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Academic research on Fuzzy Systems: A Country and Regional Analysis from its Origins in 1965 to 2023

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Abstract. This study offers a bibliometric analysis to identify tendencies and trends and establish the most prolific and important countries in Fuzzy systems research and its evolution. The need for a robust mathematical approach that model human-like perceptions, values, and decision-making processes has made Fuzzy systems research grow significantly since its creation in 1965. This research had its epicentre originally in the USA and England and has moved first to Europe and then to Asia, following global trends in other fields of study. Data were retrieved from the scientific database Web of Science. A total of 185,673 documents were revised to identify tendencies and trends and establish the most prolific and influential countries.

Keywords: Fuzzy systems, Bibliometrics, Country analysis, Web of Science.

1. Introduction

Accurately representing uncertainty in statistical and probabilistic models is crucial in multiple fields of study, including finance, healthcare, engineering, and environmental science (Abdar et al., 2021). It ensures that predictions and decisions are based on realistic assessments of risk and variability, leading to more reliable and effective outcomes across diverse applications (Petropoulos et al., 2022). The valued logic introduced by Zadeh L. in 1965 in his paper Fuzzy sets (Zadeh, 1965) provided a useful tool to address and treat uncertainty and uncertain elements in a wide range of problems.

In his seminal paper, Zadeh analyzes the concept of Fuzzy systems, allowing classical Boolean sets to use a multi-valued logic in which the value of variables may be any real number between 0 and 1. This allows the concept of partial truth, where the truth value may range between completely true and false (Novák et al., 1999). At first, this research garnered minimal attention and faced substantial criticism within the scientific community (Zadeh, 2008). However, as the mid-1970s approached, and despite initial skepticism surrounding this novel theory, an increasing number of scientists began to analyze Zadeh's work and started applying it to his fields of study (Laengle et al., 2021).

Fuzzy systems were used first in engineering application (Wee & Fu, 1969; Asai & Kitajima, 1971) and were posteriorly applied to different areas such as mathematics

(Zadeh, 1971; De Luca & Termini, 1972), computer sciences (Ruspini, 1970; Zimmermann, 1978) or business economics (Basu, 1984) in order to manage in an effective way imprecise, incomplete vague or fragmentary information in humanlike dynamic systems (Jones et al., 1986).

Although these initial researchers come from different areas, they grouped to consolidate the field with the creation in 1978 of the first international journal exclusively for the international advancement of its theory and applications, Fuzzy Sets and Systems (Merigó et al., 2015). The journal is still active and relevant in 2023, publishing 340 works in 2022 that combine fuzzy concepts with other scientific disciplines as well as modern technologies and have an H-Index of 180 and an SJR index of 1.212 in 2022, which place it in the Q1 quartile both in Logic and Artificial Intelligence.

After this initial move, researchers from different areas of study such as Fu K.S., Bonissone P., Ruspini E., Bezdek J., Yager R. R. and Zadeh L. himself initiated endeavours to form a professional association dedicated to the study and application of Fuzzy Sets, establishing the North American Fuzzy Information Processing Society (NAFIPS) in 1985 in the state of California (Filev et al., 2009). Despite being officially created in 1985, annual meetings have been taking place since 1982, when the inaugural NAFIPS conference was hosted in Utah (USA[1]) on May 18-20.

The initial community of Fuzzy systems researchers was originally based in the USA but grew very quickly thanks to the attention received by Asian and European researchers since the 1970s (Blanco-Mesa et al., 2017). This attention globalized the Fuzzy community and led to the creation of the International Fuzzy Systems Association (IFSA), which held its first conference only 3 years later than the NAFIPS on July 1-6, 1985, in Palma de Mallorca (Spain).

From then on, Fuzzy systems publications grew in number and more specialized journals strictly dedicated to Fuzzy studies appeared. These publications include, among others: the Journal of Japan Society for Fuzzy Theory and Intelligent Informatics in 1989; the IEEE Transactions on Fuzzy Systems in 1993; the International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems in 1993; the Journal of Intelligent & Fuzzy Systems in 1993; the Fuzzy Economic Review in 1995; the International Journal of Fuzzy Systems in 1999; Fuzzy Optimization and Decision Making in 2002; and the Iranian Journal of Fuzzy Systems in 2003 (Alfaro-García, Merigó, Pedrycz, et al., 2020).

Scientific production has increased exponentially in the last decades (Wuchty et al., 2007). This results in an overwhelming volume of new information and data, theories and conceptual developments that must be revised and classified quantitatively. From an academic perspective, it is important and necessary to classify all the papers published in a research field to find the leading trends and detect new lines of study and opportunities that help future investigations (Hicks et al., 2015).

In this scenario, bibliometrics studies offers a useful tool to provide a structured analysis to a large body of information, allowing one to infer trends over time and identify shifts in the boundaries of the research fields and detect the most productive and influential scholars, journals, and institutions, presenting a “big picture” of the existing

[1] Acronym: USA, United States of America

bibliography (Zupic & Čater, 2015). Thanks to the development of the internet and specialized computer software, bibliometric studies have become more viable, thus becoming a trend on its own (Ding et al., 2014). Bibliometric studies have become very common in the scientific community, within a wide range of research fields that include management (Vizuete-Luciano et al., 2021), medicine (Stenson et al., 2020), psychology (Arnett, 2008) or tourism (Jiang et al., 2019).

Production in Fuzzy systems research has increased greatly in the last years (Kumar et al., 2022) making necessary an update to previous bibliometric studies. This work tries to follow this lead and complement other works that have made a bibliometric approach to fuzzy research (Alfaro-García, Merigó, Alfaro Calderón, et al., 2020; Alfaro-García, Merigó, Pedrycz, et al., 2020; Merigó et al., 2015). Even though some of the published studies focus and analyzes specific characteristics of the Fuzzy area of study, there are no studies that analyzes Fuzzy systems research from a general perspective considering the most productive and influential countries in this academic field, being the scarce existing studies focused just in one specific region (Merino-Arteaga et al., 2022).

For that, the aim of this paper is to offer a bibliometric analysis to identify tendencies and trends and establish the most prolific and important countries in fuzzy research using the Web of Science (WoS) database and taking in account several bibliometric indicators. First, the study presents a regional analysis through time of the publications to see its evolution. Second, this paper presents a global table of nowadays Fuzzy research divided into countries with the highest number of articles, citations, and h-index. Third, we present different tables dividing the results of the previous table in periods of 10 years, in order to see how countries production evolved through time. Next, the study considers the most prolific authors and their countries, and finally introduces the most cited articles and their countries to establish a comparison between the most prolific countries and the most influential ones, which may differ. The main contribution of this approach is that it provides a general overview of the leading countries in Fuzzy research, allowing establish trends and to make comparisons between other scientific fields and geopolitics.

2. Methodology

This study classifies the data by using a bibliometric approach. Bibliometrics introduces a systematic and reproducible review process based on the statistical measurement of science, scientists, or scientific activity through a methodical quantification of the information concentrated in scientific databases (Broadus, 1987). To ensure that this review is neutral and informative, it's important to select the methods and tools that are going to be used (Merigó et al., 2015).

