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Global Research Trends of Six Sigma in Management: A Bibliometric Perspective

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ABSTRACT

This study presents a bibliometric analysis of global research trends on Six Sigma within the management discipline, covering 747 publications indexed between 2015 and 2025 with an annual growth rate of 2.3 percent. The findings reveal a fluctuating yet generally positive publication trajectory, with notable peaks in 2020 and 2023, likely driven by global operational challenges and subsequent organizational restructuring. Geographic distribution indicates a strong concentration of research in a few countries, led by India, the United States, and the United Kingdom, reflecting disparities in research capacity and collaboration networks. Keyword co-occurrence mapping identified key thematic areas, including methodological foundations such as DMAIC and process improvement, strategic themes like critical success factors, sustainability, and Industry 4.0 integration, as well as sector-specific applications in healthcare, public services, and SMEs. The results underscore the multidisciplinary nature of Six Sigma and its evolution from a technical quality improvement tool to a strategic management framework, increasingly integrated with complementary approaches such as Lean, the Theory of Constraints, and ITIL. This adaptability enhances its relevance in diverse industrial contexts, contributing to operational excellence, strategic advantage, and customer satisfaction. Future research should explore digital technology integration, cultural and institutional adoption factors, and the long-term strategic impacts of Six Sigma to strengthen its global applicability.

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1. INTRODUCTION

Six Sigma, a robust, data-driven methodology, has profoundly influenced quality management by integrating statistical methods to achieve significant improvements in profitability, market share, and customer satisfaction while simultaneously reducing waste and operational risks across various sectors [1], [2]. Initially popularized by Motorola and General Electric, its application has since expanded globally, demonstrating its versatility in diverse fields, from manufacturing to healthcare [3], [4]. This systematic approach focuses on reducing process variation and defects, ultimately leading to enhanced operational efficiency and substantial financial savings [5]. The core principle involves achieving a defect rate of no more than 3.4 defects per million opportunities, signifying a near-perfect process performance [6]. This rigorous standard is attained through the application of structured methodologies, such as DMAIC and DMADV, which guide practitioners through a systematic problem-solving and process optimization framework [7], [8]. The methodology of Six Sigma uses statistical theory, assuming that every process factor can be characterized by a statistical distribution curve [9].

This framework systematically identifies and eliminates the root causes of defects and errors, driving continuous improvement and fostering a culture of quality within organizations [10]. Despite its origins in manufacturing, Six Sigma's principles have proven highly adaptable, leading to its widespread adoption in various service industries, including banking, logistics, and human resources, where it improves process efficiency and minimizes errors [11] [12]. This pervasive adoption underscores the methodology's global relevance and necessitates a comprehensive bibliometric analysis to map its research landscape within the management domain.

This study aims to delineate the evolving trends and intellectual structure of Six Sigma research within management disciplines, identifying key thematic clusters, influential authors, and emerging areas of scholarly inquiry. Specifically, this paper will explore the geographical distribution of research, the most prolific institutions, and the conceptual evolution of Six Sigma applications in management contexts, providing a nuanced understanding of its academic trajectory. Such an analysis will illuminate the current state of Six Sigma research and forecast future directions, highlighting areas that may benefit from increased scholarly attention. Furthermore, by employing a bibliometric approach, this study offers a quantitative assessment of the research landscape, identifying publication patterns, key research themes, and collaborations that define the academic discourse around Six Sigma in management [13].

