Mapping the AI Revolution: A Global Bibliometric Analysis of Research Trends from 2019 to 2024

ABSTRACT

This study presents a bibliometric analysis of artificial intelligence (AI) research trends from 2019 to 2024, leveraging data from Scopus to evaluate the global research landscape. The analysis highlights a significant growth trajectory in AI research, with an annual growth rate of 18.2%, emphasizing AI's increasing prominence across various fields. The research identifies key contributors, with China and the United States leading in both publication volume and citations, reflecting their dominant roles in shaping global AI discourse. King Saud University, Prince Sattam Bin Abdulaziz University, and the University of Oxford are among the top academic institutions driving AI research forward. The analysis further uncovers machine learning, deep learning, and neural networks as foundational themes within the AI domain, while emerging topics like ethical AI, convolutional neural networks, and systematic approaches signify the field's evolution. The study illustrates the extensive global collaboration within AI research, particularly between leading nations such as China, the USA, and European countries, underscoring the critical role of international partnerships in advancing AI knowledge. Ethical considerations and fairness in AI have become increasingly important, as reflected in the growing body of research dedicated to ensuring responsible AI development. This study's findings offer valuable insights for academics, policymakers, and industry stakeholders, providing a roadmap for future AI research that balances technological innovation with ethical responsibility.

***Keywords** Artificial Intelligence, Bibliometric Analysis, Machine Learning, Global Collaboration, AI Research Trends*

1. INTRODUCTION

The theory of artificial intelligence (AI) integration focuses on leveraging AI technology to enhance and optimize existing systems or processes. AI is capable of autonomously processing data and information by utilizing predefined algorithms [1]. Artificial Intelligence (AI) has transitioned from a conceptual field of study to a transformative technology that is reshaping the modern world [2]. Early AI research focused on symbolic reasoning and rule-based systems, where computers were programmed to follow a set of predefined rules [3]. However, these early systems were limited by their inability to handle uncertainty or learn from new data, confining their practical applications to narrow, well-defined domains [3].

The 21st century has seen an explosion of interest in AI, driven largely by breakthroughs in machine learning, particularly deep learning, and the rise of big data [4]. Deep learning, a subfield of ML that uses neural networks with many layers, has proven to be exceptionally powerful in tasks such as image recognition, natural language processing, and autonomous systems [4]. These advances have been fueled by the availability of vast amounts of labeled data, increased computational resources through GPUs and cloud computing, and improved algorithms that allow for more efficient training of large models [5].

The interdisciplinary nature of AI has also expanded its influence across a wide range of fields, from healthcare and finance to education, logistics, and even the arts [2]. In healthcare, AI is being used to develop diagnostic tools that can detect diseases at earlier stages than human doctors, while in finance, AI algorithms are employed to predict market trends and optimize investment strategies [6]. The educational sector is seeing the rise of AI-powered personalized learning platforms, and in the creative industries, AI is being used to generate music, art, and even literature. This broad applicability of AI underscores its potential to impact nearly every aspect of modern life [7].

At the same time, the growing integration of AI into society raises important ethical and social questions. Concerns about bias in AI algorithms, the potential for mass surveillance, and the displacement of human labor by automation are driving discussions about how to develop AI responsibly [8]. These challenges highlight the need for ongoing research into not only the technical aspects of AI but also its societal implications [8].

Given the rapid advancements in AI and its far-reaching effects, it is crucial to track research trends within the field [9]. Understanding where AI research is concentrated, who the leading contributors are, and which topics are emerging can provide valuable insights for both academic researchers and industry practitioners [2]. By employing bibliometric analysis, this study seeks to map the global landscape of AI research, identifying the most influential works, authors, and regions [10]. This approach will help to illuminate the trajectory of AI development and highlight areas of opportunity and potential gaps in the current body of knowledge [10].

The justification and significance of this study are grounded in four key research questions that guided the analysis. The primary aim is to explore the trends in current artificial intelligence research, identifying the source titles, organizations, authors, and countries contributing the most to the academic output on this topic. Drawing from Chen et al. [11], the following research questions were developed: RQ1: What are the most cited papers in the field of AI? RQ2: What are the trends in AI research over a time of five years? RQ3: Who are the leading researchers in the domain of AI? RQ4: How has collaboration between authors, countries evolved in the field of AI?

This paper contributes to the growing body of literature on AI by providing a comprehensive bibliometric analysis of AI research from 2019 to 2024. Using data from the Scopus Core Collection database, we will examine publication trends, identify highly cited papers and influential authors, and assess the contributions of various countries and institutions to the advancement of AI. By analyzing patterns in AI research, this study aims to provide a clearer understanding of how AI is evolving as a discipline and offer guidance for future research directions.

2. LITERATURE REVIEWS

Artificial Intelligence (AI) has been a rapidly growing area of research, driven by the increased availability of data, advances in computational power, and breakthroughs in algorithmic design [12]. The literature on AI encompasses a broad spectrum of topics, from theoretical foundations to practical applications in various industries [2]. A key focus has been on machine learning (ML), particularly deep learning, which has shown remarkable progress in fields such as computer vision, natural language processing (NLP), and robotics [13].

2.1 Advancements in AI and Machine Learning

Machine learning is often regarded as the core of AI, where algorithms learn patterns from data and make predictions or decisions without being explicitly programmed [13]. Early advancements in AI were primarily rule-based systems, relying heavily on human-coded logic [14]. However, the shift towards data-driven methods, particularly through supervised learning, unsupervised learning, and reinforcement learning, has been transformative [15].

Deep learning, a subfield of machine learning, has garnered significant attention due to its ability to process vast amounts of unstructured data and its success in achieving human-level performance in complex tasks [15]. For instance, convolutional neural networks (CNNs) have revolutionized image recognition, enabling breakthroughs in fields such as autonomous vehicles and facial recognition [16].

Similarly, recurrent neural networks (RNNs) and long short-term memory networks (LSTMs) have advanced NLP tasks like speech recognition, translation, and text generation [17].

In recent years, the emergence of generative models, particularly Generative Adversarial Networks (GANs) has opened new avenues for AI research [18]. GANs have been used to generate highly realistic images, videos, and even deepfakes, raising both excitement for creative applications and concerns over ethical implications [18].

2.2 Natural Language Processing and AI

Natural language processing (NLP) is another critical area where AI has made significant strides. The introduction of transformer-based architectures has significantly improved the performance of NLP tasks [19]. Models like BERT and GPT-3 have demonstrated unprecedented capabilities in understanding and generating human-like text. BERT’s ability to consider the context of a word from both directions in a sentence has led to state-of-the-art results in tasks such as question answering and sentence classification [20]. GPT-3, on the other hand, with its massive 175 billion parameters, has shown impressive results in generating coherent and contextually appropriate text across various domains [20].

These advances in NLP have been applied to real-world problems such as virtual assistants (e.g., Siri, Alexa), automated customer service, and even content creation, highlighting AI's increasing presence in everyday life [21]. However, challenges remain in achieving true language understanding and avoiding biases embedded in training data, which can perpetuate stereotypes or discriminatory behavior [22].

2.3 AI in Healthcare

AI's application in healthcare has been transformative, particularly in medical imaging, drug discovery, and personalized medicine. Studies have shown that AI systems can perform at or above the level of human experts in diagnosing diseases from medical images, such as detecting cancers from radiological scans [23]. Furthermore, AI algorithms are being used to analyze genomic data, accelerating the development of personalized treatment plans tailored to individual patients' genetic profiles [24].

AI-driven drug discovery is another growing area, where machine learning models are used to predict the effectiveness of new compounds, reducing the time and cost of drug development [25]. Companies like DeepMind have demonstrated AI's potential in solving complex biological problems, such as protein folding, through the application of deep learning models [25].

Despite these successes, the adoption of AI in healthcare is accompanied by ethical and regulatory challenges. Issues of data privacy, security, and the need for explain ability in AI-driven decisions are central to ongoing debates about the role of AI in critical areas like healthcare [26].

2.4 AI Ethics and Fairness

The growing influence of AI in sensitive domains has raised concerns about fairness, accountability, and transparency [27]. Research by Okeh [28] and Editorial [29] has highlighted how AI systems can perpetuate biases present in the training data, leading to unfair outcomes in areas such as hiring, criminal justice, and credit scoring. The rise of algorithmic decision-making systems has prompted calls for more robust frameworks to ensure that AI technologies do not reinforce societal inequalities[30].

Fairness in AI is now a prominent research area, with scholars focusing on developing algorithms that mitigate bias and promote equitable outcomes [30]. Techniques such as fairness-aware machine learning and adversarial debiasing are being explored to address these challenges, but there is still much work to be done in ensuring that AI systems are transparent, interpretable, and aligned with ethical norms [31].

2.5 AI in Industry and Society

AI's impact on industries such as finance, manufacturing, and logistics is also well-documented. In finance, AI-driven algorithms are used for fraud detection, algorithmic trading, and customer service automation [25]. In manufacturing, AI is applied in predictive maintenance, quality control, and supply chain optimization, improving efficiency and reducing costs [13]. Similarly, AI-powered robotics and automation systems are transforming logistics and warehousing, enabling more intelligent inventory management and faster fulfillment times [13].

AI's societal impact is significant, particularly in the context of automation and employment. While AI-driven automation has the potential to increase productivity and economic growth, it also poses challenges for the labor market, particularly for workers in routine and repetitive jobs [2]. A Study by Capraro et al. [32] suggest that the rise of AI may exacerbate income inequality and job displacement, prompting a need for new policy frameworks that address these issues.

3. METHODOLOGY

This study employs a bibliometric analysis to evaluate global research trends in Artificial Intelligence (AI) from 2019 to 2024. Bibliometric analysis, which applies mathematical and statistical methods to quantify research outputs, is a widely recognized approach for analyzing patterns in scientific publications. It helps to uncover key insights into the development, influence, and spread of research across various disciplines. This methodology enables us to track the evolution of AI research, identify the most influential works and contributors, and assess the geographic distribution of AI research.

3.1 Data Collection

The data for this study were sourced from the Scopus database, which includes high-quality peer-reviewed publications across multiple disciplines. The database is particularly valuable for bibliometric studies due to its comprehensive coverage of top-tier journals and conferences in AI and related fields. The data extraction focused on publications explicitly related to AI in the area of computer science and Engineering.

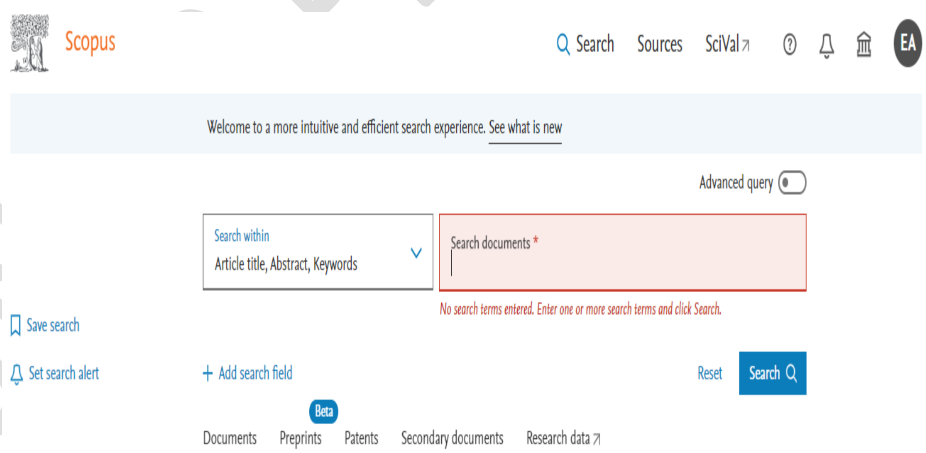

Figure 1: Scopus Interface
Source: Scopus

3.2 Keyword Selection

The initial step involved the identification of relevant keywords. Generative AI (Chart GPT) was used to generate the most relevant keywords out of the topic in focus. This led to the development of a keyword list that included terms like Bibliometric, Approach, Artificial Intelligence, Research, Trends. The first search results did not meet the researchers' expectations so a follow up question was requested to get a more precise list of keywords to be used. This led to the development of a more precise keyword list that included terms like Artificial Intelligence, Machine Learning, Deep Learning, Natural Language Processing (NLP), Neural Networks, Computer Vision, Reinforcement Learning, Robotics, AI Ethics, Autonomous Systems. However, the researcher narrowed it down to just the use of the keyword Artificial Intelligence it is the very core of the research.