This paper reports on data drawn from the WoS database. WoS is currently owned by Clarivate Analytics and includes around 1.9 billion cited references from over 171 million records and over 20,000 scientific journals tracing back to the year 1900 (Birkle et al., 2020). Note that many other databases could be considered, including Google Scholar, SCOPUS and Microsoft Academic (Martín-Martín et al., 2018). Although Google Scholar and Microsoft Academic are the two most comprehensive bibliographic

data sources, they have several limitations in their search functionalities. These limitations include restricted support for Boolean and other advanced search operators, limited filtering capabilities, and non-transparent algorithms for processing queries and ranking documents on the results page, making them less suitable for bibliometric analyses (Martín-Martín et al., 2021). In this article, the focus will be given to WoS due to being one of the largest citation databases available in the market, providing a representative view of research and being the most used database in metanalysis over Scopus (Zhu & Liu, 2020).

The procedure for the retrieval of information is the following. We have used the keyword "fuzz*" for every title, abstract, and keyword. We have added all the papers published in some journals considered fuzzy systems oriented: Fuzzy Sets and Systems, IEEE Transactions on Fuzzy Systems, International Journal of Fuzzy Systems, Iranian Journal of Fuzzy Systems, Fuzzy Optimization and Decision Making, Advances in Fuzzy Systems and Fuzzy Information and Engineering. This list of journals was compiled using the bibliometric reviews conducted by Alfaro-García and García-Orozco on fuzzy logic journals (Alfaro-García, Merigó, Alfaro Calderón, et al., 2020; García-Orozco et al., 2022). The timespan of the search includes all the papers between 1965 to December 2021. This search was carried out in January 2023 and august 2024.

The advanced search for the replicability of this procedure is (((TS=(fuzz*)) OR SO=(fuzzy sets and systems OR ieee transactions on fuzzy systems OR international journal of fuzzy systems OR Iranian journal of fuzzy systems OR fuzzy optimization and decision making OR advances in fuzzy systems OR fuzzy information and engineering)) AND PY=(1965-2023)) AND DT=(Article OR Review OR Letter OR Note).

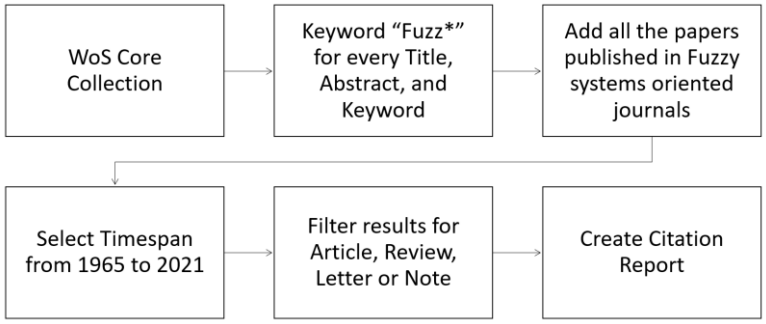

Fig. 1 Proposed search process

To measure scientific output of researchers is an increasingly important task for the scientific community (Zupic & Čater, 2015). In this study and for measure the influence of countries in the Fuzzy field of study, we rank the countries using the h-index and in the case of a tie, according to the number of citations. The h-index is a measure that aims to represent the importance of a set of papers defining the largest number of H for which an author has H papers with at least H citations each (Hirsch, 2005). For example, if an author has an h-index of 30, that means that 30 of the papers published by him have received at least 30 citations each. Since its introduction, the h-index has been extended and generalized by many authors, and it is considered a good method to value the

influence of and author or publication due to combining different metrics such as the total number of citations, the average number of citations per paper and the number and percentage of significant papers (Alonso et al., 2009). Although it has some weaknesses in measuring and analyzing very highly cited papers, it works quite well with huge volumes of publications, as is the case with a country analysis (Merigó et al., 2016).

Some papers are joint works of more than one author, some of them originally from different countries. We have made the search in the WoS database individually for each country, and the WoS database take in consideration the nationality of each of the authors to give proper data, so some papers had been counted various times. Although the search generates 185,673 documents, if we add the results of countries individually the number of papers is 235,075, reflecting this fact.

Each article is counted only once and is assigned to the country of the first author. Although it may cause some deviations, we consider that since each country has many researchers, the deviation this may cause in the overall results is minimal and may not affect the object of the study, which is to provide a general overview of the publishing countries and their evolution.

3. Results

This section presents the results of the study. Analyzing the data of the bibliometric retrieval, the results are classified by using a country study. The methodological procedure for the retrieval of information yields 185,673 documents. This contains all the publications covered by the WoS database and includes 181,631 articles, 8,236 proceeding papers, 4,061 book chapters, 3179 reviews, 529 letters, and 334 notes.

First, we group the countries utilizing the United Nations Regional Groups (United Nations Statistics Division, 2022) in Fig.2 and Fig. 3, dividing the world into 8 regions to observe the evolution of the publications of these regions throughout time (Mas-Tur et al., 2019) Following this first figure, we focused on individual countries, elaborating Table 1 which develops a global overview of the leading countries in Fuzzy research.

When conducting a country and regional analysis, some considerations must be attended. First, notable political changes took place during the timespan of the study, and some countries have changed their name, e.g. Soviet Union, Germany, and Czechoslovakia. In Table 1 we consolidated the data of the nonexistent regions to the actual territories. For example, the information of the German Democratic Republic and the Federal Republic of Germany that appears in Tables 2-3 have been unified into Germany in Tables 1-4-5-6 and 7.

Next, the results are divided into periods in Tables 2, 3, 4, 5, 6 and 7 to see the evolution of the leading countries throughout time. Same as the global overview of leading countries, due to political changes some countries disappear between tables. We grouped all the years between 1965 and 1980 because there is not much data compared to the other periods. Also, we grouped 2020 and 2023 in Table 7. It must be noted that these 4 years do not have enough time to be cited in comparison to the previous articles, causing a minor deviation in the analysis. Despite this, this table shows the tendencies for the last years and his analysis can be useful.

The work also develops an individual analysis of the most prolific authors in Fuzzy research in Table 8, so we can observe and analyze the origin of the authors. As some authors change their workplaces often, we took as criteria the last occupation and where they developed the majority of their career. We have included the Web of Science ID number of each of the authors to identify them. ORCID number is more reliable for this manner, but some of the authors who have been publishing long time as Pedrycz W. and Yagger R. R. do not have it. We have also included a time frame between his first article and the last one. Table 9 shows the most cited articles in Fuzzy research showing the year and the country of the first author with the same criteria as Table 8.

3.1. Analysis of Supranational Regions

Many regions are developing important research on Fuzzy around the World. Fig. 2 and Fig. 3 presents the number of articles published annually by 8 selected regions commented on above. Before 1991 it can be observed that Northern America was leading the field followed by Western Europe (including Scandinavian and southern countries), but then Asia took the lead and its production has risen significantly since then, with Western Europe overcoming Northern America in 1997. It is noticeable that the region including Northern Africa and Western Asia (we included Iran in this region) had remarkable growth since 2010, becoming the second-producing area in Fuzzy research in the world in 2023. We would like to emphasize the growth of Asia, especially since 2010, with his production being multiplied by 5. At the time of this article and according to the data retrieved, 101,229 out of 185,673 (which represents 54.52% of the papers produced historically worldwide) were produced in this region. This contrasts with the stagnation of production in Northern America, which had only increased by 60% in the last decade, passing from 795 papers to 1,278 according to the data.