This exploration will also assess the impact of Six Sigma on service quality improvement, considering the challenges and limitations encountered in its application beyond traditional manufacturing settings [14]. Indeed, while its initial success was predominantly in highly repetitive manufacturing processes, the challenges of applying Six Sigma to service industries, characterized by their behavioral and psychological components, highlight the need for tailored frameworks [15]. This study contributes to the extant literature by providing a robust bibliometric overview, distinguishing Six Sigma research from other quality initiatives like Total Quality Management due to its distinct statistical rigor and defect reduction targets [16] [17]. This paper will provide value to students, researchers, and practitioners by offering insights into Six Sigma's implementation, especially within manufacturing industries [13]. The subsequent sections of this paper will delve into a comprehensive literature review, outlining the theoretical underpinnings and historical development of Six Sigma

2. LITERATURE REVIEW

2.1 Six Sigma

Six Sigma, a robust, data-driven methodology, has profoundly influenced quality management by integrating statistical methods to achieve significant improvements in profitability, market share, and customer satisfaction while simultaneously reducing waste and operational risks across various sectors [1], [2]. Initially popularized by Motorola and General Electric, its application has since expanded globally, demonstrating its versatility in diverse fields, from manufacturing to healthcare [3], [4]. This systematic approach focuses on reducing process variation and defects, ultimately leading to enhanced operational efficiency and substantial financial savings [5]. The core principle involves achieving a defect rate of no more than 3.4 defects per million opportunities, signifying a near-perfect process performance [6]. This rigorous standard is attained through the application of structured methodologies, such as DMAIC and DMADV, which guide practitioners through a systematic problem-solving and process optimization framework [7], [8]. The methodology of Six Sigma uses statistical theory, assuming that every process factor can be characterized by a statistical distribution curve [9].

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The Six Sigma methodology, rooted in statistical process control, aims to reduce process variation and achieve near-perfect

quality levels, typically defined as 3.4 defects per million opportunities [18]. This rigorous standard necessitates a structured, data-driven approach, often employing methodologies like Define, Measure, Analyze, Improve, and Control for existing processes or Design for Six Sigma for new processes [19]. This methodology emphasizes the use of advanced statistical tools and techniques to identify and eliminate root causes of defects, thereby enhancing efficiency and customer satisfaction [20]. Its pervasive application extends beyond manufacturing to service sectors, including hospitality and information technology, where it is utilized to improve service quality and streamline operational processes [21] [22]. The core objective is to improve quality performance by minimizing production defects, as demonstrated by studies that have successfully reduced defect rates in complex manufacturing processes from 27% to 7% [23]. Similarly, the application of Six Sigma has been shown to eliminate machine downtime and reduce scrap rates significantly, demonstrating its practical benefits in operational settings [24]. The fundamental concept behind Six Sigma involves understanding and controlling process variability to ensure that outputs consistently fall within acceptable customer specifications [25]. This proactive approach not only enhances product and service quality but also contributes to substantial cost savings by minimizing rework, waste, and customer dissatisfaction [26]. For instance, in a food pasta company, the Six Sigma methodology identified problems related to process instability and low capability, leading to proposed improvement actions that increased the sigma quality level [27]. This systematic approach to quality improvement is distinguished from other methodologies by its rigorous emphasis on statistical analysis and its commitment to achieving measurable, significant improvements in process capability and customer satisfaction [28]. Its efficacy has been well-documented across diverse industries, leading to substantial financial savings and improvements in key performance indicators [29]. One of the most frequently utilized frameworks within Six Sigma is the Define, Measure, Analyze, Improve, and Control cycle, which provides a structured approach for problem-solving and process optimization in various industrial and business sectors [30] [31]. The DMAIC methodology systematically guides teams through problem definition, data collection, causal analysis, solution implementation, and sustained control, making it highly adaptable for complex challenges across different organizational functions [32] [33] [34]. This systematic approach allows organizations to not only identify and rectify existing inefficiencies but also to proactively prevent future defects by embedding continuous improvement mechanisms within their operational frameworks [35] [36] [37]. It is particularly effective in identifying and eliminating the root causes of defects, leading to significant reductions in defect rates and improvements in customer satisfaction [38].