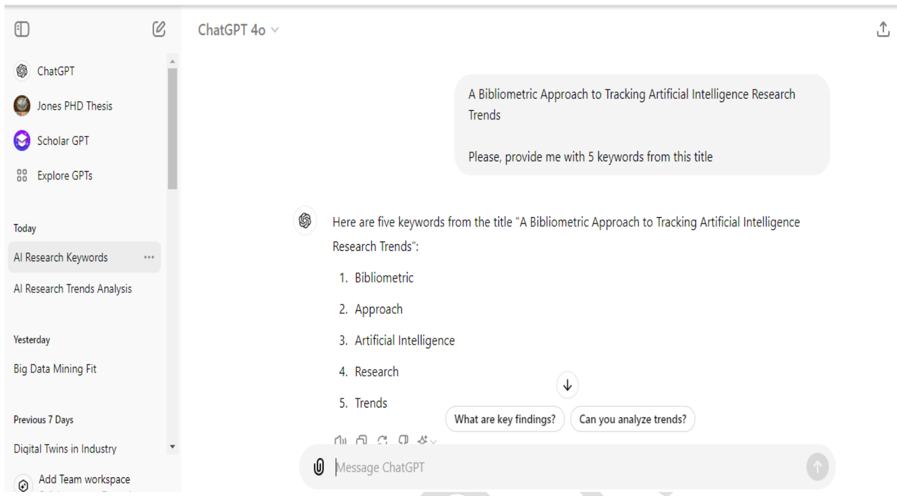

Figure 2: Initial keyword generation using ChatGPT
Source: ChatGPT

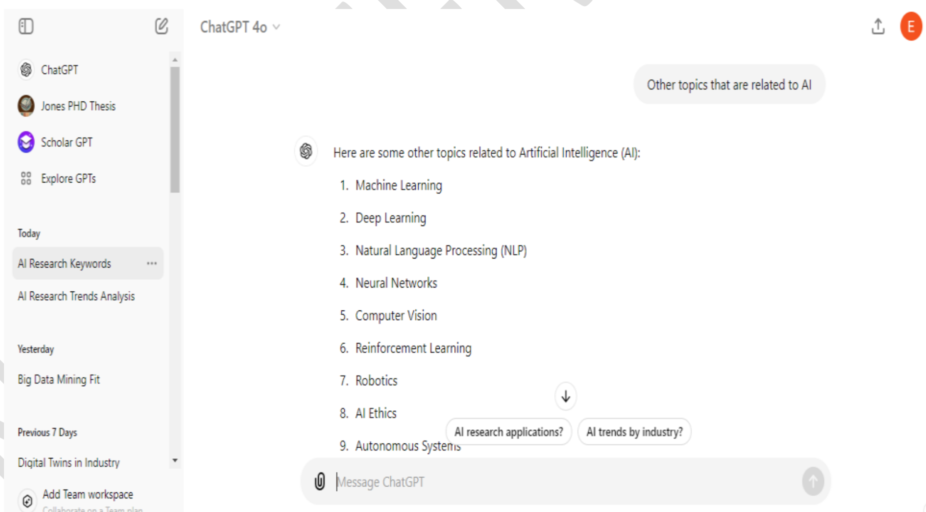

Figure 3: Advance keyword search from ChatGPT
Source: ChatGPT

3.3 Search Strategy

A search was conducted in the Scopus database using the finalized keyword "Artificial Intelligence". Boolean operator (AND) (*artificial AND intelligence) was employed to broaden the search and capture variations of key terms as it generated a relevant paper in regards to the subject area. The search was restricted to article titles, abstract, and keywords to ensure that the publications were directly related to AI. The initial timeframe for the search spanned from 2019 to 2024. However, to ensure the relevance of the dataset to the field of computer science, we filtered the search results by the Scopus categories most relevant to AI, such as Computer Science. The initial search without any filters yielded a total number of 292,612 papers from 2019 to 2024, which were further refined by limiting the search to subject areas like, “Computer Science” and document types like, “Article”, source title like, “IEEE Access amongst others “and keywords like: “Artificial Intelligence”, Country/territory like: United States, China, India, United Kingdom, Germany, Italy and Japan and Language was limited to English resulting in a final dataset of 3,149 Artificial Intelligence related publications.

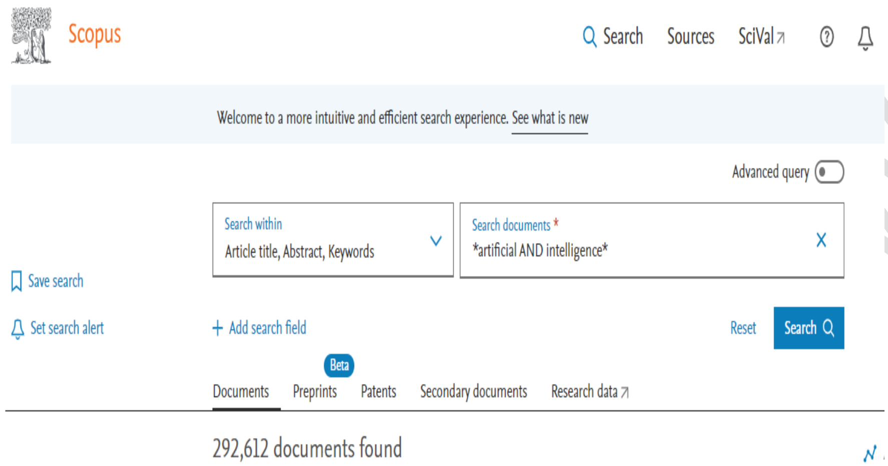

Figure 4: Initial search without filter from 2019 to 2024
Source: Scopus

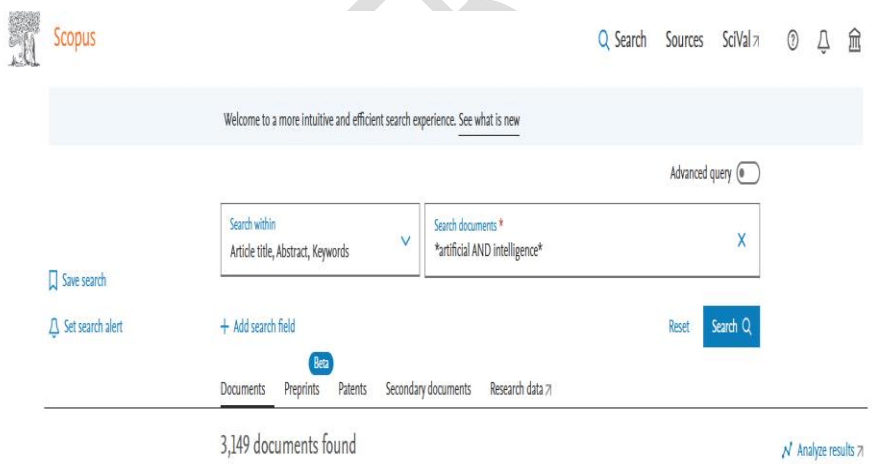

Figure 5: Search after applying relevant filters from 2019 to 2024
Source: Scopus

3.4 Data Processing

The extracted data were imported into Microsoft Excel and BibTex for further analysis. Each record included information such as document title, authors, affiliations, publication year, keywords, journal name, number of citations, and references. These bibliographic details formed the basis for quantitative analysis and citation analysis.