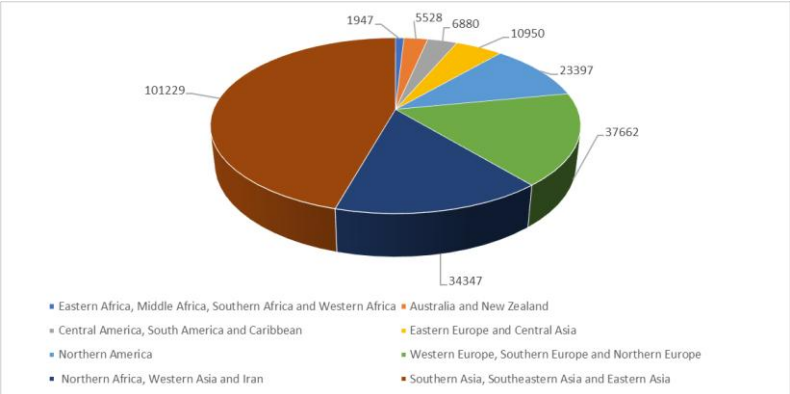

Fig. 2 Annual number of articles in Fuzzy systems published by each region

However, in terms of population, Southern, Southeastern, and Eastern Asia are one of the least productive areas. Even if these regions are the most productive regarding the

total number of papers, they are also the most populated areas in the world, with one-third of the world's entire population. Therefore, the productivity per person is very low compared to the rest of the areas of the analysis with countries like India with 14.32 papers per million inhabitants or People's Republic of China with 38.36 according to Table 1. This considered, Western Europe is the most productive area regarding its population with countries like Spain having 164.12 papers per million inhabitants or England with 130.24.

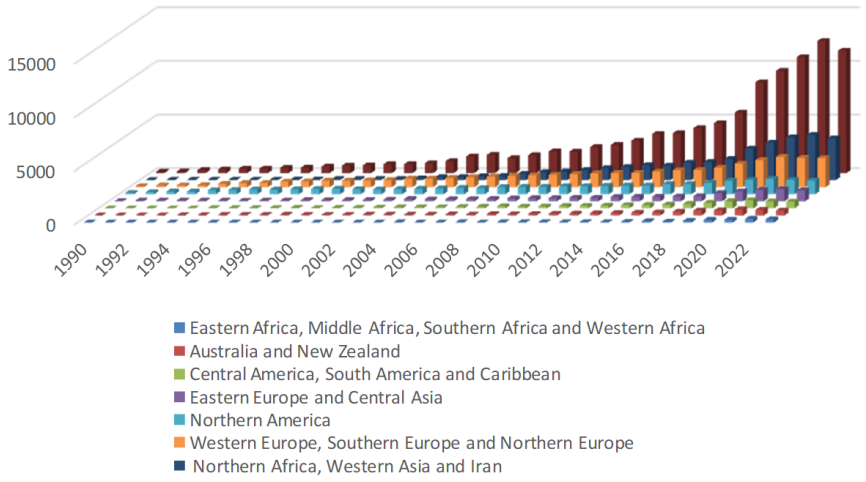

Fig. 3 Annual number of articles in Fuzzy systems published by each region

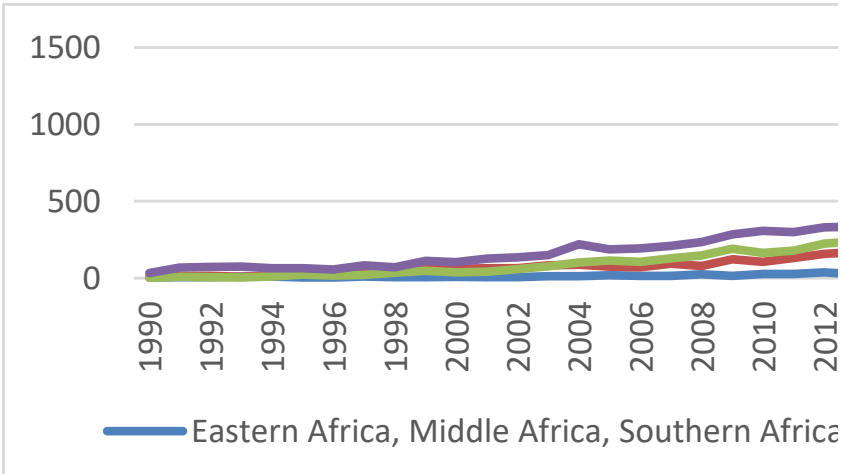

Fig. 4 Annual number of articles in Fuzzy systems published by less productive regions

Other regions not mentioned do not publish a significant number of articles and cannot be easily classified. Therefore, Fig. 4 presents a more specific analysis of the results of the less productive regions. Australia with 191.72 papers per million inhabitant and New Zealand with 109.87, for example, are publishing a relevant number

of papers according to their population, although the absolute numbers are not enough relevant as a region in Fig. 2. Central and South America (including the Caribbean) with countries like Brazil with 13.75 and México with 16.03 and Eastern Europe and Central Asia present similar total numbers and evolution, although Central and South America have twice the population, meaning that Eastern Europe with countries like Czech Republic with 174.29 papers per million inhabitant and Central Asia have a higher productivity per person. Africa (excluding North Africa) has the lowest total of papers and publications per capita with South Africa having 13.61 papers per million inhabitants being the most productive, with no other country in the region appearing in the top 50 countries.

3.2. Leading Countries in Fuzzy Systems Research

Fuzzy systems research articles are being produced by many countries. Table 1 presents the productivity and influence of the top 30 countries between 1965, when the first article about fuzzy systems was published, and 2023. The countries are ranked according to their number of publications, the total citations, the average article citations, the total number of papers per population, the total citations per population, and the total population are also included. Moreover, the table also includes the number of articles with more than 500, 250, 100, and 50 citations and the productivity per person.

The People's Republic of China is the most productive country attending to total papers with 29.45%, followed by India with 11.02, EEUU with 9.78, and Iran with 8.10. These 4 countries together represent more than 58% of total publications. Some smaller countries also obtain good results as Taiwan with 5.77%, Spain with 4.20%, England with 3.95%, Canada with 3,60% or South Korea with 3,33%

Regarding total citations, the People's Republic of China and the USA continue to obtain better results, followed at a significant distance by India, Iran, Taiwan, and England. This results in an average article citation of 41.34 for the USA and 39.32 for the Netherlands being the highest. England with 37.49, Singapore with 36.50, Belgium with 36.21 and Australia with 35.77 follows being the only countries with more than 35 average citations per article. The average article citation is an important indicator to measure the quality of the articles, especially when we compare articles of the same characteristics and fields of study (Waltman, 2016).

