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Research Article

Artificial Intelligence Research (2001-2022): A Bibliometric Journey through Trends and Patterns

Pawan Agrawal*

Department of Library, Dr. APJ Abdul Kalam Government College, Silvassa, Dadra and Nagar Haveli, INDIA.

ABSTRACT

This study scrutinizes the landscape of Artificial Intelligence (AI) research, extracting trends, and dynamics across publications, citations, and subject-wise interests. Using Web of Science (WoS) datasets encompassing publication counts, citation impacts, and keyword frequency analyses from 2001 to 2022, this research provides a comprehensive overview of AI research contributions. The analysis unveils the predominant roles of countries such as China and the United States in AI research, showcasing both the prolific output of China and the qualitative superiority of the United States' research. Subject-wise interests highlight the interdisciplinary nature of AI, emphasizing its applications in Computer Science, Engineering Sciences, and Medical Science. Moreover, temporal keyword frequency analysis outlines the evolution of specific subfields within AI, notably emphasizing the burgeoning importance of "Machine Learning" and "Deep Learning". The application of bibliometric laws such as Lotka's and Bradford's Laws provides frameworks for understanding author productivity and article distribution across journal zones, revealing slight deviations from theoretical models. This study's implications underscore the critical role of bibliometric analyses in comprehending AI research trends, guiding future research endeavours, and informing decision-making for researchers, institutions, and policymakers. It offers insights that drive strategic collaborations, innovative pursuits, and high-impact research directions within the dynamic realm of artificial intelligence.

Keywords: Artificial Intelligence, Bibliometric Analysis, Biblioshiny, Scientometrics, Network Analysis.

Correspondence:
Dr. Pawan Agrawal
Assistant Librarian, Dr. APJ Abdul Kalam Government College, Silvassa, Dadra and Nagar Haveli, INDIA.
Email: pawanagrawal4u4u@gmail.com

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INTRODUCTION

The developments in Information and Communication Technology (ICT) have opened several pathways for humanity to think about the technological advancements in every sector. Artificial Intelligence (AI) is one of such very important fields of study. Artificial intelligence is 'a system's ability to interpret external data correctly, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation.' (Kaplan and Haenlein). In simple words programming a machine in such a way that it behaves like a human and performs the tasks using human-like intelligence. The term Artificial Intelligence was used by American Computer scientist John McCarthy during the Dartmouth Conference in 1956 (McCorduck, Minsky and G.). However, the first recognized work in AI was the proposed model of 'artificial neurons' by Warren McCulloch and Walter Pits in 1943. Alan Turing's 'Turing Test' of 1950 was another example of human attention towards artificial intelligence. Since then, the research in artificial intelligence has grown constantly. By the beginning of the 20th century artificial intelligence had made its roots stronger. For the last 20 years it is playing an irreplaceable role in various fields of studies such as science, space science, Medical science, Business and Marketing, Education, etc.

This study conducts bibliometric analysis of the literature published in the journals indexed in Web of Science on Artificial Intelligence. The approach to this study is scientometrics in nature as in addition to quantitative analysis it has also taken into consideration the qualitative aspects of the data. It is not that there was no bibliometric study conducted to measure research growth and popular authors or journals in the field of artificial intelligence; however, they have either become obsolete in nature or miss one or another point. A comparison of earlier study is provided in the upcoming section of this paper. In addition, gradual study in a particular discipline with updated data provides the opportunity to compare the data for a longer duration.

Bibliometric analysis and literature review on AI

Bibliometric study is a complex statistical method to determine trending topic or author or article by analysing articles of a particular discipline (Ellegaard and Wallin). Bibliometric studies

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are important to determine the research hotspot, developmental trends, Key research institutions or countries, etc., to guide for future studies. Bibliometric analysis also helps to get information about the impact of the publication, journal, institution or a country for a particular research subject. Measurement of research on artificial intelligence is of great significance to understand current research on artificial intelligence.

In recent years bibliometric analysis has also matured due to development of different bibliometric software. Traditionally, bibliometric analysis was a manual and time-consuming process, involving the laborious collection and counting of citations from printed publications. Researchers would often compile citation data using MS Excel and conduct hand-counting to derive basic metrics. With the development of sophisticated bibliometric software, a researcher can get more accurate data as well as conduct more comparisons and filtration can be applied (Batista-Canino, Santana-Hernández and Medina-Brito). For example, with Biblioshiny one can calculate Lotka's estimation related to beta coefficient of bibliographic collection and assess the similarity of this empirical distribution with the theoretical one (Aria and Cuccurullo). Abdul Khalid Sheikh *et al.*, 2023 used Biblioshiny to apply Bradford laws to identify the core journals that publish research on artificial intelligence in the health sector. It can also help in identify 'global citation score', i.e. total citation received by a document in a particular database against 'local citation score', i.e. total citation received by a document from other documents in retrieved sample for a particular study (Beliaeva, Ferasso and Kraus). It helps to identify the broadness of a paper outside its core discipline.

A number of studies were carried by various scholars at different time to analyse the publication trends of the subject through artificial intelligence. Dhamija and Bag (2020) conducted a bibliometric study to review 1854 articles published in 2018-19 on the use of artificial intelligence in operations. Yuqi Guo, 2020, Tran *et al.*, 2019 conducted bibliometric study to analyse the use of artificial intelligence in healthcare while Bawack *et al.*, 2022 conducted bibliometric study to analyse the uses of artificial intelligence in E-commerce. Shukla *et al.*, 2019 showed the cumulative use of artificial study in Engineering application through their analysis of AI articles published over a span of thirty years.

The data for bibliometric study can be collected either manually from the resources itself or they can be downloaded from the bibliographic data bases such as Web of Science or Scopus. The quality of bibliometric analysis is highly dependent upon the quality and quantity of the collected data. Especially where the datasets are very large, it becomes difficult to gather data accurately. Bibliometric database makes the task easier and improves the quality of bibliometric study. Web of Science is a prominent bibliographic database comprising all bibliographic and citation details of research articles from most of the fields. It indexes recognized journals from every field of study. This study analyses the literature published from January, 2001 to January, 2022 based on the database of Web of Science. The reason behind choosing WoS as source of data for this study is its vast coverage and limitation in Scopus to download bibliographic data.