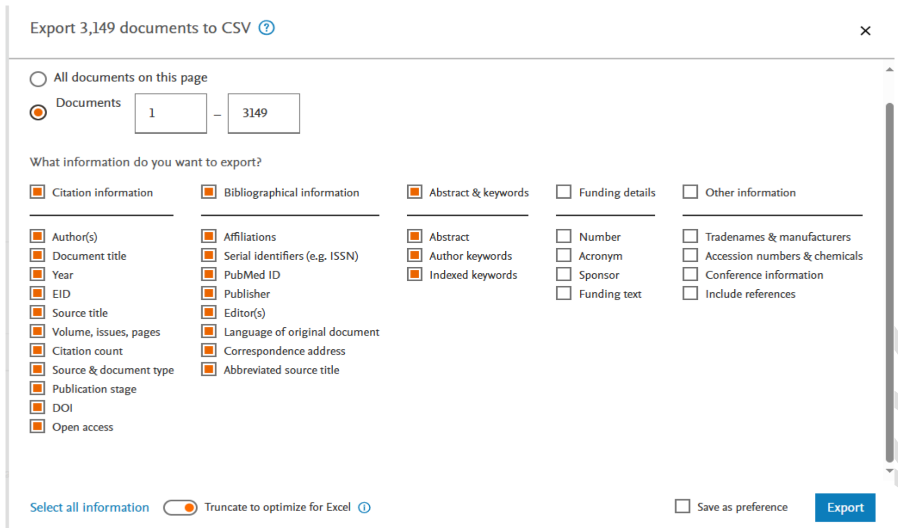

Figure 6: Exporting 3,149 documents to CSV from 2019 to 2024
Source: Scopus

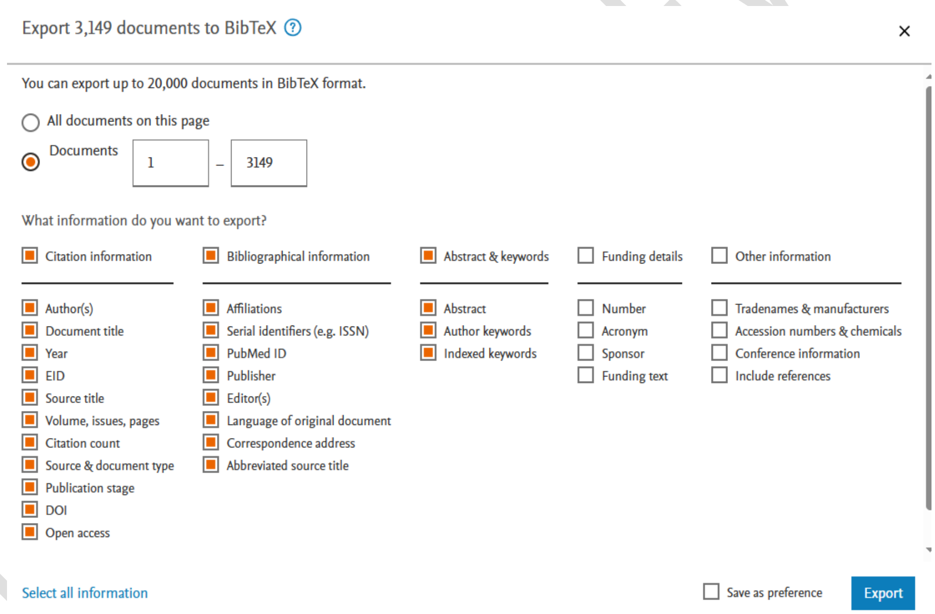

Figure 7: Exporting 3,149 documents to BibTex from 2019 to 2024
Source: Scopus

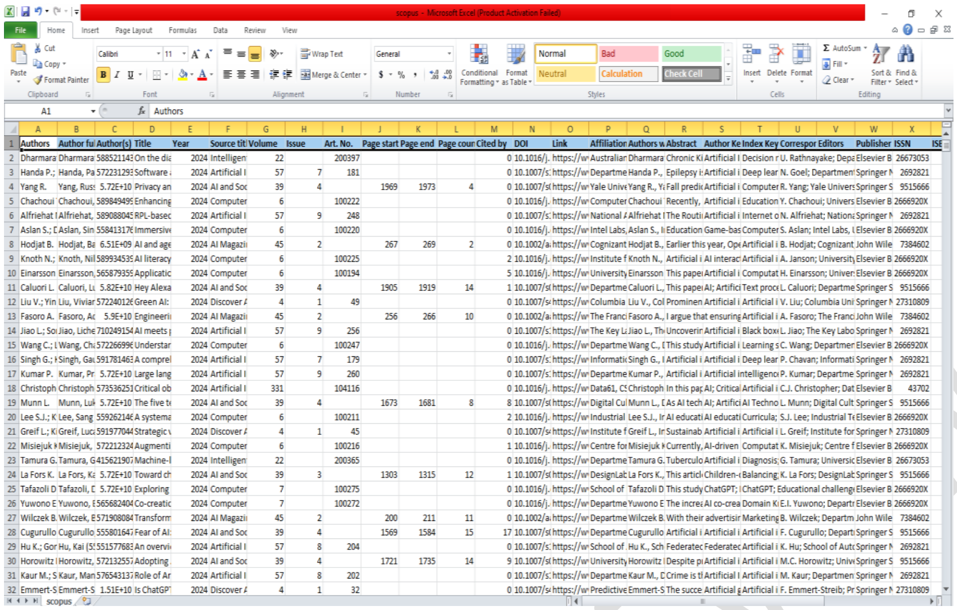

Figure 8: Excel display of data entries after export
Source: Excel 2010

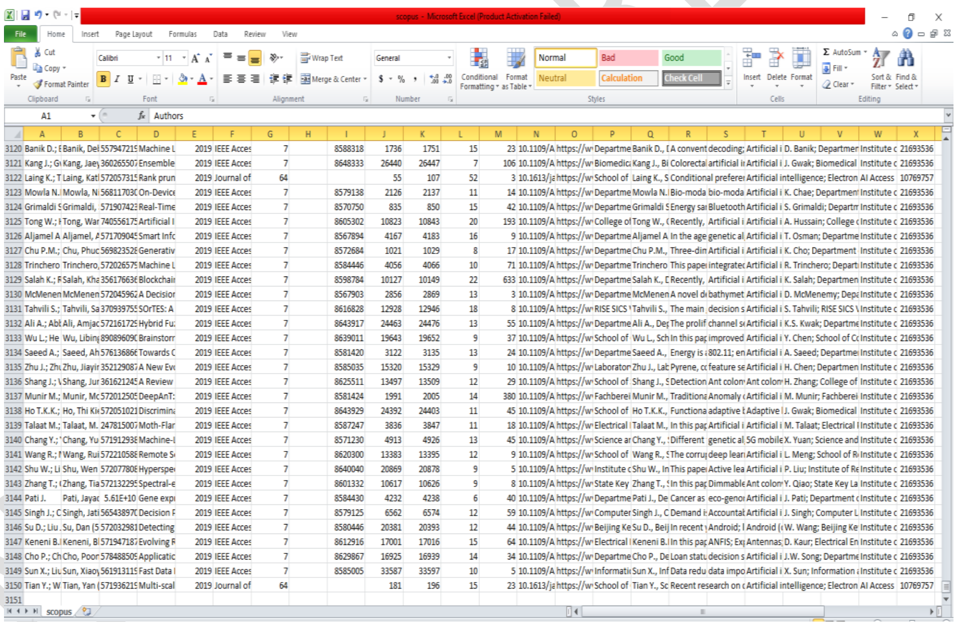

Figure 9: Excel display of data entries after export
Source: Excel 2010

4. DATA ANALYSIS AND DISCUSSION

4.1 Completeness of metadata

The table below assesses the metadata completeness for 3,118 documents out of the 3,149 documents from Scopus, evaluating various metadata fields based on their level of completeness. Key fields such as Author (AU), DOI (DI), Document Type (DT), Journal (SO), Language (LA), Publication Year (PY), Title (TI), and Total Citation (TC) show 0% missing data, earning an "Excellent" status, which indicates that these fields are fully populated and reliable across all documents.

Fields like Affiliation (C1), Abstract (AB), Keywords Plus (ID), and Corresponding Author (RP) have minor gaps, with missing percentages ranging from 0.06% to 6.86%, and are rated as "Good." This suggests that while they are not perfect, they still maintain a high degree of completeness. The Keywords (DE) field, with a missing rate of 17.93%, is marked as "Acceptable," indicating more significant gaps but still providing a reasonable amount of data.

However, both the Cited References (CR) and Science Categories (WC) fields are completely missing across all documents, with 100% missing data. This represents a critical gap, as these fields are essential for in-depth bibliometric analysis and categorization.

Completeness of metadata -- **3118** docs from **Scopus**

Metadata	Description	Missing Counts	Missing %	Status
AU	Author	0	0.00	Excellent
DI	DOI	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
LA	Language	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
C1	Affiliation	2	0.06	Good
AB	Abstract	3	0.10	Good
ID	Keywords Plus	60	1.92	Good
RP	Corresponding Author	214	6.86	Good
DE	Keywords	559	17.93	Acceptable
CR	Cited References	3118	100.00	Completely missing
WC	Science Categories	3118	100.00	Completely missing

Advice Report Save Close

Figure 10: Completeness of metadata from 2019 to 2024
Source: Biblioshiny

4.2 Main Information

The dashboard below provides a comprehensive overview of the main bibliometric details for a dataset spanning from 2019 to 2024. The dataset includes contributions from 28 sources, comprising a total of 3,118 documents, with an annual growth rate of 18.2%, reflecting steady expansion in research output. A significant number of 11,384 authors have contributed to this research, though 333 documents were single-authored, indicating that the majority of work is collaborative. On average, each document involves 4.03 co-authors, with 34.35% of the publications being the result of international collaborations, underscoring the global reach of the research.

The dataset is enriched by 8,281 unique keywords, reflecting the diversity of topics covered. However, the metadata shows 0 references, pointing to a gap in reference data collection. The documents are relatively recent, with an average age of 1.99 years, indicating that the research is up-to-date. Additionally, the documents have made a noticeable impact, with each receiving an average of 15.77 citations.

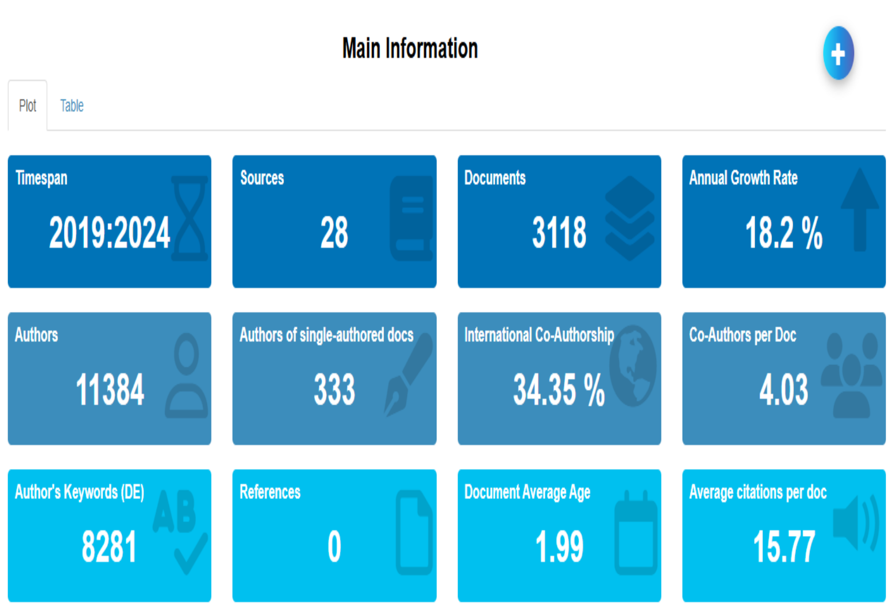

Figure 11: Main Information from 2019 to 2024
Source: Biblioshiny

4.3 Annual Scientific Production

The graph below illustrates the Annual Scientific Production from 2019 to 2024, showing a clear trend in the number of articles published each year. Starting at around 300 articles in 2019, the production gradually increases to 400 articles in 2020, followed by a sharp rise to over 600 articles in 2021. The peak occurs in 2022, with over 700 articles published, indicating a significant boost in research output. However, in 2023, there is a slight decline, bringing production back to just over 600 articles, where it stabilizes with a minor uptick in 2024. Overall, the graph highlights a period of rapid growth in scientific production, particularly between 2020 and 2022, followed by stabilization after the peak.

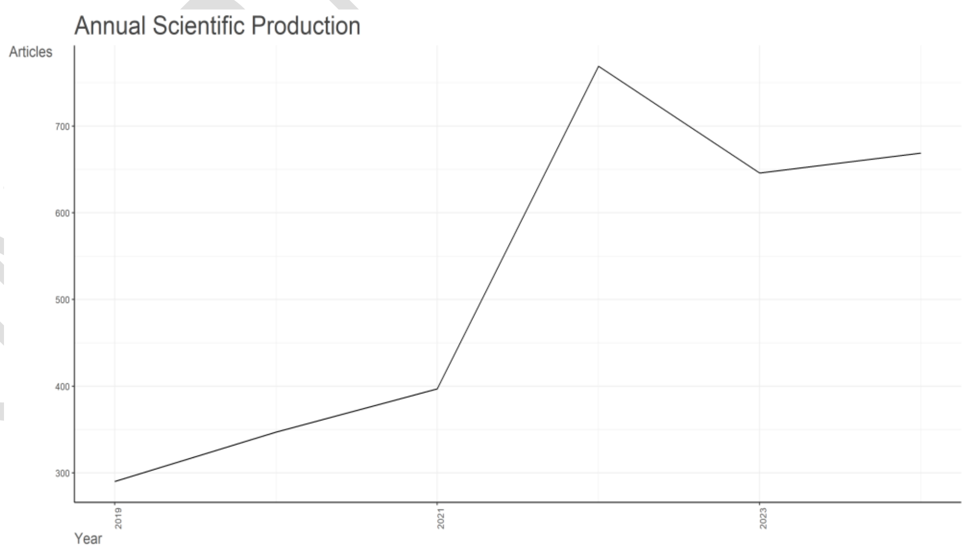

Figure 12: Annual Scientific Production 2019 to 2024
Source: Biblioshiny

4.4 Average Citations per Year

The graph illustrates the trend in Average Citations per Year from 2019 to 2024, showing a steady decline in the average number of citations received by articles over time. In 2019, the average citations per article were relatively high at around 7 citations, peaking slightly above 7 citations in 2020. However, starting in 2021, there is a noticeable decline, with the average dropping to around 6 citations. This downward trend continues through 2022 and 2023, where the average falls to approximately 4 citations and then below 3 citations. By 2024, the average citations per article reach their lowest point, dropping to around 1 citation. Overall, the graph suggests a consistent decline in average citations after 2020, potentially due to the increasing volume of publications or the time required for newer articles to accumulate citations.

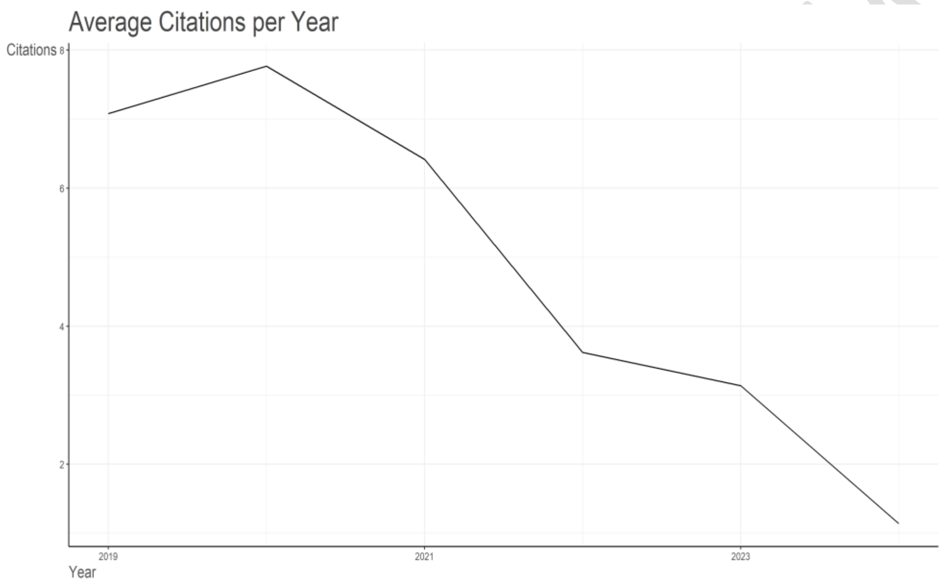

Figure 13: Average Citation per Year from 2019 to 2024
Source: Biblioshiny

4.5 Most Relevant Sources

The chart below highlights the Most Relevant Sources based on the number of documents they have published. IEEE Access leads by a significant margin, with 1,931 documents, showcasing its dominant role in the field. Computational Intelligence and Neuroscience follows distantly with 387 documents, while AI and Society ranks third with 131 documents. Other notable sources include the Journal of Artificial Intelligence Research (84 documents), Artificial Intelligence Review (83 documents), and AI Magazine (77 documents). Additional sources such as Artificial Intelligence (72 documents), Computers and Education: Artificial Intelligence (57 documents), and Journal of Advanced Computational Intelligence and Discover Artificial Intelligence (53 and 36 documents respectively) also contribute significantly to the research landscape. Overall, the chart underscores the prominence of IEEE Access as a leading source, with other journals playing supportive but impactful roles in disseminating AI and related research.