2.2 Bibliometric

This systematic approach involves identifying and eliminating the causes of defects, thereby enhancing efficiency and customer satisfaction across diverse organizational functions [39]. This ensures a robust understanding of the intellectual landscape surrounding Six Sigma, identifying influential authors, prevalent themes, and the evolution of research interests over time. Specifically, bibliometric analysis aids in mapping the conceptual structure of a field, revealing prominent research clusters and their interconnections, which is crucial for understanding the multidisciplinary nature of Six Sigma applications [40]. This analytical method allows for the quantitative assessment of research output, collaboration patterns, and the intellectual development of Six Sigma as a management philosophy. This makes bibliometric analysis an invaluable tool for discerning the global research trends, geographical distribution of studies, and the most impactful publications in the domain of Six Sigma. By employing this methodology, researchers can identify gaps in the existing literature and forecast future research directions, thereby contributing to the

advancement of Six Sigma practices and theories. This paper leverages bibliometric analysis to systematically map the intellectual landscape of Six Sigma research, identifying key themes, prominent authors, and global trends. This comprehensive approach provides a nuanced understanding of how Six Sigma principles are applied across various sectors, from healthcare to information technology, to achieve significant process improvements and operational excellence [41]. This will enable a more profound comprehension of the methodology's global dissemination and its varying impact across different industrial contexts [42].

3. METHODS

3.1. Research Design

Objective understanding of the academic landscape by mapping the intellectual structure, thematic evolution, and collaborative networks within the field. Bibliometric analysis, a quantitative application, allows for the study of scientific production, including its characteristics, evolution, and monitoring [44]. It is an expedient approach to examine the evolution of research domains, including topics and authors, based on the disciplines' social, intellectual, and conceptual structures [45]. This methodology, rooted in quantitative analysis of academic output, offers a robust framework for assessing the impact and trajectory of Six Sigma research [46]. This method relies on statistical methods to analyze academic publications, revealing patterns in research output, collaboration, and thematic development over time [47]. This comprehensive approach enables a systematic review of the global research landscape of Six Sigma, highlighting the most impactful studies and emerging areas of interest. This study, drawing from a comprehensive dataset of scholarly articles, employs bibliometric analysis to systematically uncover the intellectual backbone of Six Sigma research, revealing pivotal theories, methodologies, and their applications.

3.2. Data Collection Strategy

To ensure a comprehensive analysis, this study employed a systematic data collection strategy, focusing on peer-reviewed articles from reputable academic databases. Specifically, Scopus databases were chosen due to their extensive coverage of management and engineering disciplines, which are highly relevant to Six Sigma research [48]. This rigorous selection process ensures the inclusion of high-quality, relevant publications, thereby providing a robust foundation for discerning global research trends and thematic evolution in Six Sigma.

The initial search in the Scopus database using the term "Six Sigma" produced a total of 5,457 documents. This initial dataset was then refined by applying strict inclusion criteria to ensure relevance and quality. First, the publications were limited to those released between 2015 and 2025, allowing the study to focus on the most recent developments and trends in the field. Second, the subject area was restricted to "Business, Management and Accounting" to maintain alignment with the study's focus on the management domain. Third, only journal articles were considered, ensuring that the dataset consisted of peer-reviewed and original research contributions. Finally, the search was limited to publications written in English to allow for broader global comparability and accessibility. After applying these criteria, the dataset was reduced to 474 articles, which served as the foundation for the subsequent bibliometric analysis.

3.3. Data Analysis

The 474 articles were analyzed using bibliometric techniques to reveal key trends, intellectual structures, and emerging research fronts in Six Sigma management literature. The analysis was conducted using specialized bibliometric software such as VOSviewer and Bibliometrix (R), which are designed to handle large-scale data visualization and mapping [49], [50].

The analytical procedures included:

Performance Analysis: Quantitative assessment of publication outputs over time, identifying the most productive authors, institutions, and countries, as well as the most cited articles and influential journals.