METHODOLOGY

Data Source

A search on "Artificial Intelligence" was conducted on 22nd January 2023. The Web of Science was selected as a data source due to its waste coverage. The WOS literature was retrieved using simple search for "Artificial Intelligence" as topic so that the retrieved data remain fully relevant to the study. The literature search was limited in its periodicity i.e. from 1st January 2001 to 31st December 2022. It was further limited to document type 'articles' only. The articles with anonymous articles, reviews and calls for papers were excluded. Early Access Articles for 2023 issues were also removed. Finally, a total of 39282 relevant articles were identified for the analysis.

Statistical analysis

After finalising the articles, statistical analysis was performed in terms of type of documents, author affiliation, author countries, research category etc. Lotka's law and Broadford's laws were also applied to the data to check journal's and author's zones. To analyse the data various statistical software such as Biblioshiny, Bibexcel, Vosviewer and MS Excel were used.

RESULTS AND ANALYSIS

Document type and records

Table 1 shows types of documents retrieved after an exhaustive search from Web of Science Database for duration from 2001 to 2022. The analysis of document types in the dataset reveals that journal articles constitute the majority, accounting for 96.22% (37,798 articles) of the total publications on artificial intelligence. This highlights the significance of peer-reviewed journals as the primary medium for disseminating research findings. Additionally, a small portion of the articles are classified as book chapters (0.13%, 51 articles), data papers (0.05%, 20 articles), proceedings papers (3.54%, 1,389 articles), and retracted publications (0.06%, 24 articles).

Authorship pattern and collaboration

Table 2 shows the number of authors and authorship pattern of the article selected for the present study. 39282 articles selected for this study were authored by 108701 authors that show about 2.76 authors per document. It reveals a diverse community of 108,701 unique authors who collectively appear in 187,375 authorship records. Among the documents, 3,725 are single-authored, highlighting the importance of individual contributions, while the majority of documents (104,976) are multi-authored, showcasing

Table 1: Type of Documents and records.

Sl. No.	Type	Total records	Percentage
1	Journal Articles	37798	96.22
2	Book chapter	51	0.13
3	Data paper	20	0.05
4	Proceedings papers	1389	3.54
5	Retracted publications	24	0.06
	Total records	39282	100

Table 2: Authorship pattern and collaboration.

Sl. No.	Authorship	Numbers of records
1.	Number of unique authors	108701
2.	Author appearance	187375
3.	Authors of single-authored documents	3725
4.	Authors of multi-authored documents	104976
5.	Single-authored documents	4315

the prevalence of collaboration in the field. This signifies the dynamic nature of research in artificial intelligence, where both independent and collaborative efforts play a vital role in driving advancements and innovation.

Growth rate of publications

Figure 1 plots the annual trends of publications on artificial intelligence. Average growth rate of articles published from 2001-2022 was 16.92%. The analysis of the growth rate of articles published in the field of artificial intelligence from 2001 to 2022 reveals interesting trends. The Average Annual Growth Rate (AAGR) of approximately 16.92% highlights the substantial expansion of scholarly output in artificial intelligence over the studied period. The growth rate varied across different years, with notable peaks observed in 2018 and 2019, where the AAGR reached 70.74% and 80.03% respectively. These years likely represent periods of increased interest and investment in AI research, leading to a significant surge in publications. However, it is important to note that the growth rate experienced fluctuations, with a decline in 2022, where the AAGR was -65.96%. This indicates a significant decrease in the number of articles published compared to the previous year. The negative growth rate in 2022 suggests a potential slowdown or shift in the research landscape. These findings reflect the evolving nature of artificial intelligence research, with periods of rapid growth and potential consolidation or reorientation. Further analysis is needed to understand the underlying factors contributing to these trends and their implications for the field of artificial intelligence.

Annual citation trends

Table 3 shows different data sets regarding annual citation trends of research on artificial intelligence. Analysing the citation trend data in different three-year blocks provides valuable insights into the evolving dynamics of the field. In the earlier years (2001-2009), there was a steady increase in the number of articles published, along with a growing Total Citation Score (TCS). The mean citation per article remained relatively high, indicating significant impact and recognition of the research. However, in the later years (2010-2022), while the number of articles published continued to rise, the TCS and mean citation per article showed a declining trend. This could be attributed to factors such as increasing competition, research saturation, and changes in citation practices. Additionally, the decreasing citable years may have limited the duration for citations to accumulate, impacting the overall citation numbers.

However, a notable observation is the increasing annual mean citation over the years. This indicates that researchers are actively engaging with and citing newer research. Despite the declining individual article impact, the rising annual mean citation suggests sustained interest and involvement in the field. Researchers are recognizing and building upon recent work, demonstrating the dynamic nature of the research landscape.

Source influence

Table 4 presents top 20 journals publishing articles on artificial intelligence. "IEEE ACCESS" emerged as the leading journal with 1350 articles, followed by "SENSORS" with 572 articles and "APPLIED SCIENCES-BASEL" with 547 articles. Journals like "EXPERT SYSTEMS WITH APPLICATIONS," "SUSTAINABILITY," and "SCIENTIFIC REPORTS" demonstrated significant contributions to the field. Other noteworthy publications included "JOURNAL OF INTELLIGENT and FUZZY SYSTEMS," "ENERGIES," and "IET IMAGE PROCESSING." The presence of interdisciplinary journals like "AI MAGAZINE" and "PLOS ONE" underscores the diverse research topics within artificial intelligence. However, it is noteworthy that the total research of artificial intelligence is published in 5870 sources.