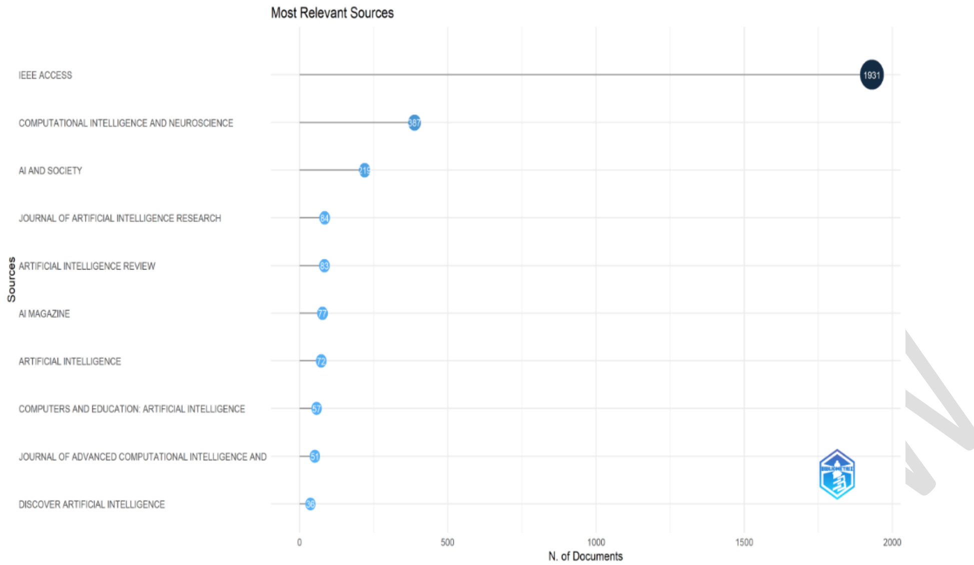

Figure 14: Most Relevant Sources from 2019 to 2024
Source: Biblioshiny

4.6 Sources' Local Impact by H index

The chart below illustrates the Sources' Local Impact by H Index, which measures the influence and citation impact of various sources. IEEE Access stands out with a significantly high H index of 82, indicating its dominant influence and impact in the field. AI and Society follows with an H index of 30, showcasing strong influence as well. Computational Intelligence and Neuroscience has an H index of 23, while Artificial Intelligence registers at 21, and Artificial Intelligence Review at 19, all indicating substantial impact. Other sources such as the Journal of Artificial Intelligence Research (18), Computers and Education: Artificial Intelligence (17), and AI Magazine (12) maintain a moderate level of influence. Further down, Frontiers in Robotics and AI and Artificial Intelligence and Law have H indices of 11 and 9, respectively, reflecting more specialized or niche impact. Overall, the chart underscores the broad range of influence across AI-related journals, with IEEE Access being the clear leader in terms of local impact.

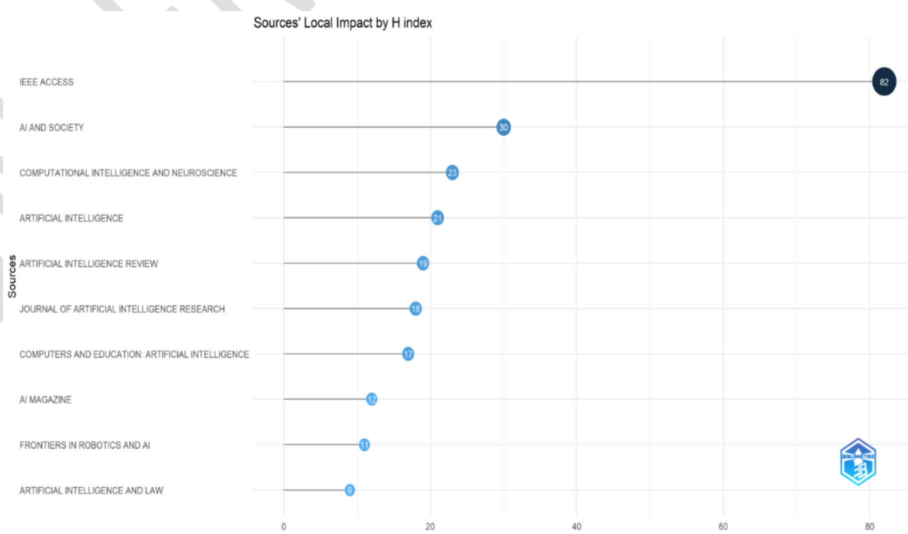

Figure 15: Sources' Local Impact by H index from 2019 to 2024
Source: Biblioshiny

4.7 Sources' Production over Time

The graph below displays the Sources' Production over Time, showing the cumulative occurrences of articles published by five major sources from 2019 to 2024. IEEE Access (blue line) is the dominant source, with a rapid and continuous growth in publications. By 2024, its cumulative number of articles approaches 2,000, significantly outpacing the other sources. Computational Intelligence and Neuroscience (green line) follows, but with a much slower growth rate, stabilizing around 400 cumulative occurrences after 2022. AI and Society (red line) and Artificial Intelligence Review (purple line) show modest but steady increases, with both sources remaining below 300 cumulative occurrences by 2024. Lastly, the Journal of Artificial Intelligence Research (yellow line) shows the slowest growth, staying relatively flat over time and remaining under 200 cumulative occurrences.

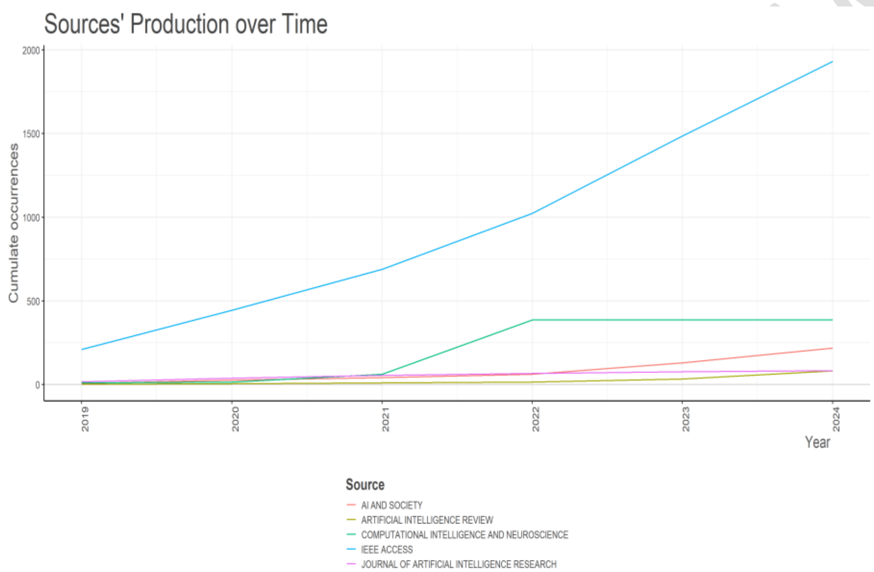

Figure 16: Sources' Production over Time 2019 to 2024
Source: Biblioshiny

4.8 Most Relevant Authors

The chart below displays the Most Relevant Authors based on the number of documents they have published. Floridi Luciano and Taddeo Mariarosaria are the top contributors, each with 12 documents, placing them at the forefront of the research landscape. Kotecha Ketan and Tanwar Sudeep follow closely with 9 documents each, reflecting their significant impact. Further down the list, authors such as Barata Jose, Gupta Rajesh, Mirjalili Seyedali, and Mosavi Amir have each contributed 6 documents, showcasing their consistent participation in research. Wang Wei also published 6 documents, and Ashraf Imran rounds out the list with 5 documents.

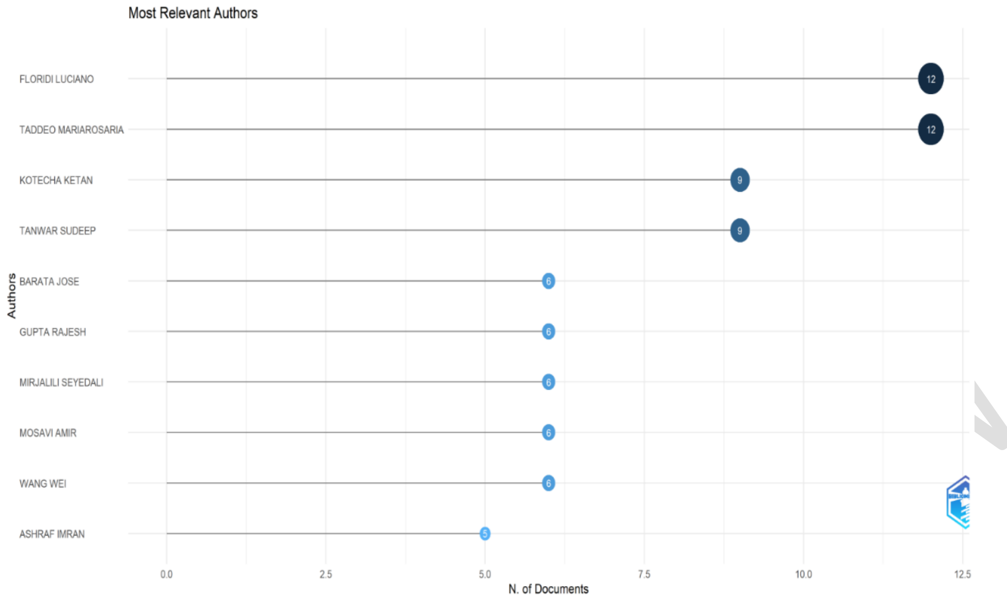

Figure 17: Most Relevant Authors from 2019 to 2024
Source: Biblioshiny

4.9 Authors' Production over Time

The chart below depicts the Authors' Production over Time, showcasing the number of articles published by each author per year along with their total citations (TC), represented by the size and color intensity of the circles. Floridi Luciano and Taddeo Mariarosaria exhibit consistent productivity, publishing multiple articles across several years, with their peak output of 7 articles in 2023 (indicated by the largest dark blue circles). Kotecha Ketan and Tanwar Sudeep also show steady contributions, with Tanwar reaching a peak of 5 articles in 2020. Other authors, including Barata Jose, Gupta Rajesh, Mirjalili Seyedali, Mosavi Amir, and Wang Wei, demonstrate regular but slightly lower productivity, generally publishing between 1 and 4 articles per year. Ashraf Imran shows a more recent pattern of contribution, with fewer publications overall, peaking in 2021 and 2022. The chart also highlights the total citations per year (TC), shown by the color intensity of the circles. Authors like Mirjalili Seyedali and Tanwar Sudeep stand out for their higher citation impact, indicated by darker circles, even with a lower number of articles. This indicates a strong influence in their respective fields despite having fewer publications.

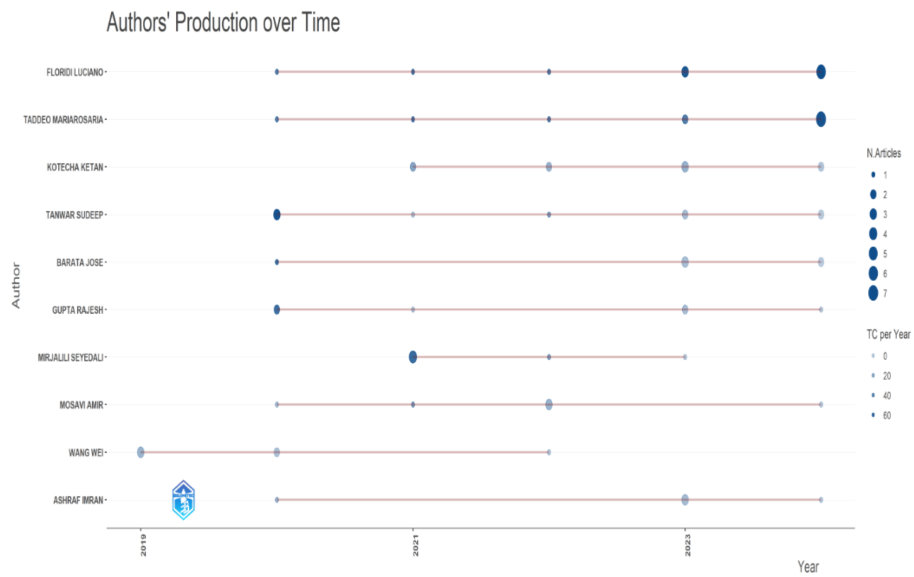

Figure 18: Authors' Production over Time from 2019 to 2024
Source: Biblioshiny

4.10 Authors' Local Impact by H index

The chart below illustrates the Authors' Local Impact by H Index, which measures the scholarly influence of authors based on their publication and citation performance. Floridi Luciano leads with the highest H index of 10, indicating his significant impact within the research community. Taddeo Mariarosaria follows closely with an H index of 8, also demonstrating strong influence. Authors such as Kotecha Ketan and Tanwar Sudeep both have an H index of 6, reflecting substantial contributions to their fields. Mirjalili Seyedali and Wang Wei have slightly lower H indices of 5, indicating a solid, though slightly lesser, impact compared to the top contributors. Further down, authors including Alazab Mamoun, Cowls Josh, El-Kenawy El-Sayed M, and Gupta Rajesh each hold an H index of 4, suggesting a more modest but notable level of influence in their respective research areas.