For having a proper overview of these indicators, it is important to compare the populations of the countries and the total articles and citations per population, as the country's characteristics have different impacts on how it can be researched (Man et al., 2003). Despite People's Republic of China having the most total publications and citations, compared to its population of 1,425.67 million, the number is not as high as it seems with 38.36 papers per million and 869.07 citations per million. The same can be observed by looking at the India data, with 14.32 articles per million inhabitants and 244.41 cites per million, despite being the fourth overall in total citations. On the other hand, Taiwan has the most articles per million inhabitants with 448.06 and 12,520.59 citations per million inhabitants. Singapore with 301.46 papers per million and 11,004.82 citations per million, Greece with 193.21 papers per million and 6,117.98 citations per million, Australia with 191.72 papers per million and 3,090.15 citations per

million and Canada with 172.51 articles per million and 6,858.09 citations per million also performs well in these indicators. The number of full-time researchers per million inhabitants has been included as a reference according to the UNESCO Science Report of 2021 (Schneegans et al., 2021) to give a better context, although some countries does not provide the information.

Lastly, Table 1 analyzes the number of articles with more than 500, 250, 100, and 50 citations. These indicators explain the impact that countries have on Fuzzy systems research, as the more articles with more than 500 and 250 citations a country has, the more influence they have in the research field and the more quality they have (Merigó et al., 2015). The USA is the most influential country in Fuzzy systems research with a total of 141 articles with more than 500 citations. China comes second with 69 articles with more than 500 citations. England with 35 and Spain with 28 and France with 24 complete the top 5. According to articles with more than 250 citations, China is the most influential country with 405 articles, followed by USA with 402, England with 140, Spain with 93, and Taiwan with 91.

Table 1. Most influential countries in Fuzzy systems research

R	R Name	TP-Fuzzy	TC-Fuzzy	AAC	%TP	TP/Pop	TC/Pop	Pop	R/Pop	>500	>250	>100	>50
1	P R CHINA	54,684	1,239,006	22.66	29.452	38.36	869.07	1,425.67	1,307	69	405	2,330	6,225
2	INDIA	20,459	349,167	17.07	11.019	14.32	244.41	1,428.63	253	23	89	1,823	1,244
3	USA	18,149	750,288	41.34	9.775	53.38	2,206.76	340.00	4,412	141	402	1,521	3,405
4	IRAN	15,032	384,534	25.58	8.096	168.57	4312.27	89.17	1,475	9	74	573	1,841
5	TAIWAN	10,719	299,530	27.94	5.773	448.06	12,520.59	23.92	N/A	23	91	586	1,602
6	SPAIN	7,799	228,546	29.30	4.200	164.12	4,809,57	47.52	3,001	28	93	353	1,089
7	TURKEY	7,406	208,229	28.12	3.989	86.30	2,426.46	85.82	1,379	12	60	409	1,130
8	ENGLAND	7,331	274,874	37.49	3.948	130.24	4,883.44	56.29	4,603	35	140	574	1,393
9	CANADA	6,690	216,060	32.30	3.603	172.51	5571.28	38.78	4,326	12	65	438	1,194
10	SOUTH KOREA	6,185	140,163	22.66	3.331	119.44	2706.69	51.78	7,980	6	38	234	699
11	ITALY	5,106	153,228	30.01	2.750	86.73	2,602.82	58.87	3,223	9	36	215	654
12	AUSTRALIA	5,069	181,321	35.77	2.730	191.72	6,858.09	26.44	N/A	12	86	381	981
13	SAUDI ARABIA	5,037	86,502	17.17	2.713	138.01	2370.11	36.50	N/A	3	27	138	430
14	JAPAN	4,658	139,458	29.94	2.509	37.78	1,131.10	123.29	5,331	21	71	233	611
15	FRANCE	4,547	153,408	33.74	2.449	70.22	2,369.02	64.76	6,419	24	61	288	719
16	GERMANY	4,426	120,438	27.21	2.384	53.14	1,445.94	83.29	7,539	9	47	219	617
17	PAKISTAN	3,915	68,397	17.47	2.109	16.28	284.41	240.49	336	3	14	76	294
18	POLAND	3,850	91,523	23.77	2.074	93.84	2,230.85	41.03	3,106	12	28	144	431
19	MALAYSIA	3,783	11,2000	29.61	2.037	110.27	3,264.54	34.31	2,397	9	49	197	591
20	BRAZIL	2,975	64,385	21.64	1.602	13.75	297.50	216.42	N/A	5	17	105	301
21	EGYPT	2,585	48,541	18.78	1.392	22.93	430.65	112.72	687	2	10	51	230
22	MEXICO	2,059	36,497	17.73	1.109	16.03	284.12	128.46	5,830	0	8	68	178
23	VIETNAM	2,018	56074	27.79	1087	20.41	567.22	98.86	315	0	17	112	331
24	GREECE	1,998	63266	31.66	1.076	193.21	6117.98	10.34	5,810	7	25	124	343
25	CZECH REPUBLIC	1,887	33457	17.73	1.016	174.29	3,090.15	10.83	708	1	5	47	157
26	SINGAPORE	1,813	66183	36.50	0.976	301.46	11004.82	6,01	6,803	4	33	145	372
27	RUSSIA	1,530	21333	13.94	0.824	10.59	147.69	144,44	2,784	1	9	32	71
28	BELGIUM	1,526	55262	36.21	0.822	130.58	4728.91	11,69	6,906	7	26	121	309
29	ALGERIA	1,489	27322	18.35	0.802	32.65	599.09	45,.61	819	1	6	44	141
30	NETHERLANDS	1,469	57755	39.32	0.791	83.38	3278.18	17.62	5,605	6	30	129	302

Acronyms: TP-Fuzzy, total papers in Fuzzy systems research. TC-Fuzzy, total citations in Fuzzy systems research. AAC, average article citation. %TP, percentage of total papers in Fuzzy systems research. TP/Pop, total papers per million inhabitants. TC/Pop, total citations per million inhabitants. Pop, Population in millions. R/Pop, Researchers per million inhabitants. >500, >250, >100 and >50, number articles with more than 500, 250,100 and 50 cites. PR CHINA, People's Republic of China. USA, United States of America.

3.3. Evolution of more Productive and Influential Countries in Fuzzy Systems Research

When analyzing the country rankings in a bibliometric study, the evolution through time becomes an interesting question (Merigó et al., 2016). This evolution depends on the economic and social situation of the country and the resources it invests in research (Man et al., 2003). Tables 2, 3, 4, 5, and 6 present the most productive and influential countries in fuzzy systems research divided into periods as explained previously. First, we have the most productive and influential countries in fuzzy research between 1980 in Table 2. The USA is by a large margin the most productive country with 153 papers. We can relate this early influence on the fact that fuzzy systems were created there in 1965. It must be highlighted that, even after producing just 28.10% of the articles the USA did, producing 43 papers, England has very similar citations with 10,804 vs the 11,853 citations of the USA. That results in an average article citation of 251.6 for England versus 77.47 for the USA. In contrast to England, Japan produced 20 papers in this period, which had only 702 citations regarding them, giving them an average of 35.3 citations per article. We should note that the average article citation in Table 2 is higher than the one in other periods due to the foundational and seminal articles of the area being created at that time. Regarding the h-Index USA has the highest number with 47, followed by England with 24, Canada with 13, and France and Japan with 10.

