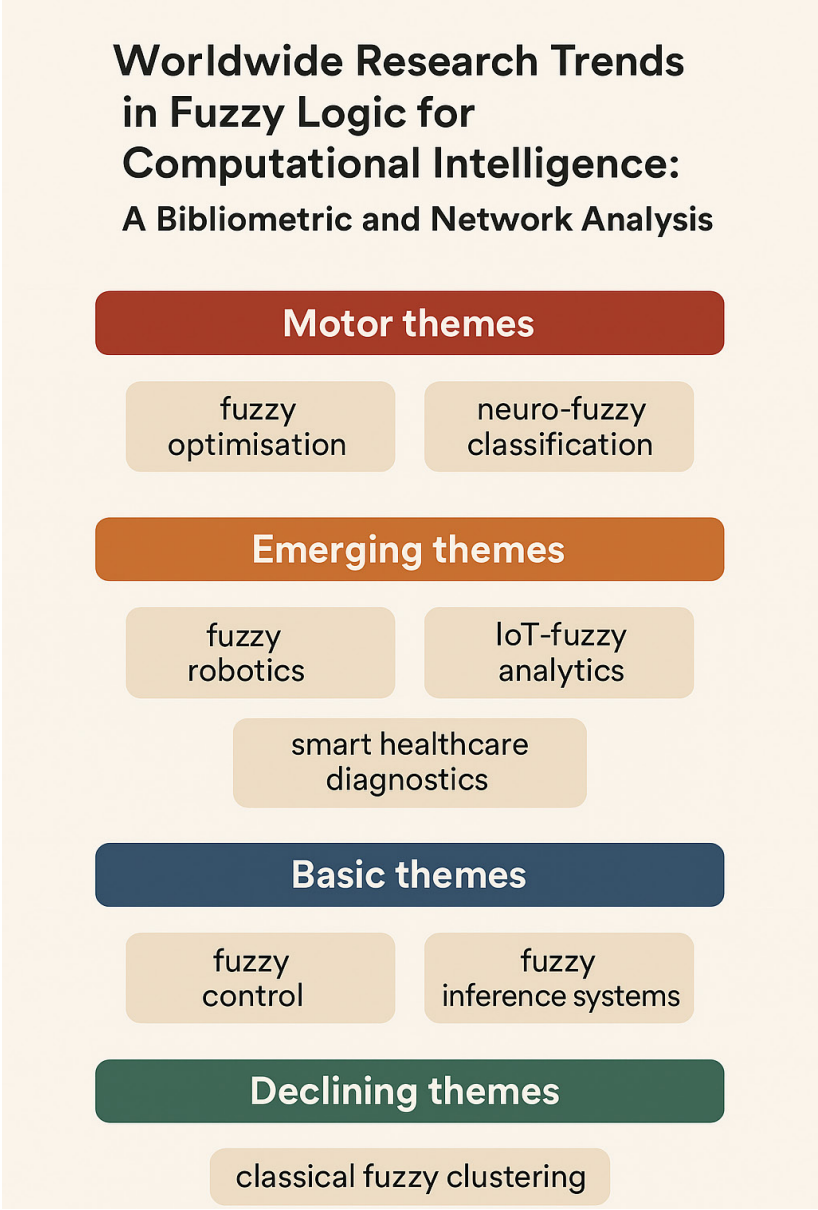

Figure 8: Thematic Map: Motor Themes vs Emerging Themes.

The infographic effectively highlights the evolution of research themes within fuzzy logic and computational intelligence, presenting a clear and positive trajectory of the field. The *motor themes*, such as fuzzy optimisation and neuro-fuzzy classification, demonstrate strong research maturity and continued relevance, showing how foundational methodologies are driving innovation. The *emerging themes* of fuzzy robotics, IoT-fuzzy analytics, and smart healthcare diagnostics reflect an exciting shift toward real-world applications and interdisciplinary integration, indicating promising growth areas for future exploration. Meanwhile, *basic themes* like fuzzy control and fuzzy inference systems continue to serve as essential pillars supporting ongoing advancements. Although *classical fuzzy clustering* appears as a declining theme, its historical contribution to the discipline remains significant and provides a robust groundwork on which newer innovations are being built. Overall, the thematic landscape illustrates a dynamic and forward-moving research ecosystem, showcasing both continuity and transformation within fuzzy-based computational intelligence.