Table 4 represents top 20 journals ordered by their H-Index. The Table 4, in addition to H-index, shows the number of papers, total

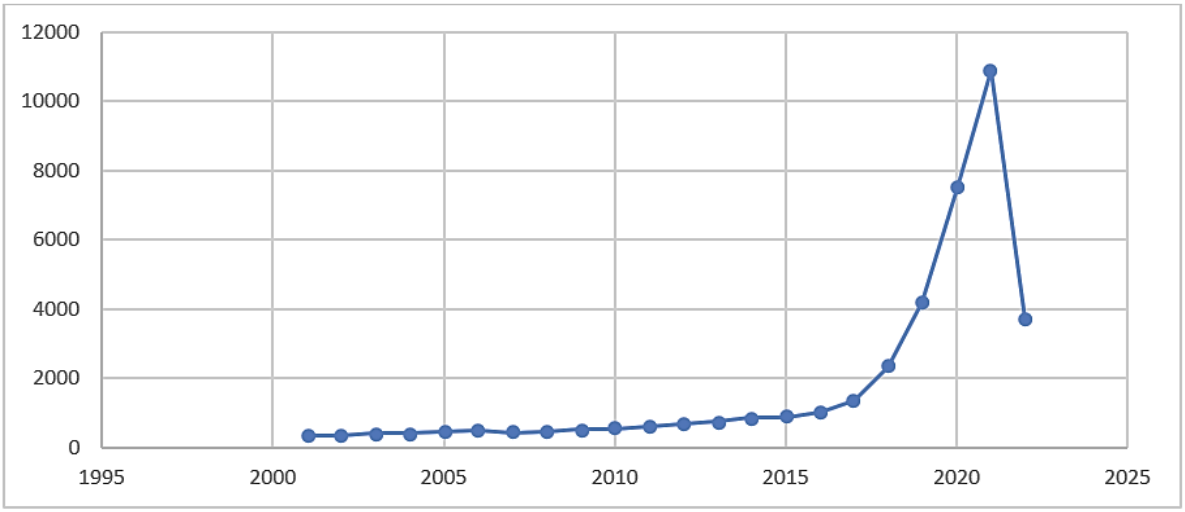

Figure 1: Distribution of Publication over the years.

Table 3: Annual Citation Trends.

In Year	2001-2003	2004-2006	2007-2009	2010-2012	2013-2015	2016-2018	2019-2022
Article Published	1132	1372	1420	1813	2492	4724	26329
TCS	33594	34229	49759	52131	56837	126869	173408
Mean Citation	29.68	24.95	35.04	28.75	22.81	26.86	6.59
Annual Mean Citation	1.41	1.39	2.34	2.41	2.56	4.66	2.66

Table 4: Top 20 Journals covering artificial intelligence research.

Journal Title	Articles
IEEE Access	1350
Sensors	572
Applied Sciences-Basel	547
Expert Systems with Applications	453
Sustainability	393
Scientific Reports	387
Journal Of Intelligent and Fuzzy Systems	317
Energies	254
IET Image Processing	248
Applied Soft Computing	242
Neural Computing and Applications	222
Wireless Communications and Mobile Computing	216
Ai Magazine	204
PLOS One	204
Engineering Applications of Artificial Intelligence	201
Electronics	198
Computational Intelligence and Neuroscience	189
Journal Of Medical Internet Research	162
Mathematical Problems in Engineering	159
Neurocomputing	152

citation received and the year of start of the journal. However, if Tables 4 and 5 are compared, about 50% journals in the tables vary. Only 9 journals of Table 4 are repeated in Table 5. It shows that the journals publishing a high number of papers does not necessarily have a high impact on researchers. Six journals in the Table 5 have published less than 100 papers, yet they appear in the list of top 20 most influential journals. However, IEEE Access and Expert Systems with Applications appearing in the top five journals of Table 4 were able to maintain their place in the top 5 journals of Table 5.

Institutional Influence

Table 6 depicts information regarding the institutions contributing highly in research on artificial intelligence. Among the Top 10 institutions, there is a diverse representation from various countries. Islamic Azad University leads the list with 545 associated articles, followed closely by Stanford University with 532 articles. Tsinghua University, Ton Duc Thang University, Zhejiang University, and Shanghai Jiao Tong University, all from China, also feature prominently in the ranking. Additionally, Harvard Medical School, Duy Tan University, Huazhong University of Science and Technology, and Sun Yat-sen University contribute significantly to the body of research on artificial intelligence. This distribution of institutions highlights the global nature of AI research, with contributions from both Iranian and international institutions. These findings demonstrate the collaborative efforts of researchers across different regions in advancing AI knowledge and innovation.

Table 5: **Top twenty journals publishing on AI ranked by H-Index.**

Journal Title	*h*_index	TC	NP	PY_start
Expert Systems with Applications	58	12686	453	2001
Applied Soft Computing	49	10008	242	2004
IEEE Access	45	11006	1350	2014
Journal Of Hydrology	45	6029	119	2004
Engineering Applications of Artificial Intelligence	38	4611	201	2001
Artificial Intelligence	35	4531	141	2001
Information Sciences	34	3811	104	2001
Energy	32	2851	86	2005
Sensors	32	4038	572	2010
IEEE Transactions on Industrial Informatics	31	2935	106	2011
Science Of the Total Environment	30	2865	69	2009
Neurocomputing	29	2795	152	2002
European Radiology	28	2295	125	2017
Neural Computing and Applications	28	2990	222	2001
Applied Energy	27	2229	69	2002
Knowledge-Based Systems	27	2274	121	2001
Nano Energy	27	2011	58	2017
Scientific Reports	27	2769	387	2012
Artificial Intelligence in Medicine	26	2591	96	2001
Nature Communications	26	3125	86	2015

Table 6: **Top 10 Institutions contributing research on Artificial Intelligence.**

Rank	Affiliation	No. of Articles
1	Islamic Azad University	545
2	Stanford University	532
3	Tsinghua University	439
4	Ton Duc Thang University	431
5	Zhejiang University	419
6	Shanghai Jiao Tong University	417
7	Harvard Med Sch	402
8	Duy Tan University	382
9	Huazhong University Sci and Technol	367
10	Sun Yat Sen University	364