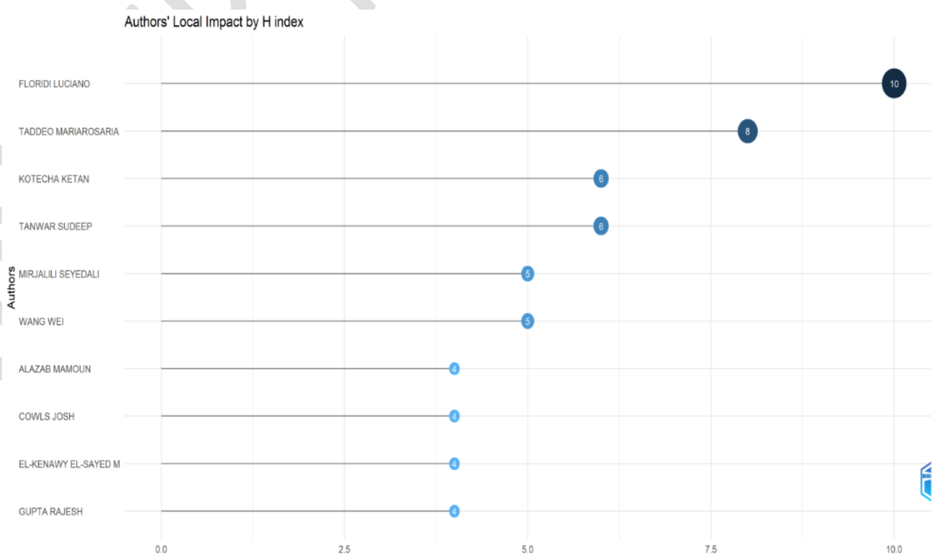

Figure 19: Authors' Local Impact by H index from 2019 to 2024
Source: Biblioshiny

4.11 Most Relevant Affiliations

The chart below highlights the Most Relevant Affiliations based on the number of articles produced by each institution. King Saud University leads with 70 articles, demonstrating its significant contribution to research output. Prince Sattam Bin Abdulaziz University follows with 40 articles, while Taif University and King Khalid University have published 37 and 34 articles, respectively. The University of Oxford is next with 33 articles, closely followed by King Abdulaziz University with 32 articles. Princess Nourah Bint Abdulrahman University and COMSATS University Islamabad both contributed 28 and 26 articles. Sejong University and the University of Johannesburg round out the list with 23 and 21 articles. Overall, the chart highlights a range of academic institutions, with a clear dominance by Saudi Arabian universities, particularly King Saud University, which leads the research efforts across these affiliations.

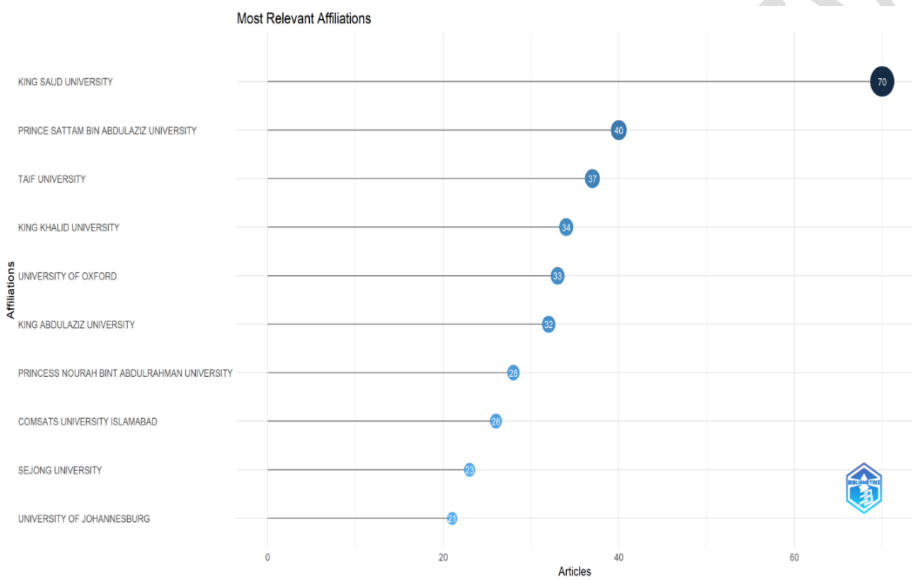

Figure 20: Most Relevant Affiliations from 2019 to 2024
Source: Biblioshiny

4.12 Affiliations' Production over Time

The graph below illustrates the Affiliations' Production over Time, showcasing the growth in article output from five key institutions between 2019 and 2024. King Saud University (yellow line) shows the most significant growth, especially after 2021, with its production sharply increasing to over 60 articles by 2024. Prince Sattam Bin Abdulaziz University (green line) and King Khalid University (red line) exhibit steady growth, with both institutions producing around 40 articles by 2024. Taif University (blue line) and the University of Oxford (pink line) also demonstrate consistent increases in article production, though at a slower pace, each reaching approximately 30 articles by 2024. Overall, the graph highlights the upward trajectory in research output across these institutions, with King Saud University emerging as the leading contributor, followed by Prince Sattam Bin Abdulaziz University and King Khalid University.

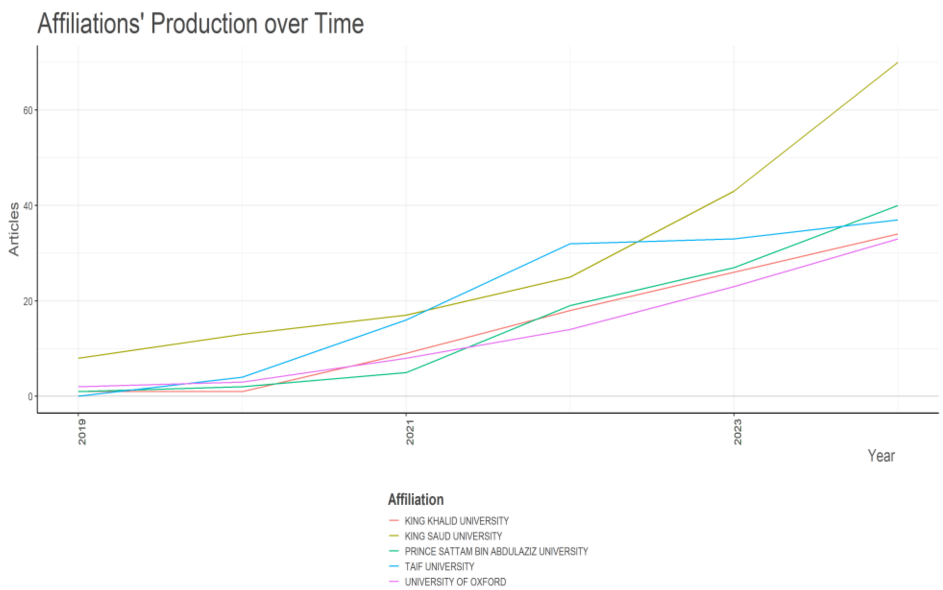

Figure 21: Affiliations' Production over Time from 2019 to 2024
Source: Biblioshiny

4.13 Corresponding Author's Countries

The chart below presents the Corresponding Author's Countries based on the number of documents, distinguishing between Single Country Publications (SCP) and Multiple Country Publications (MCP). China leads by a substantial margin, with the majority of its publications being SCPs, indicating a strong focus on national collaborations. The USA follows closely, showing a more balanced mix between SCPs and MCPs, reflecting its high level of international collaborations. Korea and India are also prominent, with a significant portion of their publications being SCPs, while the United Kingdom and Saudi Arabia show a healthy balance between national and international collaborations. Germany, Italy, and Japan demonstrate a similar pattern of mixed SCPs and MCPs, indicating active participation in both domestic and international research efforts. Countries like Spain, Pakistan, Malaysia, Australia, and Canada contribute a notable number of publications, with a tendency towards SCPs but also maintaining international collaborations. Other nations such as Egypt, Brazil, and Turkey have a more balanced output between SCPs and MCPs, showing their involvement in both local and global research networks. Overall, the chart highlights China and the USA as the leading contributors, with a diverse range of other countries participating in global research efforts through a combination of domestic and international collaborations.

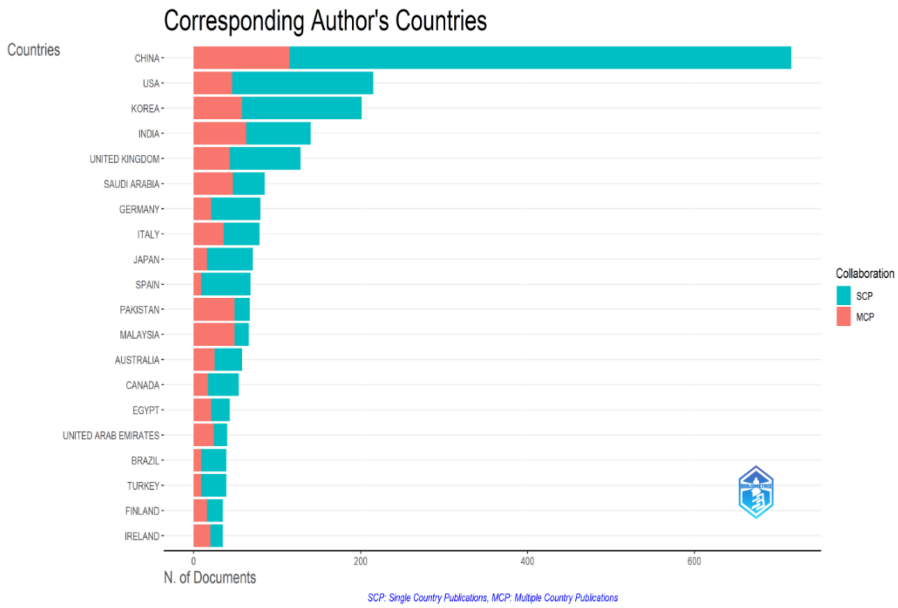

Figure 22: Corresponding Authors' Countries from 2019 to 2024
Source: Biblioshiny

4.14 Country Scientific Production

The world map below illustrates Country Scientific Production, with darker shades of blue representing higher levels of scientific output. China is the dominant producer, highlighted in the darkest blue, followed by the USA, which also exhibits significant scientific activity. Other countries like India, Germany, Brazil, and South Korea are shaded in lighter blues, indicating moderate levels of research output. Countries across Europe, Asia, and parts of South America show active scientific contributions, while regions in Africa and some parts of the Middle East and Central America, represented in gray, demonstrate lower levels of production. Overall, the map reflects a global distribution of scientific activity, with clear leaders in China and the USA, and notable contributions from various other countries across continents.

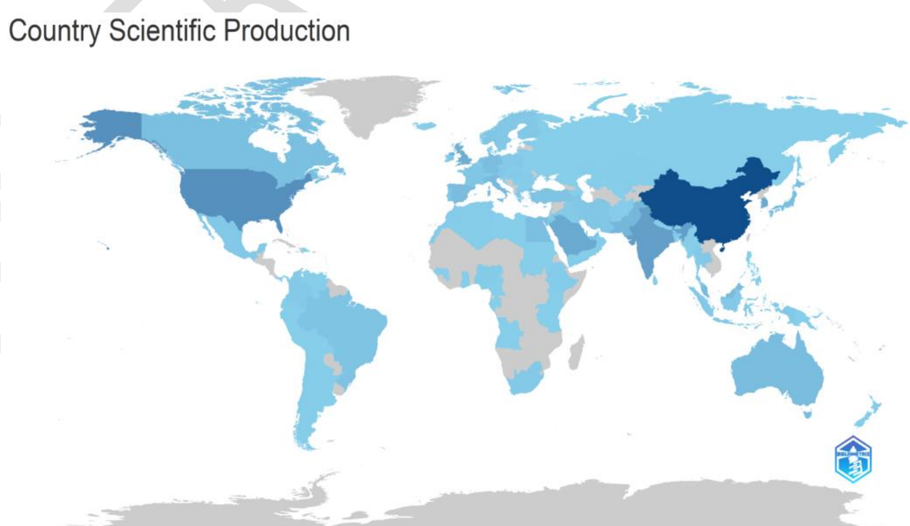

Figure 23: Country Scientific Production from 2019 to 2024
Source: Biblioshiny

4.15 Most Global Cited Documents

The chart below showcases the Most Global Cited Documents, highlighting the papers with the highest citation counts. Gunning D's 2019 article in AI Magazine leads the list with 901 citations, followed closely by Rasheed A's 2020 paper in IEEE Access with 876 citations. Park SM's 2022 publication in IEEE Access follows with 834 citations, and Bentéjac C's 2021 paper in Artificial Intelligence Review has 805 citations. Other highly cited documents include Akyildiz IF's 2020 IEEE Access paper with 742 citations and Chen L's 2020 IEEE Access paper, which has 731 citations. Salah K's 2019 work in IEEE Access also ranks high with 633 citations. Further down the list, Nguyen G's 2019 paper in Artificial Intelligence Review and Deng W's 2019 IEEE Access paper have received 496 and 486 citations, respectively. Xu G's 2019 IEEE Access publication rounds out the list with 436 citations. This chart highlights influential papers across AI-related journals, with IEEE Access dominating the field, contributing most of the top-cited documents.