Intellectual Structure Analysis:

- *Co-citation Analysis* to identify foundational theories, methods, or research areas through patterns of joint citations.
- *Bibliographic Coupling* to detect clusters of research with shared references, indicating thematic connections.
- *Co-occurrence of Keywords Analysis* to map main themes and subtopics, showing thematic progression and interlinkages.

Thematic Evolution Analysis: Examination of how major research themes evolved between 2015 and 2025, highlighting emerging and declining areas of interest. This comprehensive analytical framework allows for a robust exploration of the dynamic research landscape of Six Sigma in management, providing a quantitative basis for understanding its trajectory and future directions.

4. RESULTS AND DISCUSSION

4.1. Publication Trends and Growth in Six Sigma

The trend of Six Sigma publications between 2015 and 2025 (figure 1) demonstrates a generally positive trajectory despite notable fluctuations. Starting from approximately 43 documents in 2015, research output increased sharply in 2016, followed by a decline in 2017. A steady recovery occurred between 2018 and 2020, culminating in a peak of around 86 documents. This growth period coincided with a heightened global focus on operational efficiency during the COVID-19 pandemic. Although there was a subsequent decline in 2021 and 2022, research output rebounded strongly in 2023 before decreasing again in 2024 and showing a sharp drop in 2025, likely due to incomplete indexing for the current year. The overall total of 747 documents and an annual growth rate of 2.3 percent indicates sustained scholarly interest in Six Sigma over the past decade.

Geographic distribution (Figure 2) analysis shows that Six Sigma research is concentrated in a few countries, with India leading at nearly 290 publications, followed by the United States and the United Kingdom with just over 120 and 110 documents, respectively. Mid-tier contributors such as the United Arab Emirates, Brazil, and Malaysia each produced 25–45 publications, while Italy, Indonesia, Ireland, and Taiwan contributed fewer outputs. This uneven distribution underscores the need to examine cultural, economic, and institutional factors that shape Six Sigma adoption across national contexts. Insights from successful implementations, particularly in Indian SMEs, could inform tailored strategies for developing economies [51] [52], while exploring the role of cultural and regulatory environments may enhance understanding of Six Sigma's global adaptability.

4.2. The global leading authors in Six Sigma

This section identifies and discusses the most influential researchers contributing to the Six Sigma body of knowledge, table 1 highlighting their impact based on publication volume and citation metrics. Their contributions are instrumental in shaping the theoretical foundations and practical applications of Six Sigma methodologies across diverse industries, reflecting a growing global recognition of its efficacy in enhancing organizational performance [53].

Table 1 above presents the top five most prolific authors in Six Sigma research, with Jiju Antony from the United Kingdom leading significantly with 87 documents, followed by Rajeev Rathi from India with 22 documents. Jose Arturo Garza-Reyes, also from the United Kingdom, contributed 20 documents, while E.V. Gijo and Shreeranga Bhat, both from India, published 16 and 15 documents, respectively. This distribution highlights the concentrated expertise within specific geographic regions and emphasizes the considerable individual contributions to the academic discourse on Six Sigma. These

authors, through their consistent research output, have significantly shaped the understanding and application of Six Sigma principles in various industrial and service sectors. Their extensive work has not only advanced the theoretical underpinnings of Six Sigma but also provided empirical evidence of its benefits, such as cost reduction and quality improvement, in diverse organizational contexts [54], [55]. Their collective efforts, particularly in developing economies, have facilitated the adaptation of Six Sigma methodologies to address specific regional challenges and opportunities [56] [20].

4.3. Key thematic areas Six Sigma

The VOSviewer map (Figure 3) illustrates the interconnected network of keywords in Six Sigma research, highlighting dominant themes and their relationships. The largest nodes, such as six sigma, lean six sigma, dmaic, process improvement, quality management, and critical success factors, indicate central topics that serve as anchors within the research landscape [57], [58], [59]. The prominence of lean six sigma alongside six sigma reflects the methodological integration trend aimed at combining waste reduction and efficiency improvement. Moreover, terms like project management, industry 4.0, sustainability, and total quality management suggest an expansion of Six Sigma applications beyond manufacturing into strategic, technological, and sustainability-oriented domains [49], [60].