The data in Table 6 reveals the annual publication counts for different affiliations over multiple years. Duy Tan University experienced significant growth in research output from 2015 onwards, reaching 382 publications in 2022. Harvard Medical School displayed gradual growth, while Huazhong University of Science and Technology showcased steady progress with 367 publications in 2022. Islamic Azad University exhibited a consistent rise in publications, recording 545 in 2021. Shanghai Jiao Tong University demonstrated steady growth, and Stanford University maintained a strong research presence with 532 publications in 2022. Sun Yat Sen University displayed consistent growth, while Ton Duc Thang University showed a gradual increase, reaching 431 publications in 2022. Tsinghua University and Zhejiang University demonstrated steady growth, recording 439 and 419 publications, respectively, in 2022. These findings underscore the diverse publication trends and the active research contributions of different affiliations in the field of study.

Most influential Authors

Figure 2 presents a visualization of the top authors in the field of artificial intelligence out of a total of 108,701 authors who have contributed articles between 2001 and 2022. The graph highlights the top authors based on the number of articles authored. Zhang Y, Wang Y, Liu Y, Zhang J, Li J, Kim J, Li Y, Wang J, Park J, and Zhang L emerge as the leading contributors in the field. Their significant presence indicates their prominent role and extensive engagement in AI research. This visualization effectively captures the notable authors who have made substantial contributions to advancing the field of artificial intelligence.

Figure 3 shows top 20 authors of the articles on artificial intelligence during 2001-2022 as reflected in WoS. The figure shows annual increments in the articles of the authors. The graph easily shows that more than 80% of the articles were produced during the last 5 years which shows that research in artificial intelligence has

Table 7: Most influential authors as per their *h*-Index.

Sl. No.	Name of the Author	*h*_index	TC	NP	PY_start
1	Bui Dt	34	3110	56	2016
2	Pham Bt	33	2753	62	2016
3	Raja Maz	31	2218	62	2010
4	Shahabi H	29	2798	38	2017
5	Kisi O	27	2484	62	2009
6	Shirzadi A	27	2503	35	2017
7	Wang Zl	26	3121	57	2011
8	Chen W	25	2201	61	2001
9	Li Y	24	2028	148	2003
10	Nguyen H	24	1519	61	2017
11	Wang J	24	1803	135	2001
12	Zhang J	24	1794	152	2002
13	Zhang Y	24	2049	166	2001
14	Chau Kw	23	2369	46	2001
15	Yaseen Zm	23	1501	62	2016
16	Liu Y	22	2565	156	2009
17	Wang H	22	1675	103	2002
18	Wang Y	22	1959	162	2003
19	Zhou J	22	1505	66	2008
20	El-Shafie A	21	1319	45	2007

grown up sustainably during this period. Not only this figure but other data under this study also shows similar trends. Out of 20 authors 17 have produced more than 100 papers each. Zhang Y, Wang Y, and Zhang J stand out as prolific authors, consistently maintaining a high publication count throughout the years. The data also hints at possible collaborations, with multiple authors publishing together in certain years. Overall, this comprehensive data offers valuable insights into the publication trends of various authors in the dynamic field of artificial intelligence, shedding light on both established contributors and emerging researchers, while uncovering fluctuations in their publication activity over time.

However, the data relating to top authors as per their *h*-index, as shown in Table 7 is telling a different story. The Table 7 represents top 20 authors as per their H-Index. When we compare data related to top authors as per number of publications and top authors as per their H-Index, we find that there is vast difference in listing of authors in both lists. All authors who are appearing in the top 20 authors list don't appear in most influential authors. When comparing authors in both lists we find only 7 authors who have authored the highest number of papers are appearing in the list of most influential authors. Additionally, the top 8 most influential authors are not included in dataset 1 (Figure 4) which is related to top authors according to number of publications. The author with highest number of publications i.e. Zhang Y has the *h* index of 24 which is 13 rank out of 20 authors in dataset 2 (Table 7). Another finding this data provides is that none of the top 8 authors with highest H-index has more than 100 papers.

Further, when this analysis extended to authors ranked by citation counts, a notable shift occurred. Surprisingly, none of the authors previously deemed most influential based on their prolific publication activity or high *h*-index appeared in the top 20 authors by citation count. This sharp contrast highlights the nuanced nature of influence in AI research. It reaffirms that an author's impact cannot be solely attributed to the quantity of papers or their H-index but rather hinges on the recognition and impact reflected in citation counts. This disparity emphasizes the need for a multifaceted evaluation when assessing an author's true influence in AI research. Authors achieving a balance between prolific output and impactful work that gathers citations tend to attain higher levels of influence in the field. A comprehensive, multidimensional assessment remains essential for an accurate determination of an author's true influence in the dynamic AI research landscape.

Most relevant documents

Figure 5 highlights top 20 most 'locally cited' papers and compared with 'globally cited' scores. These have been the most prolific

papers in the advancement of Artificial Intelligence research. The gist of the top 3 documents is as follows.

First paper 'Dermatologist-level classification of skin cancer with deep neural networks' was published by Nature in 2017 and was authored by Andre Esteva *et al*. This article is first in receiving of 'local citations' and second in receiving 'global citations'. This paper demonstrates the Use of a deep Convolutional Neural Network (CNN), an AI model, to classify skin lesions using clinical images. CNN is trained with a large dataset of images from different diseases. On evaluation with dermatologists, its performance was found at per the expert dermatologists to classify skin cancers. This study suggests that use of CNN can be a great tool for dermatologists to reduce the cost of the diagnosis of skin cancer (Esteva, Kuprel and Novoa).