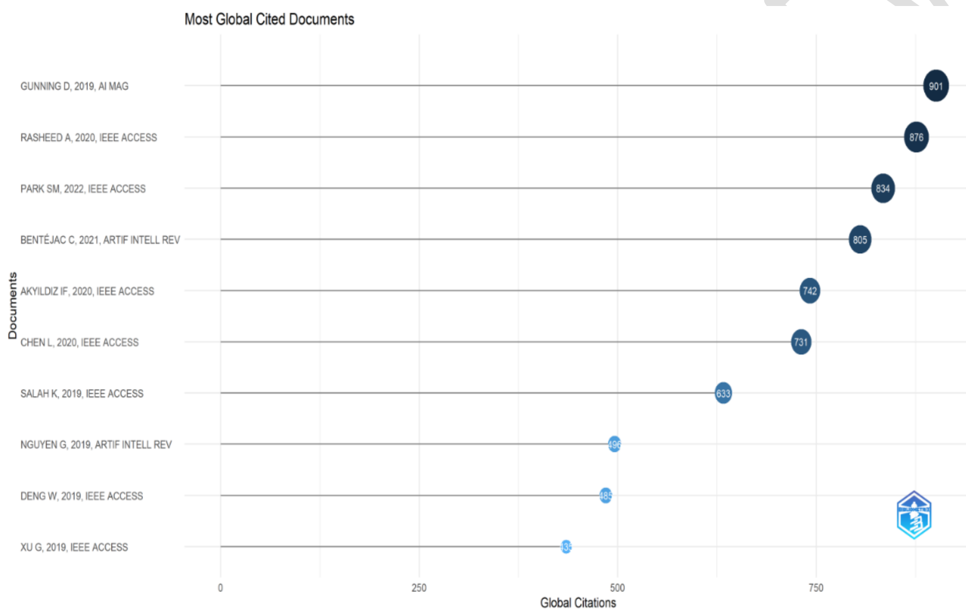

Figure 24: Most Global Cited Documents from 2019 to 2024
Source: Biblioshiny

4.16 Most Relevant Words

The chart below highlights the Most Relevant Words in research, ranked by the number of occurrences. Artificial intelligence dominates with 2,880 occurrences, reflecting its central role in academic discussions. Learning systems follows with 914 occurrences, showing its importance in AI-related research. Machine learning appears frequently as well, with 371 occurrences, underscoring its significance as a key topic. Other prominent terms include deep learning with 156 occurrences and learning algorithms with 135 occurrences, both critical subfields in AI. Neural networks appear with 77 occurrences, continuing to be a relevant area of study. Additionally, more specific terms like forecasting (77 occurrences), decision making (43 occurrences), predictive models (41 occurrences), and internet of things (38 occurrences) reflect the diverse applications and theoretical extensions of AI research.

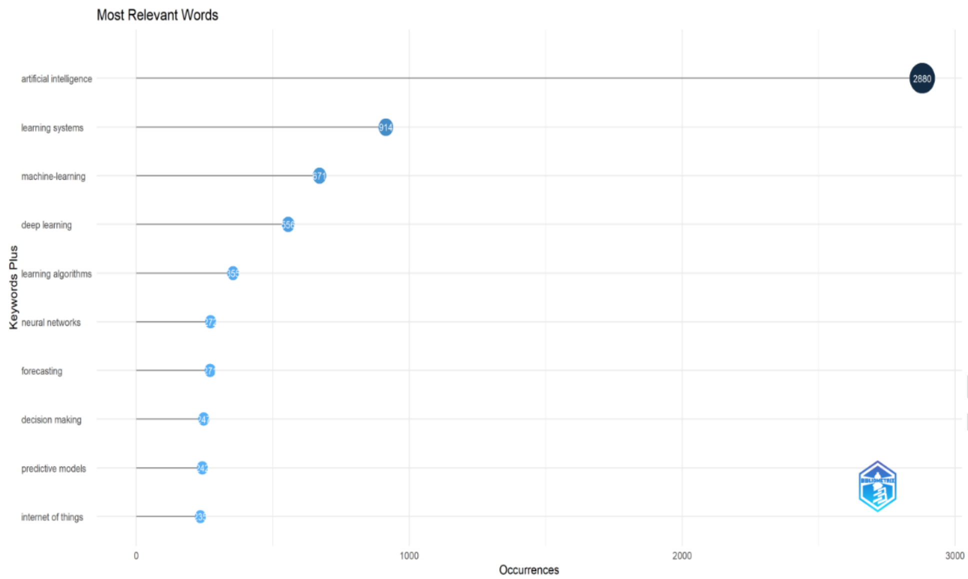

Figure 25: Most Relevant Words from 2019 to 2024
Source: Biblioshiny

4.17 WordCloud

The WordCloud below visually represents the most prominent research keywords based on their frequency, with larger words indicating higher occurrences. Artificial Intelligence dominates the cloud as the most frequently mentioned term, reflecting its central importance in current research. Other significant terms include Learning Systems, Machine Learning, and Deep Learning, all of which appear prominently, showcasing their relevance in the AI landscape. Additional keywords such as Learning Algorithms, Neural Networks, Decision Making, and Predictive Models also feature, though with smaller sizes, indicating they are important but less frequently cited compared to the core AI topics.

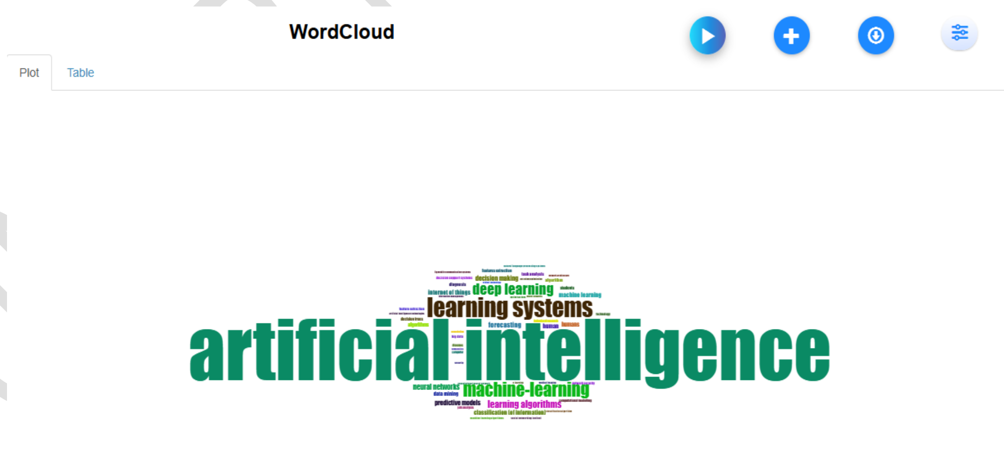

Figure 26: WordCloud from 2019 to 2024
Source: Biblioshiny

4.18 TreeMap

The TreeMap below visualizes the most relevant research topics based on their frequency of occurrence, with the size of each block representing the prominence of the term. Artificial Intelligence dominates the map with 2,880 occurrences (24%), clearly establishing itself as the central focus in current research. Learning Systems follows with 914 occurrences (8%), and Machine Learning with 671 occurrences (6%), highlighting their significance within the AI field. Other important topics include Deep Learning with 556 occurrences (5%) and Learning Algorithms with 355 occurrences (3%). Smaller blocks represent a range of specialized topics such as Neural Networks (272 occurrences, 2%), Predictive Models (242 occurrences, 2%), Internet of Things (235 occurrences, 2%), and Forecasting (271 occurrences, 2%), indicating areas of active research but with narrower focus. Additional fields such as Decision Making, Data Mining, Security, and Big Data each account for 1-2% of the research landscape, reflecting diverse applications and theoretical interests in AI. Overall, the TreeMap highlights the dominance of AI and its related fields like learning systems and machine learning while showcasing a broad spectrum of specialized topics that contribute to the richness of the research landscape.

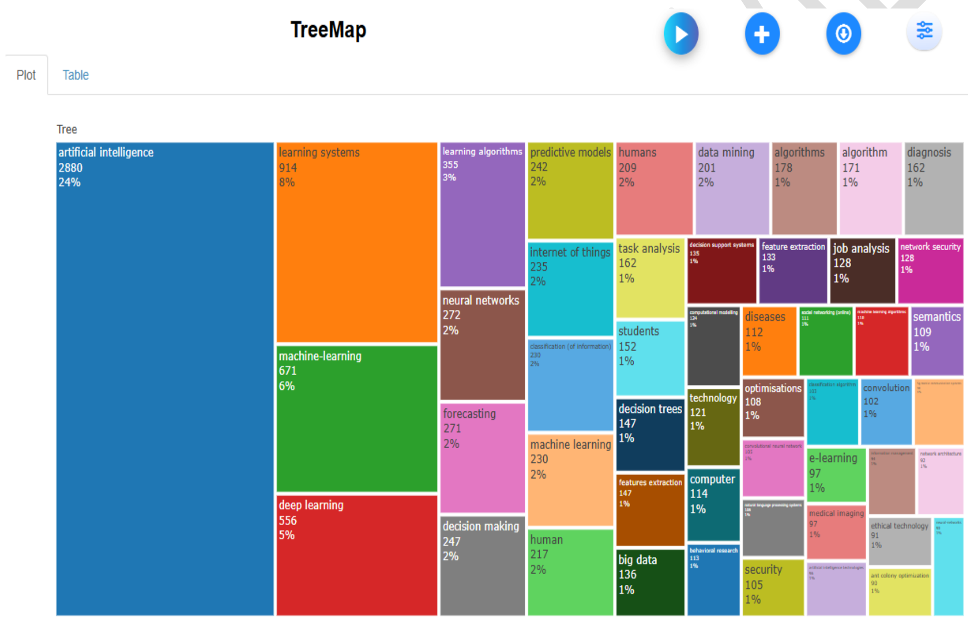

Figure 27: TreeMap from 2019 to 2024
Source: Biblioshiny

4.19 Words' Frequency over Time

The chart below illustrates the Words' Frequency over Time, showcasing the cumulative occurrences of various key research terms from 2019 to 2024. Artificial Intelligence (represented by the red line) dominates the chart with a steep upward trajectory, significantly outpacing other terms as its frequency surpasses 2,500 occurrences by 2024. This reflects the central focus on AI in scholarly research. Other terms, such as Learning Systems, Machine Learning, Deep Learning, and Neural Networks, follow with much slower but steady growth. These terms show a consistent increase in their usage, each reaching around 500 occurrences or slightly above by 2024, indicating their ongoing relevance in the AI and machine learning fields. Smaller terms, such as Decision Making, Predictive Models, Forecasting, Internet of Things, and Learning Algorithms, show gradual growth but remain below the major AI-related terms in terms of cumulative frequency. These terms reflect more specialized areas of research that are steadily gaining attention. Overall, the chart emphasizes the overwhelming prominence of Artificial Intelligence, with consistent growth in related fields such as machine learning and learning systems, while other specialized terms show slower but steady increases over time, contributing to the diversity of the research landscape.

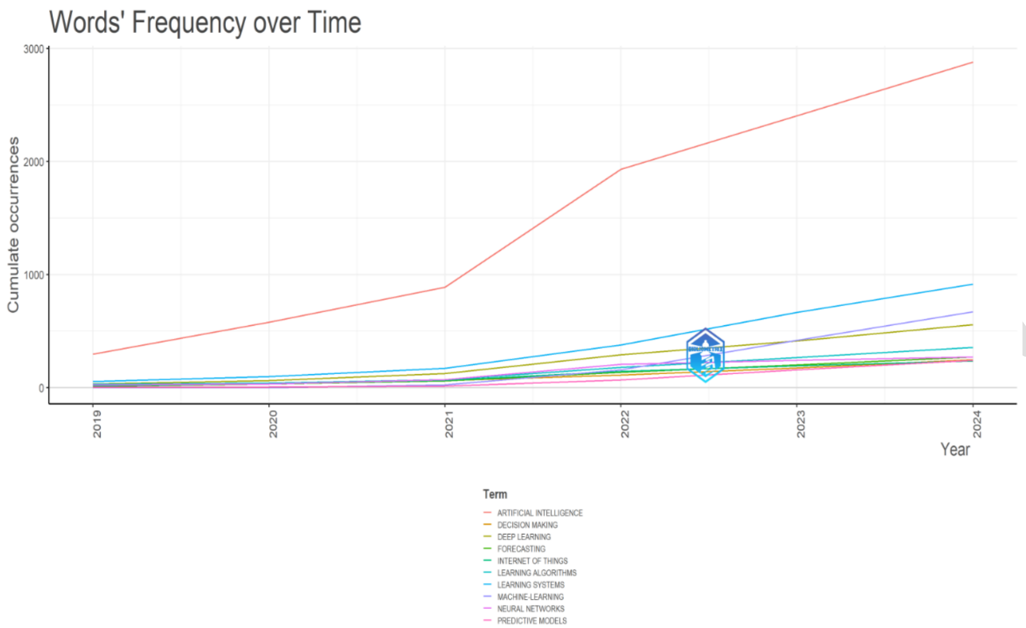

Figure 28: Words' Frequency over Time from 2019 to 2024
Source: Biblioshiny

4.20 Trend Topics

The Trend Topics chart below visualizes the evolution of key research terms from 2019 to 2024, with the size of each bubble representing the term's frequency. Artificial Intelligence stands out as the most prominent term, consistently increasing in usage across this period and reaching its peak around 2023. Terms such as Machine Learning, Deep Learning, Learning Systems, and Forecasting also show significant growth, reflecting their continued relevance in the AI field. Other topics like Convolutional Neural Networks, Learning Algorithms, and Optimization Algorithms emerge strongly around 2020, steadily gaining attention as research in these areas expands. More specialized terms such as Ant Colony Optimization, Multilayer Neural Networks, and Computational Methods also experience growth, but at a slower pace, indicating niche but impactful research areas. Emerging fields like Ethical Technology, Systematic, and Computational Linguistics gain traction in the later years, showing increased frequency by 2024, signaling a shift towards addressing broader concerns and specialized computational methods. Overall, the chart highlights the rapid expansion of AI-related topics, with foundational technologies like machine learning leading the way, while newer and more focused areas of research steadily rise in prominence.