The map also reveals strong methodological linkages, with clusters of keywords such as *survey*, *factor analysis*, *case study*, *statistical process control*, and *design of experiments*. These demonstrate the variety of research approaches applied in Six Sigma studies, ranging from empirical and quantitative techniques to case-based and action research methodologies. The presence of context-specific terms like *hospitals*, *public sector*, *higher education*, and *small and medium enterprises* highlights the cross-sectoral adaptability of Six Sigma, indicating that research has increasingly focused on sector-specific implementation challenges and success factors.

To gain a deeper understanding of the intellectual structure and thematic development of Six Sigma research, the keyword co-occurrence network generated through VOSviewer was examined. This visualization not only identifies the most frequently occurring terms but also groups them into distinct thematic clusters based on their co-occurrence relationships. Each cluster represents a specific research orientation, whether methodological, strategic, or application-based, providing valuable insights into how Six Sigma scholarship has evolved and diversified across disciplines and sectors.

- Green Cluster – Process and Methodology Focus
  This cluster centers on *dmaic*, *process improvement*, *statistical process control*, *regression analysis*, and *design of experiments*. It represents the technical and methodological foundation of Six Sigma, focusing on process capability, defect reduction, and continuous improvement tools.
- Red Cluster – Strategic Implementation and Organizational Factors
  Includes keywords such as *critical success factors*, *barriers*, *enablers*, *framework*, *implementation*, *sustainability*, and *industry 4.0*. This cluster emphasizes the organizational, cultural, and strategic considerations necessary for successful Six Sigma adoption, particularly in the context of technological transformation and sustainable operations.
- Blue Cluster – Quality Management Integration
  Contains terms like *quality management*, *total quality management*, *kaizen*, *project selection*, and *higher education*. This reflects research integrating Six Sigma with broader quality management philosophies

and its application in academic and service environments.

- Yellow Cluster – Sector-Specific Applications
  Includes *service quality*, *public sector*, *logistics*, *hospitals*, and *SMEs*. This cluster focuses on the adaptation of Six Sigma principles to different industry contexts, analyzing sectoral challenges and customization needs.
- Light Blue Cluster – Research Methods and Validation Features *survey*, *factor analysis*, *CFA*, and *empirical study*. This cluster represents the methodological rigor and validation techniques used to examine Six Sigma frameworks and measure implementation success.

4.4. Managerial implications

The findings from the bibliometric analysis highlight the imperative for organizations to tailor Six Sigma methodologies to their specific operational environments, moving beyond generic applications to address unique challenges and capitalize on industry-specific opportunities [65]. Furthermore, the insights gained emphasize the need for robust project selection methodologies, ensuring that Six Sigma initiatives are strategically aligned with organizational objectives and possess a high probability of yielding substantial improvements [66]. Moreover, understanding the interplay between leadership styles and Six Sigma implementation, as well as the critical success factors, is pivotal for driving employee motivation and achieving business excellence within these varied contexts [67] [68]. Leadership, for instance, has been identified as a critical success factor for Lean Six Sigma, with particular leadership styles and traits significantly impacting deployment effectiveness. Weak management, particularly a lack of focus on leadership, culture, and employee training, can lead to the failure of Six Sigma initiatives [68]. Conversely, robust leadership commitment and employee engagement, fostered through comprehensive training and effective communication, are instrumental in overcoming resistance to change and embedding a culture of continuous improvement. This comprehensive approach ensures that Six Sigma initiatives are not merely tactical improvements but contribute to a lasting strategic advantage, enhancing both profitability and customer satisfaction [69] [70].