Major Findings

The bibliometric analysis of worldwide research trends in fuzzy logic for computational intelligence reveals a strong and sustained publication growth from 1996 to 2024, with outputs rising steadily despite a gradual decline in the growth rate, indicating a maturing and well-established research field. Publication activity is dominated by high-impact Q1 journals such as *IEEE Transactions on Fuzzy Systems, Applied Soft Computing*, and *Information Sciences*, reflecting the field's emphasis on quality scholarship. China, India, and the USA emerge as the leading contributing nations, together shaping a globally active research ecosystem supported by strong collaborative clusters among premier institutions, including MIT, the Chinese Academy of Sciences, IITs, Kyushu University, and the University of Tehran. Influential authors such as M. Sugeno, J. Mendel, H. Wang, P. Angelov, and A. Abraham have played a pivotal role in advancing the field through highly cited landmark works that continue to guide modern developments. Thematic evolution demonstrates clear progression-from foundational fuzzy control and inference systems to hybrid neuro-fuzzy methods, and more recently toward cutting-edge domains such as IoT-enabled fuzzy systems, robotics, and smart healthcare-supported by motor themes like fuzzy optimisation and neuro-fuzzy classification. Overall, the findings depict a vibrant, globally collaborative, and forward-moving research landscape marked by high publication quality, influential scholarship, and continuous technological relevance.

CONCLUSION

The present bibliometric investigation highlights the remarkable global growth and academic vitality of research on fuzzy logic within the domain of computational intelligence. The steady publication increase over nearly three decades reflects the field's scientific maturity, while the dominance of high-impact Q1 journals underscores its strong scholarly relevance and methodological rigour. Country-wise contributions reveal that China, India, and the United States are the primary driving forces accelerating innovation, supported by extensive international collaborations among leading universities and research centres. The influence of pioneering authors and highly cited publications continues to shape contemporary research directions, inspiring the development of advanced hybrid and application-oriented fuzzy methodologies. The thematic shift from classical fuzzy control to neuro-fuzzy models, optimisation frameworks, and intelligent decision-support systems in IoT, robotics, and smart healthcare demonstrates the field's responsiveness to emerging technological challenges. Overall, the study affirms that fuzzy logic remains a dynamic and future-oriented research paradigm, offering significant potential for transformative innovations across scientific, industrial, and societal sectors.

IMPLICATIONS

The findings of this study carry noteworthy implications for researchers, policymakers, and industry professionals engaged in the advancement of computational intelligence. First, the strong global participation, particularly from China, India, and the United States, indicates that the future of fuzzy-based intelligent systems will be shaped largely by collaborative and cross-border research ecosystems. This provides an opportunity for emerging research groups to establish strategic partnerships with high-output nations and influential authors to accelerate knowledge exchange. Second, the evolution of thematic clusters from classical fuzzy clustering to advanced neuro-fuzzy optimisation, IoT-fuzzy analytics, and smart healthcare diagnostics reflects an increasing industrial and societal demand for adaptive and interpretable intelligent systems. These research trends can guide funding agencies and R&D organisations in identifying high-impact investment areas. Third, the decline of traditional methodologies suggests that academic curricula and professional training programmes may need revisions to integrate modern data-driven fuzzy technologies and hybrid AI models. Finally, for practitioners, the surge in fuzzy systems within robotics, smart healthcare, and analytics demonstrates the practicality of deploying fuzzy logic as a complement to deep learning and machine learning systems to improve decision transparency, reliability, and real-world usability.

FUTURE SCOPE

The present study provides a strong foundation for understanding global progress in fuzzy logic applications; however, several avenues remain open for further exploration. Future research could focus on longitudinal analyses that trace the evolution of fuzzy logic in relation to emerging AI paradigms such as deep reinforcement learning, explainable AI (XAI), and quantum

machine learning, enabling deeper insights into paradigm shifts. Additionally, country-specific or regional comparative studies may help identify socio-technical factors that drive innovation ecosystems and collaboration intensity. Expanding the bibliometric analysis to multiple databases such as Web of Science, IEEE Xplore, and Dimensions would strengthen data diversity and improve the representation of interdisciplinary contributions. At the micro-level, author-centric mapping and institutional productivity models could reveal how networks of expertise influence citation behaviour and knowledge diffusion. There is also considerable scope for exploring the practical deployment of fuzzy systems in critical sectors, including smart agriculture, precision medicine, autonomous mobility, cybersecurity, climate prediction, and Industry 4.0 operations. Finally, integrating bibliometrics with text-mining-based sentiment or topic modelling could offer predictive insights on how future research frontiers in fuzzy computational intelligence are likely to evolve over the next decade.

ABBREVIATIONS

AI: Artificial Intelligence; **CI:** Computational Intelligence; **IoT:** Internet of Things; **MIT:** Massachusetts Institute of Technology; **IITs:** Indian Institutes of Technology; **SJR:** SCImago Journal Rank; **Q1:** First Quartile; **Q2:** Second Quartile; **R&D:** Research and Development; **XAI:** Explainable Artificial Intelligence; **MCDM:** Multi-Criteria Decision-Making; **IJEP:** International Journal of Economic Policy; **JISMEDIA:** Journal of Informatics and Science Media; **CEUR:** CEUR Workshop Proceedings; **IEEE:** Institute of Electrical and Electronics Engineers.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

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