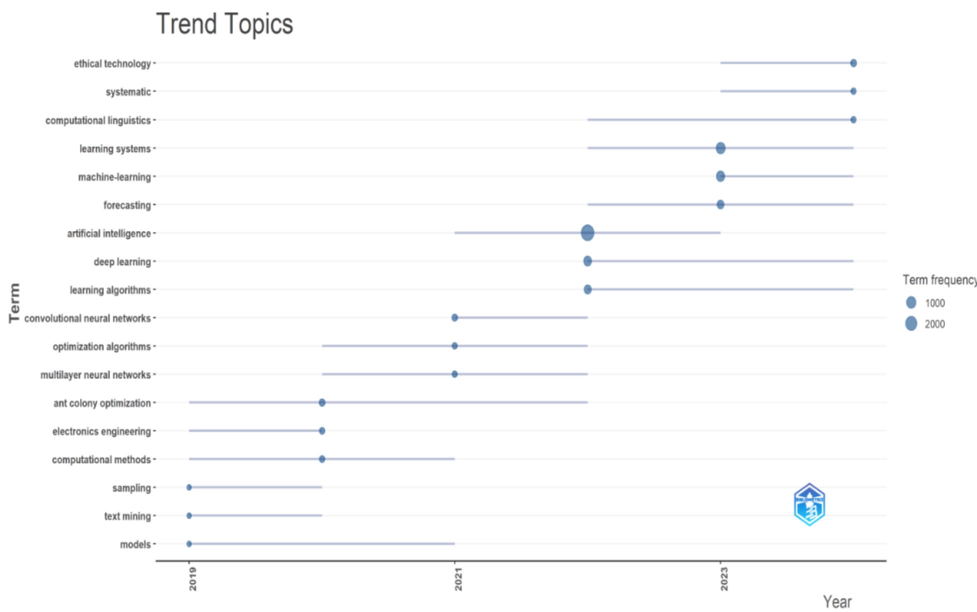

Figure 29: Trend Topics from 2019 to 2024
Source: Biblioshiny

4.21 Co-occurrence Network

The Co-occurrence Network below visualizes the relationships between key research terms based on how often they appear together in scholarly work. Artificial Intelligence is the central and most prominent node, heavily interconnected with other significant topics, such as Learning Systems and Machine Learning, which are also large nodes in the network. This reflects the strong association between these fields in academic research. Clusters of related terms are grouped around these central concepts. For instance, Deep Learning, Neural Networks, and Medical Imaging form a closely-knit cluster, indicating their frequent co-occurrence and focus in research areas related to AI and machine learning applications. Similarly, topics like Network Architecture, Diagnosis, and Students are tightly linked, suggesting a focus on education and healthcare within AI. Another dense cluster includes terms like Decision Making, Big Data, Social Networking, and Semantics, which are often associated with AI's applications in decision support systems and data analysis. More specialized fields such as Ethical Technology, Ant Colony Optimization, and Convolutional Neural Networks are also represented, reflecting the broader scope of AI's impact on various industries and disciplines. Overall, the network illustrates the highly interconnected nature of AI-related research, with Artificial Intelligence at the core, surrounded by key topics that demonstrate the breadth of its influence across multiple domains.

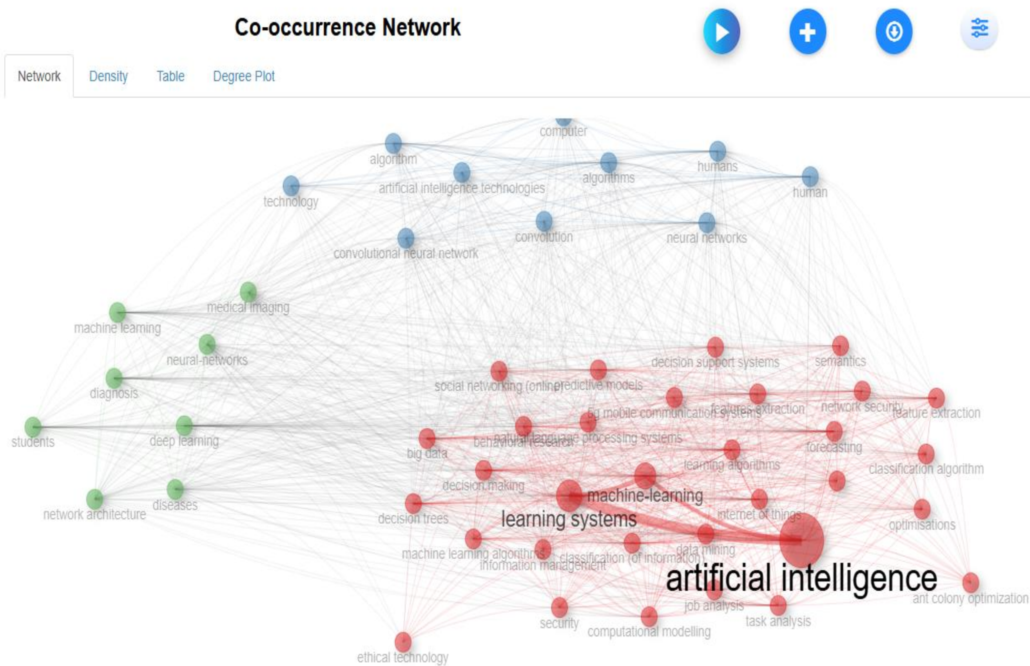

Figure 30: Co-occurrence Network from 2019 to 2024
Source: Biblioshiny

4.22 Thematic Map

The Thematic Map below categorizes key research topics based on their Development Degree (Density) and Relevance Degree (Centrality), dividing them into four quadrants: Motor Themes, Basic Themes, Niche Themes, and Emerging or Declining Themes. In the Motor Themes quadrant (upper-right), which contains topics that are both well-developed and highly relevant, we find Artificial Intelligence, Learning Systems, and Machine Learning. These are critical, highly influential areas driving research forward due to their strong centrality and continuous development.

The Basic Themes quadrant (lower-right) includes terms like Deep Learning, Classification (of information), and Diagnosis, which are central to research but less developed. These topics serve as fundamental building blocks for AI research, providing essential support to the broader field. In the Niche Themes quadrant (upper-left), we observe terms like Neural Networks, Humans, Security, Network Security, and 5G Mobile Communication Systems. These topics are well-developed but less central, indicating that they cater to more specialized areas of research. Finally, the Emerging or Declining Themes quadrant (lower-left) contains terms like Natural Language Processing Systems and Natural Languages, suggesting that these topics are either in the early stages of development or are losing relevance in the current research landscape.

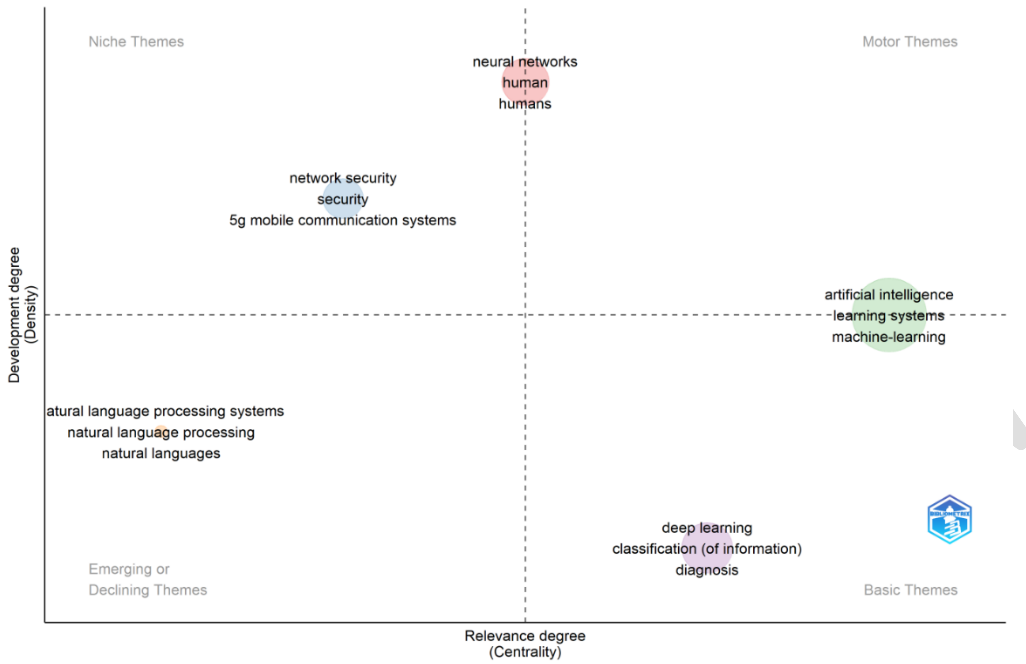

Figure 31: Thematic Map from 2019 to 2024
Source: Biblioshiny

4.23 Conceptual Structure Map

The Conceptual Structure Map using the MCA method below provides a comprehensive visualization of how various research topics within AI and machine learning are interconnected. The map is divided into two dimensions, which represent different conceptual relationships between the terms, with the proximity and clustering of these terms reflecting their co-occurrence in research. At the center of the map lies the core cluster of AI research, dominated by fundamental concepts such as machine learning, learning algorithms, deep learning, classification of information, and predictive models. This centrality highlights the foundational role these topics play in AI research, supporting a wide range of applications and methodologies. Closely linked to these core topics are terms like data mining, decision trees, forecasting, and network security, which further emphasize the central role of AI in solving complex data-driven problems and enhancing system security. To the right of the map, a cluster focused on practical applications and methodologies emerges. Here, terms such as task analysis, job analysis, machine learning algorithms, and features extraction dominate. This area emphasizes the practical side of AI, particularly the development and optimization of algorithms to extract meaningful insights from data. Medical imaging and classification algorithms also appear here, underscoring the importance of AI in healthcare and diagnostic tasks. The top section of the map is home to advanced

AI techniques, especially those related to neural networks. Terms like convolutional neural networks, convolution, and features extraction highlight the significance of deep learning techniques, particularly in image processing and visual data analysis. This cluster points to the cutting-edge research in AI-driven image recognition and automated diagnostics, such as in medical imaging. In the bottom left corner, we find a more isolated cluster focused on algorithms and human-related topics, including humans and computers. This suggests a research area that leans towards the fundamental and conceptual aspects of AI, exploring the development of general algorithms and their interactions with human factors, raising ethical and foundational questions about AI design and its impact on society. Finally, in the bottom right, a cluster reflects emerging and interdisciplinary areas in AI research. Terms like artificial intelligence technologies, ethical technology, and X5G mobile communication systems point to new and evolving fields, where AI intersects with cutting-edge technologies like 5G networks and ethical concerns. The inclusion of topics like behavioral research and e-learning suggests AI’s growing influence in education and behavioral sciences.