4.5. Practical implications

The findings from the bibliometric analysis highlight the imperative for organizations to tailor Six Sigma methodologies to their specific operational environments, moving beyond generic applications to address unique challenges and capitalize on industry-specific opportunities (Cheng, 2017). Furthermore, the insights gained emphasize the need for robust project selection methodologies, ensuring that Six Sigma initiatives are strategically aligned with organizational objectives and possess a high probability of yielding substantial improvements (Holmes et al., 2015). Moreover, understanding the interplay between leadership styles and Six Sigma implementation, as well as the critical success factors, is pivotal for driving employee motivation and achieving business excellence within these varied contexts (Alnadi & McLaughlin, 2020; Motiani & Kulkarni, 2021). Leadership, for instance, has been identified as a critical success factor for Lean Six Sigma, with particular leadership styles and traits significantly impacting deployment effectiveness. Weak management, particularly a lack of focus on leadership, culture, and employee training, can lead to the failure of Six Sigma initiatives (Alnadi & McLaughlin, 2020). Conversely, robust leadership commitment and employee engagement, fostered through comprehensive training and effective communication, are instrumental in overcoming resistance to change and embedding a culture of continuous improvement. This comprehensive approach ensures that Six Sigma initiatives are not merely tactical improvements but contribute to a lasting strategic advantage, enhancing both

profitability and customer satisfaction (Iswanto, 2021; Shilpa et al., 2021).

4.6. Future Research Recommendation

Future research on Six Sigma should place greater emphasis on examining its integration with emerging digital technologies, particularly in the context of Industry 4.0. While existing studies have explored the methodological foundations and sector-specific applications, there remains significant potential to investigate how tools such as artificial intelligence, machine learning, and big data analytics can enhance the efficiency, predictive capability, and adaptability of Six Sigma initiatives. Such research could provide actionable frameworks for organizations seeking to align quality improvement practices with technological transformation.

Another promising avenue for further study lies in exploring cultural and institutional influences on Six Sigma adoption across diverse economic contexts. The geographic distribution of publications reveals an uneven concentration of research activity, suggesting that contextual factors play a critical role in shaping implementation success. Comparative studies across countries with varying industrial maturity could uncover how organizational culture, leadership styles, regulatory frameworks, and workforce capabilities influence both the uptake and outcomes of Six Sigma programs. This line of inquiry could help design context-specific strategies for emerging and developing economies.

Finally, future investigations should focus on evaluating the long-term sustainability and strategic impact of Six Sigma initiatives. Much of the current literature emphasizes short-term performance gains, yet there is a need to assess whether these improvements are sustained over extended periods and how they contribute to broader organizational resilience and competitiveness. Longitudinal studies that link Six Sigma implementation to metrics such as innovation capacity, environmental sustainability, and stakeholder satisfaction could deepen understanding of its role as a strategic management tool beyond immediate operational benefits.