Table 3 follows the evolution of Fuzzy systems research between 1980 and 1989. USA continues leading the table in total papers with 598 representing 26.91% of the total, 43,500 citations, and an h-index of 94. Japan goes second with 193 total articles and 26,590 cites and an h-index of 50. The People's Republic of China started appearing on the list in third place with 163 articles but only 3,869 total cites. Poland and France also performed well with 135 and 121 total articles and 6,937 and 7,510 total citations respectively.

In Table 4 we can see that the article production in Fuzzy systems research between 1990 and 1999 greatly increased. If we add up the results of the top ten countries, we obtain 9,016 articles in comparison to the 1,655 produced between 1980 and 1989. The USA remains the most productive country and the one with the most citations, but it is noticeable how the People's Republic of China increased its total citations by 5.7 times. Taiwan also appears for the first time in the 4th place in total papers but is the second one in total citations with 34,014 and an h-index of 91. The tendency of European and northern American countries heading the rankings starts to change with Asian countries becoming more productive and producing articles with more quality.

Tables 5, 6, and 7 continue with this tendency, with the People's Republic of China being the most productive and influential country in the last 20 years. Its article production in the fuzzy research field increased dramatically every year to the point that between 2010 and 2019 the People's Republic of China produced more papers than the top ten countries in fuzzy research between 2000 and 2009 including himself. The USA falls to the 4 position overall, remaining a very influential and productive country in the field but not leading anymore. Taiwan, India, and Iran also perform well in the rankings, confirming that the center of the Fuzzy systems research has been displaced to the east, as can be seen in Fig. 2.

Table 2. Most influential countries in Fuzzy systems research before 1980

R	Name	TP-Fuzzy	TC-Fuzzy	AAC	% TP	H Index	TP/Pop	TC/Pop	Pop
1	USA	153	11,853	77,47	34.152	47	0.69	53.12	223.14
2	ENGLAND	43	10,804	251,26	9.598	24	0.92	230.92	46.79
3	JAPAN	26	959	36,88	5.804	10	0.22	8.15	117.62
4	FRANCE	19	2,988	157,26	4.241	10	0.35	55.63	53,71
5	CANADA	19	753	39,63	4.241	13	0.78	30.72	24,51
6	FED REP GER	12	1,129	94,08	2.009	8	0.19	18.31	61.66
7	BELGIUM	9	1,152	128,00	2.679	6	0.92	117.22	9.83
8	INDIA	9	446	49,56	2.009	6	0.01	0.64	696.83
9	POLAND	9	237	26,33	2.009	6	0.25	6.67	35.52
10	NETHERLANDS	9	1,966	218,44	2.009	8	0.64	139.14	14.13
11	ITALY	7	234	33,43	1.339	5	0.12	4.15	56.33
12	CZECHOSLOVAKIA	6	971	161,83	1.563	5	0.58	94.43	10.28
13	ISRAEL	6	23	3,83	1.339	3	1.60	6.14	3.74
14	AUSTRALIA	6	176	29,33	1.339	5	0.41	11.97	14.71
15	NEW ZEALAND	5	480	96,00	1.116	4	1.59	152.53	3.15
16	ROMANIA	4	51	12,75	0.893	3	1.27	16.21	22.125
17	GER DEM REP	4	13	3,25	0.893	2	0.24	0.78	16.74
18	GREECE	4	364	91,00	0.893	3	0.43	39.11	9.31
19	SPAIN	3	90	30,00	0.893	3	0.08	2.40	37.49
20	HUNGARY	3	19	6,33	0.670	3	0.28	1.78	10.70
21	IRAN	3	174	58,00	0.670	2	0.08	4.52	38.52
22	SOUTH AFRICA	3	121	40,33	0.670	3	0.10	4.11	29.46
23	BRAZIL	3	204	68,00	0.670	1	0.02	1.67	122.17
24	BUNDES REPUBLIK	3	18	6,00	0.670	1	0.18	1.08	16.74
25	DENMARK	2	1	0,50	0.446	1	0.39	0.20	5.13
26	DEUTSCH DEM REP	1	7	7,00	0.223	1	0.06	0.42	16.74
27	FINLAND	1	47	47,00	0.223	1	0.21	9.83	4.78
28	SWEDEN	1	240	240,00	0.223	1	0.12	28.88	8.31
29	UGANDA	1	0	0,00	0.223	0	0.08	0.00	13.28
30	USSR	1	6	6,00	0.223	1	0.00	0.02	270.00

Acronyms: H, h-index. FED REP GER, Federal Republic of Germany. GER DEM REP, German Democratic Republic. DEUTSCH DEM REP, Deutsche Demokratische Republik. USSR, Union of Soviet Socialist Republics

Table 3. Most influential countries in Fuzzy research between 1980 and 1989

R	Name	TP-Fuzzy	TC-Fuzzy	AAC	% TP	H Index	TP/Pop	TC/Pop	Pop
1	USA	598	43,500	70.22	26.913	94	2.44	177.58	244.95
2	JAPAN	193	26,590	147.26	8.686	50	1.57	215.71	123.27
3	PEOPLES R CHINA	163	3,869	22.69	7.336	27	0.14	3.41	1134.41
4	POLAND	135	6,937	48.53	6.076	40	3.56	182.85	37.94
5	FRANCE	121	7,510	64.92	5.446	36	2.15	133.70	56.17
6	INDIA	103	3,756	35.71	4.635	31	0.12	4.41	852.01
7	ENGLAND	102	3,887	32.02	4.590	31	2.15	81.74	47.55
8	ITALY	93	1,928	20.37	4.185	18	1.64	34.00	56.71
9	SPAIN	74	2,440	32.63	3.330	18	1.90	62.81	38.85
10	CANADA	73	3,099	38.4	3.285	27	2.68	113.75	27.24
11	FED REP GER	65	4,147	58.14	2.925	24	1.03	65.85	62.98
12	BELGIUM	58	2,001	33.12	2.610	25	5.84	201.37	9.94
13	USSR	52	356	6.6	2.340	10	0.18	1.22	290.93
14	GER DEM REP	37	547	14.5	1.665	15	2.25	33.28	16.43
15	CZECHOSLOVAKIA	35	443	12.82	1.575	9	3.38	42.75	10.36
16	FINLAND	34	3,072	83.61	1.530	14	6.85	618.86	4.96
17	AUSTRALIA	29	926	36.95	1.305	15	1.73	55.13	16.80
18	AUSTRIA	26	872	42.33	1.170	13	3.41	114.45	7.62
19	NETHERLANDS	25	3,287	140.55	1.125	16	1.68	221.35	14.85
20	GREECE	19	752	36.74	0.855	12	1.86	73.65	10.21
21	ROMANIA	19	290	15.82	0.855	8	0.83	12.73	22.79
22	EGYPT	18	321	19.06	0.810	10	0.32	5.76	55.77
23	HUNGARY	18	468	29.56	0.810	8	1.73	45.01	10.40
24	NORWAY	18	409	28.23	0.720	9	4.26	96.76	4.23
25	ISRAEL	18	1345	100.5	0.720	10	3.86	288.26	4.67
26	CZECH REPUBLIC	16	72	6.64	0.720	5	1.55	6.98	10.31
27	BULGARIA	11	13,501	1190.4	0.495	8	1.25	1,533.51	8.80
28	SWEDEN	11	132	11.9	0.495	5	1.29	15.52	8.50
29	SOUTH AFRICA	10	201	21.44	0.450	5	0.26	5.20	38.67
30	TURKEY	9	140	15.56	0.450	5	0.17	2.64	52.99