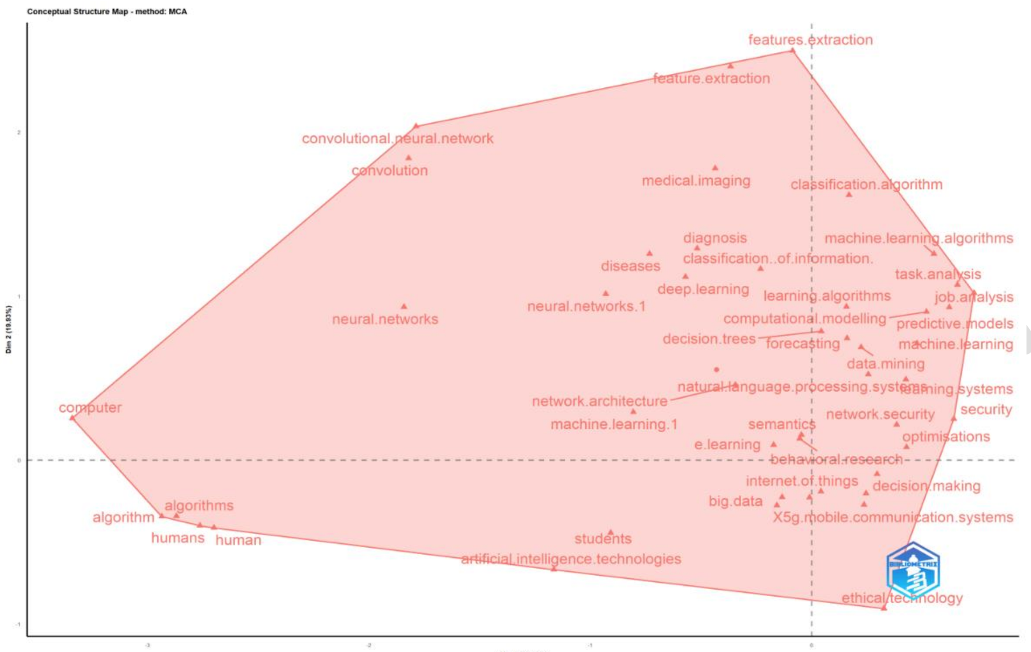

Figure 32: Conceptual Structure Map from 2019 to 2024
Source: Biblioshiny

4.24 Collaboration Network

The Collaboration Network below visualizes the relationships between various researchers based on their co-authorships, highlighting key collaborative clusters within the academic community. The size of the nodes represents the prominence of the authors within the network, and the connections between them show their collaborative efforts. At the center of the network, Floridi Luciano and Taddeo Mariarosaria stand out as a prominent duo, forming a tightly connected cluster. This indicates a significant collaborative relationship between these two influential researchers, likely contributing to the centrality of their work within the field. To the right, Tanwar Sudeep forms another notable cluster, connected to other researchers like Sharma Gulshan, Pau Giovanni, and Alazab Mamoun. This grouping suggests strong collaboration among these scholars, with Tanwar Sudeep leading the efforts. In other parts of the network, smaller clusters of collaboration are visible. For instance, Abraham Ajith and Kotecha Ketan form a pair, showing their close academic relationship. Similarly, Kreinovich Vladik and Nguyen Hoang Phuong are connected, reflecting their cooperative work.

The network also highlights various other collaborations, such as El-Kenawy El-Sayed M and Mirjalili Seyedali, who work closely together, and Ansari Sam and Khater Tarek, who also form a distinct group. Each of these clusters reflects ongoing collaborative research efforts within the academic community, with various researchers contributing to shared knowledge and publications. Overall, the Collaboration Network provides a clear view of how researchers are connected through co-authorships, with central figures like Floridi Luciano and Tanwar Sudeep leading prominent groups, while other clusters reflect strong, smaller collaborations contributing to the broader research landscape.

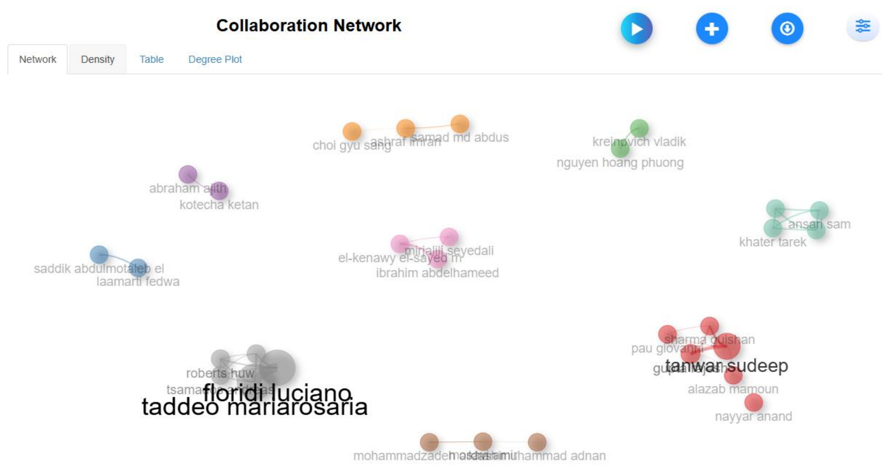

Figure 33: Collaboration Network from 2019 to 2024
Source: Biblioshiny

4.25 Countries' Collaboration World Map

The Countries' Collaboration World Map below visualizes the global network of research collaborations between countries, illustrated by lines connecting different regions. The map highlights the interconnected nature of academic research across continents, with thicker and more numerous lines indicating stronger or more frequent collaborations. China and the United States stand out as the central hubs of global research collaboration, with numerous connections spanning across Asia, Europe, North America, and Australia. The collaboration lines between China and other countries, particularly in Europe and North America, emphasize China's strong participation in international research networks. Similarly, the United States is highly connected to countries worldwide, indicating its significant role in fostering global academic partnerships. Other countries, such as Australia, Germany, and the United Kingdom, also show strong international collaboration networks, with connections extending across continents. The map further reveals robust academic ties between countries in Asia, Europe, and North America, forming a dense web of collaborative efforts aimed at advancing scientific knowledge.

Figure 34: Countries' Collaboration World Map from 2019 to 2024
Source: Biblioshiny

4.26 Most Cited Countries

The chart below displays the Most Cited Countries in academic research, highlighting the global influence of various nations based on the number of citations their publications have received. China leads by a significant margin with 9,825 citations, showcasing its dominant role in contributing to highly influential research. Korea follows as the second most cited country with 5,583 citations, further emphasizing its strong presence in the global research community. The United States holds the third position with 3,032 citations, reflecting its continued impact and leadership in producing widely recognized and cited research. The United Kingdom and India are also prominent, with 2,632 and 2,426 citations respectively, underlining their contributions to global academic discourse. Other countries such as Saudi Arabia (2,109 citations), Germany (1,888 citations), and the United Arab Emirates (1,446 citations) are notable for their significant citation counts, indicating their growing influence in the academic world. Italy and Spain round out the list with 1,339 and 1,288 citations, respectively, highlighting their role in international research efforts.

Overall, the chart reflects the global distribution of academic influence, with China clearly at the forefront, followed by other key players like Korea, the USA, and several European and Middle Eastern countries, all of which contribute substantially to the body of cited academic work.

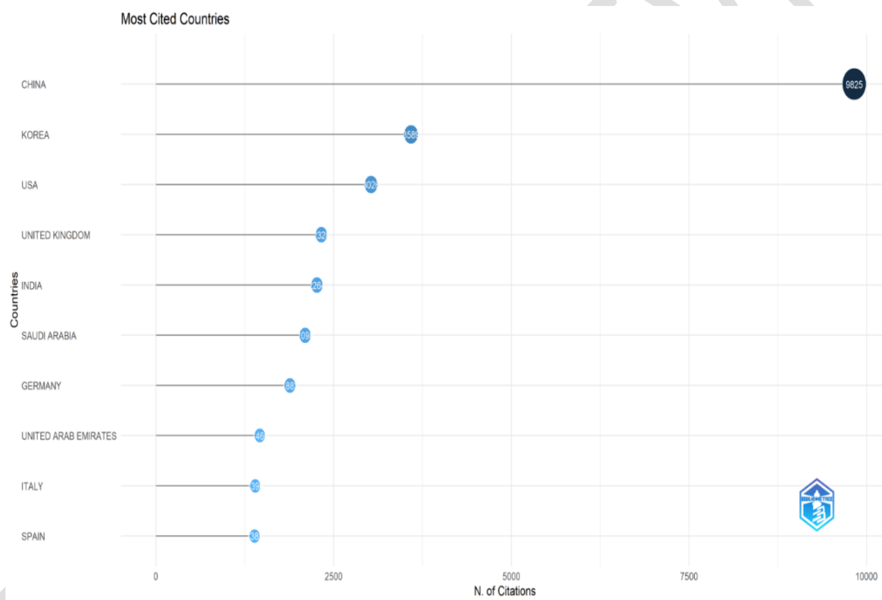

Figure 35: Most Cited Countries from 2019 to 2024
Source: Biblioshiny

5. LIMITATIONS

Despite the comprehensive nature of this bibliometric analysis, several limitations must be acknowledged. First, the study primarily relies on data from Scopus, which, while extensive, may not cover all relevant AI research across different databases such as Web of Science or Google Scholar. This reliance could lead to an underrepresentation of certain works or fields. Second, the analysis focuses on publications from 2019 to 2024, which may not capture longer-term trends or the full spectrum of AI development across earlier periods. Furthermore, the study is limited by the scope of available metadata, with some data fields missing or incomplete, such as cited references and keywords, potentially skewing the analysis of research impact.

Additionally, the analysis could delve deeper into more specialized AI applications across different sectors, providing a clearer view of AI's societal impact. Ethical and fairness concerns, while addressed, could be expanded further to give a more in-depth discussion of how these issues are being tackled across the globe. Finally, while this study emphasizes global trends, it may overlook local or regional nuances in AI research that could provide a more detailed understanding of how AI is evolving in specific contexts.

6. FUTURE RESEARCH DIRECTIONS

Future research could expand this bibliometric analysis by incorporating additional databases like Web of Science, IEEE Xplore, and others, to create a more comprehensive dataset that better represents the diversity of AI research. Moreover, extending the time frame beyond 2024 would allow for the capture of longer-term trends and the assessment of how AI research responds to new technological innovations and societal needs. Another area for future research involves a more in-depth analysis of specific emerging topics, such as ethical AI and AI governance, to understand how these concerns are being addressed across different sectors and geographical regions. Additionally, exploring the impact of AI on specific industries, such as healthcare, finance, and education, could provide a more nuanced understanding of the technology's societal implications. Finally, a closer examination of the role that policy and regulation play in shaping AI research and development globally could offer critical insights into how governments and institutions are influencing the direction of AI.

7. CONCLUSION

The findings from this bibliometric analysis successfully address the research questions posed in the introduction section. First, the analysis reveals that global AI research has experienced remarkable growth between 2019 and 2024, with an annual growth rate of 18.2%. This upward trend highlights the increasing importance of AI across multiple sectors, confirming the hypothesis that AI research is expanding at an accelerated pace. Although the peak occurred in 2022, the slight decline in subsequent years may suggest a consolidation phase or the effects of shifting research priorities.

In terms of key contributors, China and the United States emerge as the most influential countries, leading not only in the volume of publications but also in citations, demonstrating their pivotal roles in shaping global AI research. The analysis confirms that institutions such as King Saud University, Prince Sattam Bin Abdulaziz University, and the University of Oxford are significant players in the field. Moreover, Floridi Luciano and Taddeo Mariarosaria stand out as leading authors, central to the collaborative networks that drive knowledge production in AI. These findings directly respond to the second research question by identifying the major entities driving AI advancements.

Regarding research topics, the study identifies machine learning, deep learning, and neural networks as the core areas of focus, reaffirming their foundational role in AI development. At the same time, emerging topics such as ethical AI, systematic approaches, and convolutional neural networks suggest a broadening of the research scope to address not only technical innovations but also societal impacts. This shift aligns with the third research question, which sought to understand how AI research topics have evolved over time.

The global collaboration networks depicted in the analysis demonstrate the extensive interconnectedness of AI research across continents, particularly between China, the USA, Europe, and Australia. These networks highlight how international cooperation enhances research productivity and impact, thus directly answering the fourth research question. The visualization of global collaboration underscores the significance of cross-border partnerships in driving the field forward, with leading countries fostering a web of scholarly exchange that transcends national boundaries.

The implications of these trends for future technological and ethical developments are profound. The rise of topics related to ethical AI and fairness in machine learning indicates a growing awareness of the need to ensure that AI technologies are developed responsibly. As AI continues to permeate various domains, the ethical considerations that accompany its growth are becoming a central concern for researchers, as reflected in the increased focus on these issues in recent years. This finding directly addresses the fifth research question, emphasizing the importance of aligning AI advancements with societal values and ethical standards.

Finally, the findings from this bibliometric analysis have answered the key research questions posed at the outset of this study. The paper successfully mapped global trends in AI research, demonstrating a rapid expansion of publications from 2019 to 2024, with China and the United States leading in both output and influence. The identification of core contributors both in terms of institutions like King Saud University and prominent authors such as Floridi Luciano confirms the hypothesis that AI research is highly collaborative and geographically distributed. Moreover, the study traced the evolution of key research themes, with machine learning and deep learning continuing to dominate, while emerging topics like ethical AI and fairness in AI have become more prevalent. These insights not only highlight the dynamic nature of AI research but also emphasize the field's growing attention to societal and ethical implications, which are critical to its future trajectory. The findings provide a robust foundation for further inquiry, offering pathways for new research that aligns technological innovation with responsible and ethical practices.

Disclaimer (Artificial intelligence)

Author(s) hereby declare the use of generative AI technologies model (ChatGPT) was used to generate keywords that were then used to find papers regarding the topic during editing of manuscripts.

Ethics Approval Statement

This study did not involve human subjects, so no ethical approval was required.

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