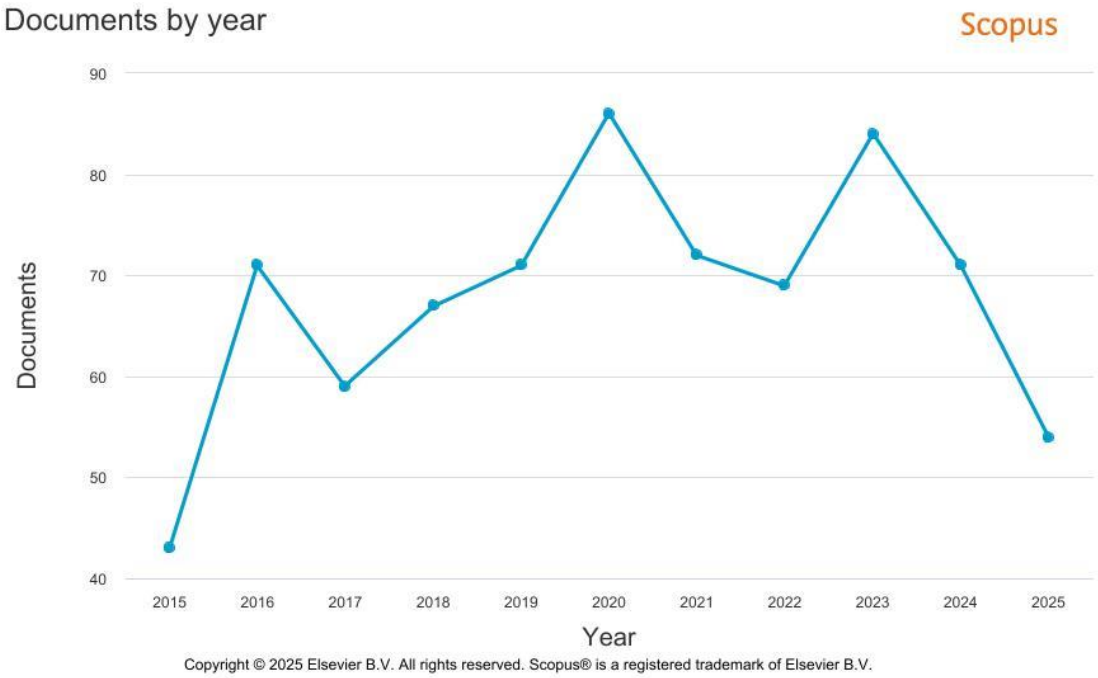

Figure 1. Annual Publication Growth

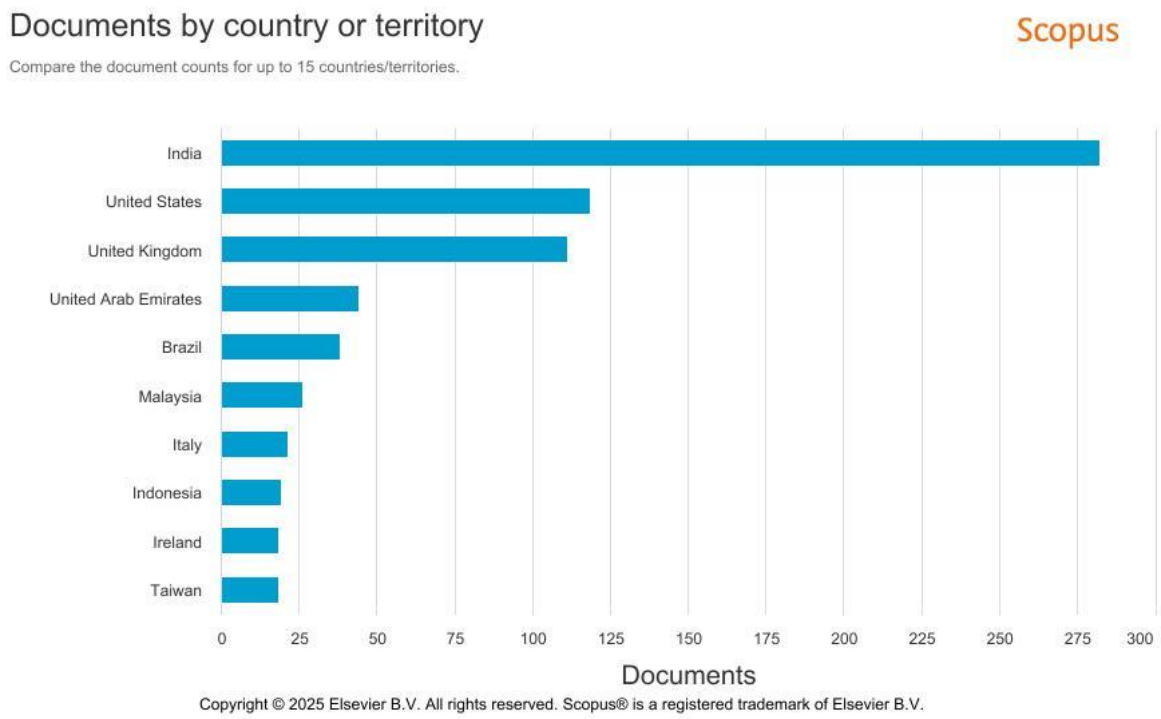

Figure 2. Geographic distribution

Table 1. Global Leading Auhtor

No	Authoir	Country	N.Document
1	Jiju Antony	United Kingdom	87
2	Rajeev Rathi	India	22
3	Jose Arturo Garza-Reyes	United Kingdom	20
4	E.V. Gijo	India	16
5	Shreeranga Bhat	India	15