Table 4. Most influential countries in Fuzzy research between 1990 and 1999

R	Name	TP-Fuzzy	TC-Fuzzy	AAC	% TP	H Index	TP/Pop	TC/Pop	Pop
1	USA	3,038	168,309	55.40	25.440	164	10.88	602.87	279.18
2	JAPAN	1,156	32,448	28.07	9.680	80	9.13	256.39	126.56
3	PEOPLES R CHINA	838	22,200	26.49	7.017	70	0.67	17.68	1,255.43
4	TAIWAN	794	34,014	42.84	6.649	91	36.00	1542.10	22.06
5	GERMANY	685	15,854	23.14	5.736	63	8.40	194.39	81.56
6	INDIA	574	17,391	30.30	4.807	58	0.55	16.71	1,040.50
7	CANADA	536	23,475	43.80	4.488	73	17.63	772.23	30.40
8	ENGLAND	499	17,035	34.14	4.179	66	10.18	347.43	49.03
9	FRANCE	448	30,346	67.74	3.751	67	7.68	520.05	58.35
10	SOUTH KOREA	448	11,419	25.49	3.751	57	9.63	245.46	46.52
11	SPAIN	447	17,305	38.71	3.743	60	11.14	431.09	40.14
12	ITALY	406	12,365	30.46	3.400	53	7.13	217.14	56.95
13	AUSTRALIA	285	11,704	41.07	2.387	57	15.16	622.55	18.80
14	SINGAPORE	194	4,002	20.63	1.625	37	48.92	1,009.08	3.97
15	BELGIUM	184	7,541	40.98	1.541	45	18.00	737.58	10.22
16	POLAND	158	6,462	40.90	1.323	33	4.12	168.48	38.35
17	EGYPT	157	1,853	11,80	1.315	19	2.25	26.51	69.91
18	NETHERLANDS	138	6,882	49.87	1.156	42	8.73	435.24	15.81
19	RUSSIA	135	3,632	26.90	1.130	14	0.92	24.65	147.34
20	GREECE	125	4,200	33.60	1.047	36	11.37	382.06	10.99
21	BRAZIL	108	3,007	27.84	0.904	27	0.62	17.33	173.49
22	FINLAND	105	2,686	25.58	0.879	26	20.33	520.04	5.17
23	HUNGARY	105	4,027	38.35	0.879	32	10.26	393.65	10.23
24	CZECH REPUBLIC	99	1,860	18.79	0.829	23	9.63	180.88	10.28
25	AUSTRIA	98	2,825	28.83	0.821	29	12.26	353.52	7.99
26	YUGOSLAVIA	91	2,187	24.03	0.762	24	3.87	92.95	23.53
27	SCOTLAND	89	1,788	20.09	0.745	21	17.58	353.22	5.06
28	HONG KONG	87	2,897	33.30	0.729	29	13.10	436.23	6.64
29	ISRAEL	80	2,857	35.71	0.670	23	13.35	476.64	5.99
30	BULGARIA	77	2,415	31.36	0.645	21	9.43	295.88	8.16

Table 5. Most influential countries in Fuzzy research between 2000 and 2009

R	Name	TP-Fuzzy	TC-Fuzzy	AAC	% TP	H Index	TP/Pop	TC/Pop	Pop
1	PEOPLES R CHINA	4,865	184,504	37.92	16.212	184	3.63	137.78	1339.13
2	USA	4,204	229,159	54.51	14.009	197	13.63	742.79	308.51
3	TAIWAN	3,156	129,532	41.04	10.517	146	136.96	5621.07	23.04
4	SPAIN	1,589	64,694	40.71	5.295	112	34.27	1395.26	46.37
5	CANADA	1,530	61,497	40.19	5.098	113	45.55	1830.65	33.59
6	INDIA	1,530	62,285	40.71	5.098	113	1.25	50.90	1223.64
7	ENGLAND	1,470	81,178	55.22	4.899	135	28.16	1555.25	52.20
8	SOUTH KOREA	1,423	37,038	26.03	4.742	85	29.29	762.29	48.59
9	TURKEY	1,282	60,591	47.26	4.272	119	17.75	838.92	72.23
10	JAPAN	1,263	35,281	27.93	4.209	87	9.86	275.38	128.12
11	ITALY	1,240	39,482	31.84	4.132	90	20.82	662.87	59.56
12	GERMANY	1,031	37,091	35.98	3.436	89	12.69	456.45	81.26
13	FRANCE	1,030	38,663	37.54	3.432	94	16.59	622.66	62.09
14	IRAN	928	33,866	36.49	3.092	90	12.49	455.67	74.32
15	POLAND	813	27,247	33.51	2.709	73	21.09	706.70	38.56
16	AUSTRALIA	673	27,340	40.62	2.243	83	31.07	1262.23	21.66
17	GREECE	555	25,285	45.56	1.849	76	50.20	2287.20	11.06
18	BELGIUM	470	23,246	49.46	1.566	77	43.51	2152.21	10.80
19	SINGAPORE	463	21,814	47.11	1.543	80	92.42	4354.09	5.01
20	BRAZIL	429	17,563	40.94	1.430	60	2.21	90.29	194.52
21	CZECH REPUBLIC	367	11,565	31.51	1.223	58	34.99	1102.69	10.49
22	MEXICO	314	7,562	24.08	1.046	45	28.42	684.41	11.05
23	NETHERLANDS	305	17,647	57.86	1.016	72	18.44	1067.19	16.54
24	EGYPT	271	6,687	24.68	0.903	40	3.17	78.21	85.50
25	ROMANIA	255	6,474	25.39	0.850	43	12.46	316.33	20.47
26	FINLAND	218	7,885	36.17	0.726	45	40.84	1477.14	5.34
27	RUSSIA	214	3,350	15.65	0.713	25	1.49	23.40	143.16
28	AUSTRIA	212	7,535	35.54	0.706	51	25.41	903.26	8.34
29	MALAYSIA	190	4,912	25.85	0.633	40	6.73	174.08	28.22
30	HUNGARY	185	9,868	53.34	0.616	52	18.49	986.01	10.01