Second paper 'Mastering the game of Go with deep neural networks and tree search' was published in 2016 by Nature and authored by David Silver *et al*. This paper was second in receiving 'local citation' but first in receiving 'global citation'. It was a landmark paper that presents a novel approach to computer Go using value and policy networks trained from human expert games and games of self-play. The program AlphaGo achieved remarkable success, outperforming other Go programs. This

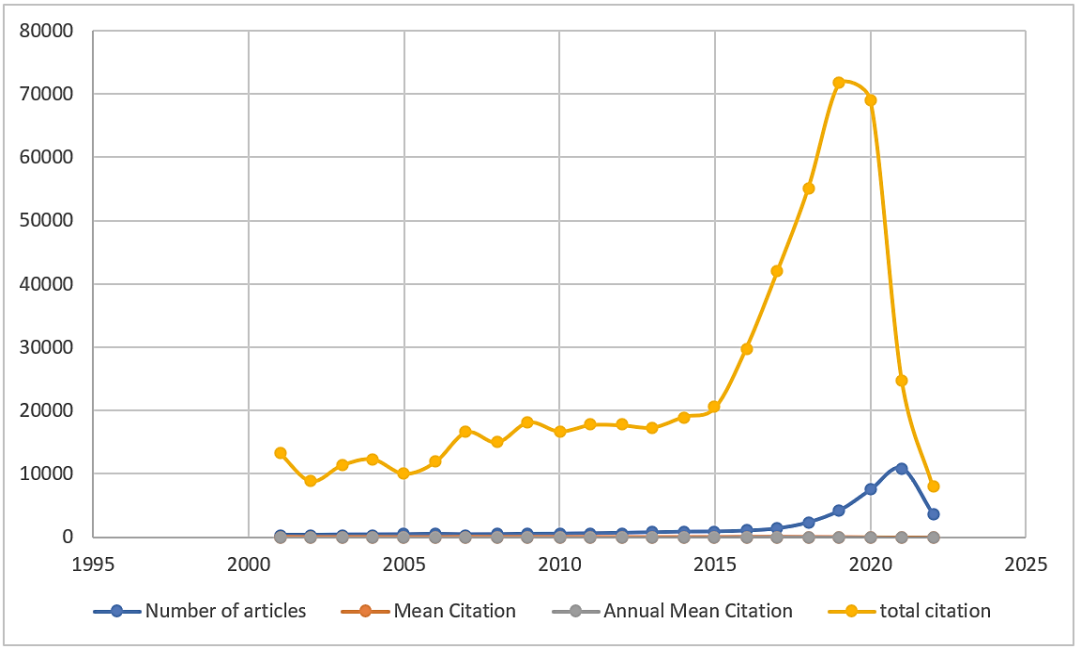

Figure 2: Annual Citation Trends.

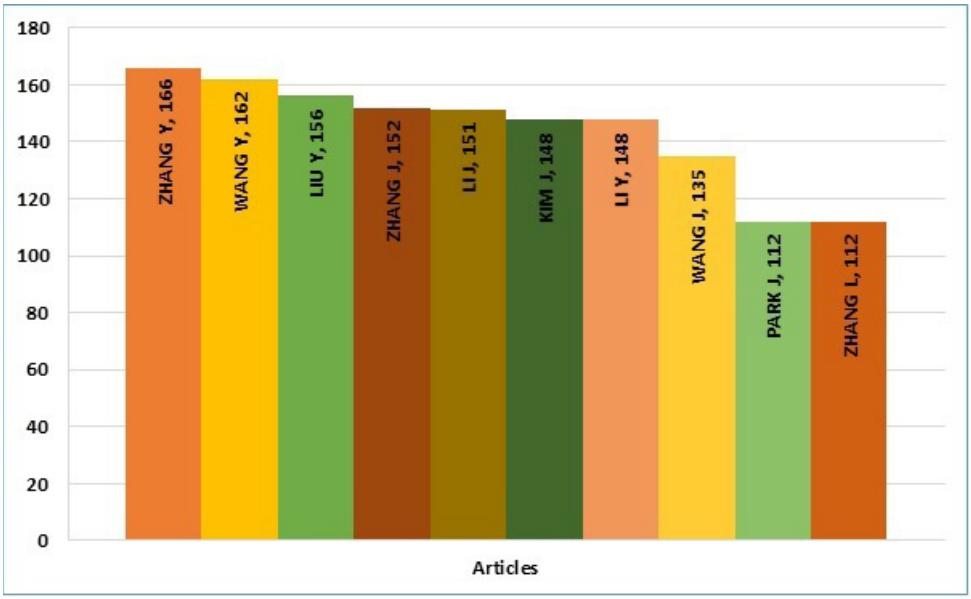

Figure 3: Most Productive Authors.

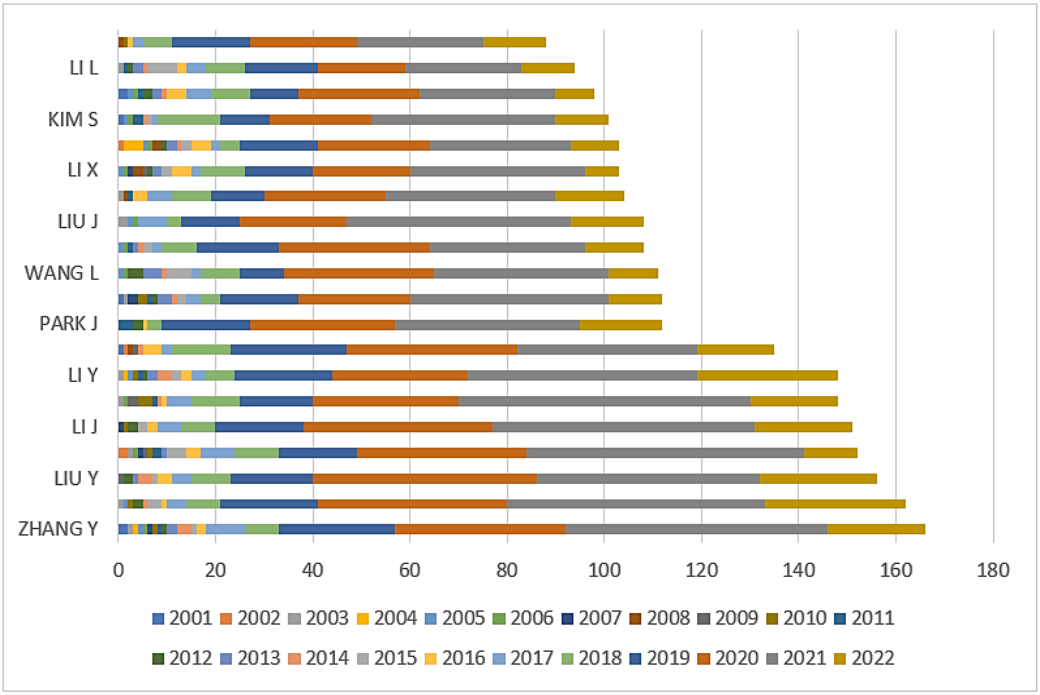

Figure 4: Most productive author by period.