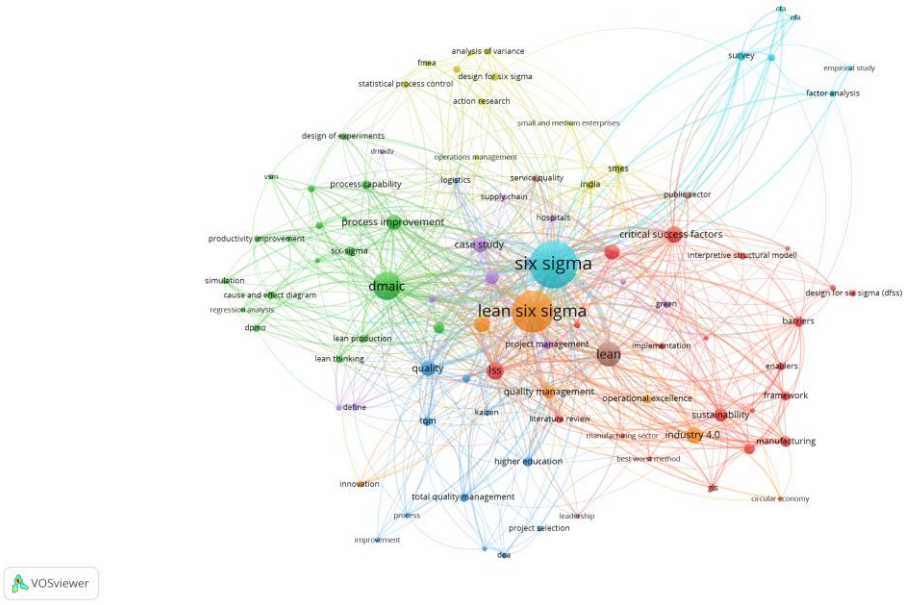

Figure 3. Keyword network Visualization

5. CONCLUSION

This bibliometric review of 747 publications on Six Sigma in the management discipline (2015–2025) reveals a generally positive growth trajectory with an annual growth rate of 2.3 percent, marked by peaks in 2020 and 2023 and fluctuations likely influenced by global operational challenges and sectoral shifts. India leads global research output, followed by the United States and the United Kingdom, indicating both strong industrial and academic ecosystems in these countries and disparities in research capacity across regions. The analysis has provided a comprehensive overview of global research trends, highlighting Six Sigma's multidisciplinary nature, evolving applications, and core themes ranging from methodological foundations such as DMAIC and process improvement to strategic dimensions like critical success factors, sustainability, and Industry 4.0 integration, as well as sectoral applications in healthcare, public services, and SMEs. It has also elucidated the key themes, prominent authors, and influential publications that have shaped the discourse, offering insights into the intellectual structure and thematic progression of the field. These findings underscore the persistent relevance of Six Sigma as a robust methodology for process improvement and quality management, adapting to new technological paradigms and integrating with complementary approaches such as Lean, the Theory of Constraints, and ITIL to amplify effectiveness. This adaptability ensures its continued importance in navigating the complexities of modern business environments, fostering operational excellence, strategic advantage, significant financial savings, and enhanced customer satisfaction, while future research should focus on digital technology integration, cultural and institutional adoption factors, and the long-term strategic impact of Six Sigma initiatives to strengthen its global applicability.

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