Table 6. Most influential countries in Fuzzy research between 2010 and 2019

R	Name	TP-Fuzzy	TC-Fuzzy	AAC	% TP	H Index	TP/Pop	TC/Pop	Pop
1	PEOPLES R CHINA	22,788	718,372	31.52	30.684	252	16.03	505.23	1421.86
2	IRAN	8,030	239,546	29.83	10.812	160	92.76	2767.27	86.56
3	INDIA	7,350	189,933	25.84	9.897	142	5.31	137.32	1383.11
4	USA	6,465	243,502	37.66	8.705	178	19.34	728.35	334.32
5	TAIWAN	4,471	107,853	24.12	6.020	118	188.04	4536.02	23.78
6	TURKEY	3,552	107,743	30.33	4.783	131	42.55	1290.63	83.48
7	SPAIN	3,467	117,516	33.90	4.668	138	73.56	2493.39	47.13
8	ENGLAND	2,714	118,441	43.64	3.654	143	48.22	2104.23	56.29
9	CANADA	2,683	96,221	35.86	3.613	129	71.50	2564.39	37.52
10	SOUTH KOREA	2,396	60,502	25.25	3.226	104	46.25	1167.92	51.80
11	AUSTRALIA	2,164	105,362	48.69	2.914	146	85.34	4155.14	25.36
12	ITALY	1,959	57,914	29.56	2.638	97	32.80	969.65	59.73
13	MALAYSIA	1,906	81,468	42.74	2.566	124	58.10	2483.48	32.80
14	FRANCE	1,868	61,252	32.79	2.515	105	29.01	951.13	64.40
15	GERMANY	1,595	52,776	33.09	2.148	101	19.18	634.72	83.15
16	POLAND	1,487	36,909	24.82	2.002	81	38.63	958.85	38.49
17	SAUDI ARABIA	1,318	46,788	35.50	1.775	102	36.79	1305.94	35.83
18	BRAZIL	1,279	32,300	25.25	1.722	77	6.04	152.52	211.78
19	JAPAN	1,211	34,715	28.67	1.631	83	9.63	275.97	125.79
20	PAKISTAN	1,163	32,323	27.79	1.566	83	5.21	144.76	223.29
21	MEXICO	990	20,494	20.70	1.333	69	7.91	163.83	125.10
22	CZECH REPUBLIC	818	15,355	18.77	1.101	53	77.36	1452.15	10.57
23	GREECE	806	26,898	33.37	1.085	77	75.38	2515.48	10.69
24	EGYPT	745	21,639	29.05	1.003	70	7.05	204.88	105.62
25	ALGERIA	732	17,441	23.83	0.986	68	17.14	408.41	42.71
26	SERBIA	706	16,319	23.11	0.951	61	95.39	2204.97	7.40
27	SINGAPORE	691	32,191	46.59	0.930	86	117.80	5487.73	5.87
28	ROMANIA	664	13,429	20.22	0.894	62	34.01	687.82	19.52
29	VIETNAM	624	26,943	43.18	0.840	88	6.52	281.31	95.78
30	NETHERLANDS	599	23,540	39.30	0.807	76	34.50	1355.76	17.36

Table 7. Most influential countries in Fuzzy research between 2020 and 2023

R	Name	TP-Fuzzy	TC-Fuzzy	AAC	% TP	H Index	TP/Pop	TC/Pop	Pop
1	PEOPLES R CHINA	26,027	310,061	11.91	38.977	140	18.25	217.45	1425.89
2	IRAN	6,024	74,650	12.39	16.313	82	68.51	849.04	87.92
3	INDIA	4,923	110,216	22.39	9.021	91	3.50	78.30	1407.56
4	USA	3,690	53,965	85.00	5.526	53	10.95	160.13	337.00
5	SAUDI ARABIA	3,564	43,442	12.19	5.337	71	99.14	1208.40	35.95
6	PAKISTAN	2,705	34,975	12.93	4.051	65	11.69	151.14	231.40
7	ENGLAND	2,502	43,362	17.33	3.747	79	44.29	767.62	56.49
8	TURKEY	2,488	37,809	15.20	3.726	72	29.26	444.59	85.04
9	TAIWAN	2,289	27,310	11.93	3.428	62	95.94	1144.64	23.86
10	SPAIN	2,219	26,397	11.90	3.323	62	46.73	555.89	47.49
11	AUSTRALIA	1,912	35,813	18.73	2.863	76	73.76	1381.62	25.92
12	SOUTH KOREA	1,910	27,532	14.41	2.860	67	36.85	531.20	51.83
13	CANADA	1,848	30,909	16.73	2.768	71	48.43	810.09	38.16
14	MALAYSIA	1,671	25,150	15.05	2.502	66	49.77	749.11	33.57
15	ITALY	1,400	20,512	14.65	2.097	61	23.63	346.25	59.24
16	EGYPT	1,396	17,962	12.87	2.091	56	12.78	164.39	109.26
17	VIETNAM	1,337	27,531	20.59	2.002	76	13.72	282.46	97.47
18	POLAND	1,248	13,632	10.92	1.869	46	32.58	355.86	38.31
19	BRAZIL	1,151	11,184	9.72	1.724	44	5.37	52.18	214.33
20	GERMANY	1,099	14,717	13.39	1.646	51	13.18	176.45	83.41
21	FRANCE	1,061	12,649	11.92	1.589	45	16.44	196.01	64.53
22	JAPAN	809	11,191	13.83	1.551	52	6.49	89.81	124.61
23	IRAQ	789	9,465	12.00	1.212	45	18.12	217.42	43.53
24	RUSSIA	780	6,471	8.30	1.182	35	5.38	44.60	145.10
25	MEXICO	732	7,833	10.70	1.168	39	5.78	61.82	126.71
26	SERBIA	689	10,171	14.76	1096	47	94.44	1394.05	7.30
27	ALGERIA	619	4,484	7.24	1032	28	14.01	101.50	44.18
28	THAILAND	616	5,247	8.52	0.927	33	8.60	73.28	71.60
29	CZECH REPUBLIC	592	4,563	7.71	0.923	31	56.25	433.58	10.52
30	GREECE	489	5,696	11.65	0.887	33	46.82	545.33	10.45

3.4. Most Productive Authors in Fuzzy Systems Research

We included Table 8 with the most prolific researchers in the Fuzzy field. 15 out of 30 produced their work in the People's Republic of China, which we can relate to China being the most productive country. 20 out of 30 authors come from Asia. Despite this, the most prolific author is Pedrycz W. from Canada with 1,011 papers, way more than the other authors. Wang J. from Liverpool University is the second most prolific author with 735 articles, but Xu, Z. is the most cited one with 44,169 articles. The first USA author is Yager R. R. in the 14th position with 403 papers published but the third one on the total citation. It must be noted that Iran, being one of the most productive countries in Table 2 doesn't have any author in this top 30.

Looking at the period of activity of the authors, the majority of them started publishing in the 1990s, when the first point of growth in the area of study occurred. Garg. H. from India is the most recent author in the table, having his first article published in 2012. In future analysis, other authors that started publishing in the 2010s will probably appear, as pointed out in Fig.2 and Table 6, that decade shows the bigger expansion of the Fuzzy systems field. It is also remarkable that some authors that showed interest and started publishing very early like Pedrycz W. and Yager R. R. are still active in 2021, meaning that they have a very long career of more than 40 years.