Table 8: Most influential authors as per their Citation count.

Sl. No.	Name of the Author	h_index	TC	NP	PY_start
1	Hassabis D	13	11172	16	2016
2	Karaboga D	13	10602	15	2007
3	Silver D	7	9025	9	2012
4	Lillicrap T	5	8828	5	2016
5	Sifre L	5	8828	5	2016
6	Graepel T	5	8564	7	2016
7	Van Den Driessche G	3	8523	3	2016
8	Antonoglou I	4	8465	4	2016
9	Guez A	4	8465	4	2016
10	Schrittwieser J	4	8465	4	2016
11	Huang A	4	8163	4	2016
12	Basturk B	2	6046	2	2007
13	Lanctot M	3	5889	4	2016
14	Kavukcuoglu K	3	5727	3	2016
15	Kalchbrenner N	2	5278	2	2016
16	Dieleman S	2	5277	2	2016
17	Grewe D	1	5267	1	2016
18	Leach M	1	5267	1	2016
19	Maddison Cj	1	5267	1	2016
20	Nham J	1	5267	1	2016

Table 9: Top 10 countries in production of research on AI.

Country	No. of Articles
China	9332
USA	5725
United Kingdom	1960
Korea	1670
India	1576
Spain	1493
Iran	1302
Germany	1295
Italy	1094
Canada	1046

Table 10: Top 10 cited countries for the research in AI.

Country	TC	Average Article Citations
USA	106845	18.70
China	99585	10.70
United Kingdom	44996	23.00
Turkey	22395	25.70
Iran	21984	16.90
Canada	18468	17.70
India	17559	11.10
Spain	17024	11.40
Australia	13004	14.30
Korea	12793	7.70

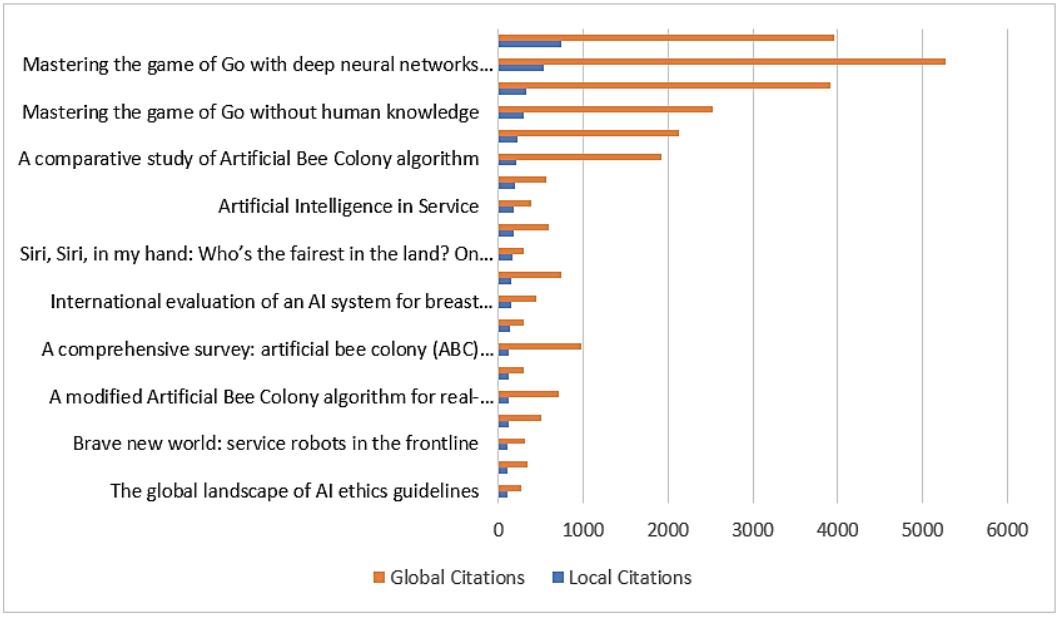

Figure 5: Top twenty most cited documents on AI.

AI-enabled program defeated a human European Go champion, making a significant revolution in artificial intelligence for the game of Go (Silver, Huang and Maddison).

Third most locally and globally cited paper is 'A powerful and efficient algorithm for numerical function optimization: Artificial Bee Colony (ABC) algorithm' published in 2007 in Journal of Global Optimization and authored by Dervis Karaboga and Bahriye Basturk. Authors in this paper explores swarm intelligence and its application in the Artificial Bee Colony (ABC) Algorithm for optimizing multivariable functions. When compared to other algorithms like GA, PSO, and PS-EA, ABC demonstrates superior performance in optimization results (Karaboga and Basturk).

Influence of various countries in AI research

Every country sets a high value on economic growth and prosperity. Research plays an important part in enabling countries to develop a competitive advantage and potentially achieve a monopoly in different industries. Governments around the world provide resources to research activities undertaken within educational institutions, research centres, and other organisations in order to boost their economies and stimulate innovation in various sectors. Hence, it is important to identify and recognize the leading countries actively engaged in research. Two datasets were extracted from data related to research papers, giving insight on the nations at the forefront of research contributions. These datasets are excellent resources for understanding the worldwide research landscape and its consequences for global economic growth and innovation. First dataset presents the top ten countries from which maximum papers were published, and the second dataset provides ten most cited countries for AI research. When we observe the first dataset represented by Table 9, we can see a list of the top ten countries based on the number of AI research articles published. With a considerable publishing count

of 9,332 articles, China emerges as the predominant contributor, highlighting its significant influence in AI research. The United States comes in second with 5,725 papers, demonstrating its long-standing dominance in this field. Other countries that make significant contributions to the global AI research environment include the United Kingdom, Korea, India, Spain, Iran, Germany, Italy, and Canada. This dataset sheds light on the distribution of AI research production across countries. Table 10 highlights the citation impact of these countries. The USA stands out with the highest Total Citations (TC) at 106,845, signifying the significant influence of its research on the academic community. The United Kingdom follows closely with a TC of 44,996, demonstrating the quality and impact of their research. When we compare the number of articles in Table 9 with the citation impact in Table 10, we can see that the USA has a relatively lower number of articles compared to China, yet it has a much higher TC, indicating the citation impact of its research. Furthermore, Turkey's research stands out for having the highest average article citations at 25.70, showcasing that their articles receive a high number of citations per article, suggesting a strong impact. This data provides a comprehensive view of research productivity and influence, shedding light on the varying contributions and impacts of different countries in the academic world.

Subject wise interest towards AI

The provided data under Table 11 offers insights into the distribution of AI research across different subjects. Notably, Computer Science emerges as the primary field with 16,519 occurrences, underscoring its central role in AI research. Engineering Sciences follow closely with 13,822 occurrences, indicating extensive AI applications in engineering and technological advancements. Medical Science, with 6,619 occurrences, reflects AI's increasing presence in healthcare, ranging from diagnostics to patient care. Telecommunications, Chemistry, Physics, and Materials Science all exhibit substantial AI research activity, demonstrating its versatility across various scientific domains. Environmental Sciences benefit from AI's data analysis and resource optimization capabilities, with 2,155 occurrences. Furthermore, AI's multidisciplinary nature is evident in 1,428 occurrences categorized under Multidisciplinary Sciences, where it bridges multiple fields. Lastly, Energy and Fuels with 1,217 occurrences indicates AI's contributions to energy optimization. This data highlights the widespread impact of AI research across diverse subject areas, emphasizing its crucial role in advancing science and technology.

Table 12 provides a comprehensive temporal perspective on the keyword frequency within AI-related academic articles spanning from 2001 to 2022. A salient observation is the steady ascent of the "Artificial Intelligence" keyword, with a discernible exponential surge in recent years, signifying a sustained and escalating interest in the overarching domain of artificial intelligence. Furthermore, "Machine Learning" and "Deep Learning" exhibit remarkable prominence, illustrating the burgeoning significance of these subfields, with "Machine Learning" attaining eminence as one of the most frequently employed terms. The consistent ascension of "Neural Networks" and "Artificial Neural Networks" highlights their pivotal role, notably within the paradigm of deep learning. Concurrently, keywords such as "Feature Extraction" and "Optimization" manifest a gradual yet persistent growth, elucidating their foundational status in AI and machine learning discourse. Conversely, "Learning (Artificial Intelligence)" and "Artificial Intelligence (AI)" subsist with lower frequencies in relation to other keywords, however, these keywords are almost similar to top keywords in the list. This dataset highlights the evolving landscape of AI research, characterized by an expanding interest, diversification, and intensification in specific AI subfields, which mirrors the rapid technological advancement

Table 11: Top 10 Subjects where AI research is conducted.

Subject	Frequency
Computer Science	16519
Engineering Sciences	13822
Medical Science	6619
Telecommunications	3043
Chemistry	2643
Physics	2321
Materials Science	2175
Environmental Sciences	2155
Multidisciplinary Sciences	1428
Energy and Fuels	1217

Table 12: Periodic growth of Top 10 keywords.

Range	Artificial Intelligence	Machine Learning	Deep Learning	Learning (Artificial Intelligence)	Neural Networks	Artificial Neural Network	Artificial Neural Networks	Feature Extraction	Optimization	Artificial Intelligence (AI)
2001-2005	1457	108	0	0	288	36	148	12	60	21
2006-2010	4276	316	0	21	881	202	509	35	208	100
2011-2016	10765	875	15	262	1875	1132	1437	155	649	306
2017-2022	42248	11477	7518	4557	4079	3750	3413	2425	2272	1865

Table 13: **Author productivity through Lotka's Law.**

Doc. written	N. of Authors	Proportion of Authors	Doc. written	N. of Authors	Proportion of Authors	Doc. written	N. of Authors	Proportion of Authors
1	80871	0.744	35	10	0	77	2	0
2	15117	0.139	36	7	0	79	2	0
3	5173	0.048	37	7	0	82	1	0
4	2559	0.024	38	13	0	84	1	0
5	1392	0.013	39	4	0	86	1	0
6	870	0.008	40	7	0	87	1	0
7	608	0.006	41	4	0	88	1	0
8	408	0.004	42	2	0	94	1	0
9	292	0.003	43	1	0	98	1	0
10	228	0.002	44	3	0	101	1	0
11	167	0.002	45	2	0	103	2	0
12	119	0.001	46	2	0	104	1	0
13	120	0.001	47	2	0	108	2	0
14	97	0.001	49	2	0	111	1	0
15	70	0.001	50	4	0	112	2	0
16	66	0.001	51	2	0	135	1	0
17	58	0.001	52	4	0	148	2	0
18	47	0	54	3	0	151	1	0
19	36	0	55	4	0	152	1	0
20	29	0	56	6	0	156	1	0
21	37	0	57	4	0	162	1	0
22	17	0	58	1	0	166	1	0
23	26	0	59	1	0			
24	16	0	60	2	0			
25	20	0	61	2	0			
26	22	0	62	4	0			
27	19	0	63	2	0			
28	14	0	66	2	0			
29	17	0	68	3	0			
30	9	0	69	1	0			
31	15	0	70	1	0			
32	6	0	71	1	0			
33	7	0	72	2	0			
34	5	0	73	1	0			

Table 14: **Zone wise scattering of AI articles and Journals.**

Zone	Journals	No. of Articles	Bradford Multiplier *(k)*
Zone 1	92 (1.57%)	12984 (33.05%)	
Zone 2	626 (10.66%)	13339 (33.96%)	6.8
Zone 3	5152 (87.77%)	12959 (32.99%)	8.23
	5870 (100%)	39282 (100%)	7.51

and the extensive interdisciplinary integration of AI across various scholarly domains.

Testing Lotka's and Bradford's law of bibliometrics

Lotka's Law is one of the very basic laws of bibliometrics devised by Alfred J. Lotka in 1926. He described the frequency of the publications by authors in any field of study. He correlated contributors of research articles to their number of publications. As per his observation, the number of authors having 2 publications is about one-fourth of those who have 1 publication. The number of authors having 3 publications is about one-ninth and so on. He conceived a formula for this, i.e. $1/n^2$ where n=number of publications. Table 13 highlights the number of documents written by a number of authors. As per Lotka's observation more than 60 more precisely about 75 percent authors have published a single paper. We observe that the calculated frequencies from Lotka's Law are lower for lower numbers of authors and higher for higher numbers of authors. This trend aligns with the expected inverse relationship described by Lotka's Law.

However, the proportion observed by the Lotka is a bit deviating from the calculated frequencies but not enough to reject the whole observation by Lotka.

We can say that while Lotka's Law provides an overarching trend in the distribution of authors, individual data might not precisely adhere to this law due to numerous real-world complexities and variations.

Another Law of bibliometrics, i.e., law of scattering was propounded by S.C. Bradford in 1934. It is also known as Bradford's Law. In his study he divided the articles under study in three almost equal zones. He termed zone one as nuclear zone, i.e. highly productive zone, zone 2 as moderately productive zone and zone three as low productive zone. He further said that if the journals in a field are sorted by the number of articles then the number in each group will be proportional to 1: n: n^2. The number of journals in the second and third zones will increase considerably.

To check the validity of Bradford's Law the Sample data of this study was distributed in three zones as shown in Table 14. Almost one-third articles are kept in all three zones as suggested by Bradford's Law. Zone 1 contains 92 journals, contributing to 1.57% of the total journals and producing 33.05% of the articles. Zone 2 comprises 626 journals, accounting for 10.66% of the total journals and generating 33.96% of the articles. Zone 3 includes 5152 journals, representing 87.77% of the total journals and producing 32.99% of the articles.

As per observation of Bradford zones will form about a geometric pattern following pattern 1:n:n^2. In the given data the pattern that exhibited by Table 14 is 92:626:5152. 92 Journals in Zone 1 form a nucleus zone. 7.51 is the mean of multipliers.

Thus as per Bradford's Law

$=1: n : n^2$

$=92: 92*57.51: 92(7.51)^2$

$=92: 690.92: 5188.8$

$=5971.72$

Calculation of error is $=((5870-5971.72)/5870)*100 = -1.72$

This analysis resulted in a derived sequence (92:691:5189) that approximates the expected geometric progression but shows a minor deviation from the observed distribution, as demonstrated by a -1.72% error. While this sequence follows the expected pattern, resembling Bradford's Law, the divergence suggests nuances or variations in the real dataset, implying variables other than the ideal model impacting the distribution of AI journals between zones. As a result, while there is some agreement with Bradford's Law in principle, the minute divergence shows real-world complications influencing journal distribution in the domain of AI papers.

DISCUSSION AND CONCLUSION

This study offers a nuanced understanding of the evolving landscape within Artificial Intelligence (AI) research. The assessment of citation patterns and bibliometric indices has unveiled compelling insights into the dynamics of research contributions across various facets of AI, providing a comprehensive picture of the field.

The findings under this study demonstrate the significant influence of certain countries in AI research. China's prolific output in terms of research articles underscores its emerging dominance in the sheer volume of contributions. However, the United States' lower publication count yet higher citation impact signifies the qualitative superiority of its research output, emphasizing the importance of both quantity and impact in assessing research contributions.

The examination of subject-wise interests in AI revealed the interdisciplinary nature of this domain. Fields such as Computer Science, Engineering Sciences, and Medical Science emerged as primary arenas for AI research, emphasizing its versatile applications across multiple scientific domains. Moreover, the temporal analysis of keyword frequency unveiled the evolving trends within AI, emphasizing the growing importance of specific subfields like "Machine Learning" and "Deep Learning."

The application of bibliometric laws, particularly Lotka's and Bradford's Laws, provided theoretical frameworks to understand author productivity and article distribution across journal zones. However, the minor deviations observed in our data from these laws suggest real-world complexities influencing the distribution of AI articles, highlighting the need for a nuanced approach beyond theoretical models.

Lastly, this comprehensive bibliometric analysis offers critical insights that guide the trajectory of AI research. It unveils dominant research trends, underscores the interdisciplinary nature of AI, and highlights the evolving interests within the field. This study serves not only to delineate current trends but also as a guiding compass for future research endeavours.

Understanding the nuanced dynamics of AI research is paramount for researchers, institutions, and policymakers. It lays the foundation for informed decision-making, fostering impactful research, and guiding strategic collaborations that drive innovation and address societal challenges.

Moving forward, future perspectives entail a deeper exploration of emerging subfields within AI, intensified global collaborations among countries and institutions, and a concerted focus on research endeavours with high societal impact. Our study underscores the indispensable role of bibliometric studies in offering systematic insights into AI research dynamics, providing a robust foundation for steering the future trajectory of AI research. This research contributes to the broader scholarly discourse by offering a methodical understanding of AI trends, thus facilitating informed decision-making, strategic planning, and the pursuit of high-impact research in the dynamic and ever-evolving realm of artificial intelligence.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

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