Table 8. Most productive authors in Fuzzy research

R	Name	Country	TP-Fuzzy	TC-Fuzzy	H-Fuzzy	Active Period	WoS ID
1	Pedrycz W.	CANADA	1,011	33,041	83	1981-2023	FPE-7309-202
2	Wang J.	ENGLAND	735	22,944	81	1993-2023	AAX-4516-20
3	Zhang Yingmiao	PEOPLES R CHINA	707	12,922	54	1988-2023	GSC-0345-202
4	Liu Yang	PEOPLES R CHINA	693	13,557	57	1999-2023	AAD-5667-20
5	Xu Z.	PEOPLES R CHINA	621	44,169	103	2002-2023	N-8908-2013
6	Wang Y.	PEOPLES R CHINA	597	11,291	56	1999-2023	BBC-2658-202
7	Li Yue	PEOPLES R CHINA	578	11,545	50	1996-2023	DBQ-8192-20
8	Kumar A.	INDIA	513	10,232	51	1994-2023	DCA-4254-20
9	Wang L.	PEOPLES R CHINA	507	10,651	49	1992-2023	EFM-4090-20
10	Liu Jun	PEOPLES R CHINA	455	9,325	47	1996-2023	C-1338-2011
11	Li J.	PEOPLES R CHINA	443	8,614	46	1997-2023	FIA-2393-202
12	Zhang J.	PEOPLES R CHINA	428	8,132	43	1995-2023	ABT-0791-20
13	Zhang L.	SINGAPORE	417	9,676	51	1997-2023	EIW-2267-202
14	Yager R. R.	USA	403	28,619	73	1977-2023	GKQ-0038-20
15	Huang G.	CANADA	391	11,406	53	1993-2023	H-5306-2011
16	Li Xiang	PEOPLES R CHINA	382	7,589	46	1996-2023	DDJ-7834-202
17	Castillo O.	MEXICO	379	12,957	67	1999-2023	I-5578-2019
18	Akram M.	PAKISTAN	379	10,156	50	2008-2023	N-3369-2014
19	Garg H.	INDIA	375	16,201	73	2012-2023	C-6063-2012
20	Li Y.	PEOPLES R CHINA	365	20,644	70	1999-2023	F-8379-2016
21	Zhang H.	PEOPLES R CHINA	358	8,151	48	1999-2023	GLM-3140-20
22	Tong S.	PEOPLES R CHINA	343	28,47	94	1994-2023	JCM-4762-202
23	Kahraman C.	TURKEY	338	16,347	70	1999-2023	N-9259-2013
24	Mesiar R.	SLOVAKIA	326	9,246	51	1989-2023	DZI-2965-202
25	Wang H.	PEOPLES R CHINA	285	5,046	38	1998-2023	EGI-7701-202
26	Shi Peng	AUSTRALIA	279	23,281	93	2004-2023	EOZ-7086-202
27	Melin P.	MEXICO	274	8,849	57	1994-2023	B-3611-2013
28	Herrera-Viedma	SPAIN	270	27,414	84	2006-2023	FWR-4541-20
29	Zhang Q.	PEOPLES R CHINA	265	4,7	35	1994-2023	ABU-1212-20
30	Herrera F.	SPAIN	261	39,96	102	2006-2023	K-9019-2017

3.5. Most Cited Articles in Fuzzy Research

Lastly, we included Table 9 with the most cited articles in the Fuzzy systems research area. None of the authors shown in Table 8 appear in Table 9, despite some of them like Pedrycz W., Xu Z., Yager, R.R., Tong S. or Herrera F. having more than 20,000 citations. The country with the most contributions to the list is the USA with 12 out of 30 articles, followed by England with 3 and Taiwan, Bulgaria, Australia, and Spain with 2. People's Republic of China only have 1. The total number of articles from Northern America and England is 16, showing that this area is the most important one, in contrast to what is shown in Table 8 where China and Asia were leading.

Table 9. Most cited articles in Fuzzy research

R	Article Title	Authors	TC	Year	Country
1	Fuzzy Sets	Zadeh, LA	54,314	1965	USA
2	Fuzzy identification of systems and its applications to modeling and control	Takagi, T; Sugeno, M	13,808	1985	Japan
3	ANFIS - Adaptative-Network-Based Fuzzy Inference System	Jang, JSR	10,963	1993	Taiwan
4	Intuitionistic Fuzzy-Sets	Atanassov, KT	9,983	1986	Bulgaria
5	Fuzzy nanoassemblies: Toward layered polymeric multicomposites	Decher, G	9,237	1997	Germany
6	Enrichr: a comprehensive gene set enrichment analysis web server 2016 update	Kuleshov, MV; Jones, MR; Rouillard, AD	5,462	2016	USA
7	Experiment in linguistic synthesis with a fuzzy logic controller	Mamdani, EH; Assilian, S	4,435	1975	England
8	FCM - The Fuzzy C-means clustering-algorithm	Bezdek, JC; Ehrlich, R; Full, W	4,192	1984	Australia
9	Survey of clustering algorithms	Xu, R; Wunsch, D	3,665	2005	USA
10	Core affect and the psychological construction of emotion	Russell, JA	3,393	2003	USA
11	Fuzzy-Logic in control-systems - Fuzzy-Logic controller .1.	Lee, CC	3,124	1990	USA
12	Soft set theory - First results	Molodtsov, D	3,026	1999	Russia
13	Survey over image thresholding techniques and quantitative performance evaluation	Sezgin, M; Sankur, B	2,969	2004	Turkey
14	Applications of the extent analysis method on fuzzy AHP	Chang, DY	2,949	1996	USA
15	Hesitant Fuzzy Sets	Torra, V	2,942	2010	Spain
16	Building Better Causal Theories: A Fuzzy Set Approach to typologies in organization research	Fiss, PC	2,767	2011	USA
17	Fuzzy identity-based encryption	Sahai, A; Waters, B	2,762	2005	USA
18	Validation of the theoretical domains framework for use in behaviour change and implementation research	Cane, J; O'Connor, D; Michie, S	2,576	2012	England
19	Extensions of the TOPSIS for group decision-making under fuzzy environment	Chen, CT	2,452	2000	Taiwan
20	Interval Valued Intuitionistic Fuzzy-Sets	Atanassov, K; Gargov, G	2,395	1989	Bulgaria
21	On digital soil mapping	McBratney, AB; Santos, MLM; Minasny, B	2,350	2003	Australia
22	Decision-Making in a Fuzzy Environment	Bellman, RE; Zadeh, LA	2,333	1970	USA
23	A review on image segmentation techniques	Pal, NR; Pal, SK	2,322	1993	India
24	A validity measure for Fuzzy clustering	Xie, XLL; Beni, G	2,296	1991	PR China
25	Application of Fuzzy algorithms for control of simple dynamic plant	Mamdani, EH	2,273	1974	England
26	Gene trees in species trees	Maddison, WP	2,209	1997	Canada
27	A 2-tuple fuzzy linguistic representation model for computing with words	Herrera, F; Martinez, L	2,146	2000	Spain
28	Fuzzy hierarchical analysis	Buckley, JJ	2,146	1985	USA
29	Fuzzy cognitive maps	Kosko, B	2,132	1986	USA
30	Fuzzy logic equals Computing with words	Zadeh, LA	2,043	1996	USA

4. Conclusion

The aim of this paper is to offer a bibliometric analysis to identify tendencies and trends and establish the most prolific and important countries in Fuzzy systems research. For that, an analysis of research documents focused on Fuzzy systems using bibliometric tools and techniques has been presented. The analysis is focused on the most productive and influential countries between 1965 and 2023. The results obtained show that the last decade has been the most prolific both in articles and citations, representing that the average article citation is getting lower every decade.

First, we made a supranational analysis in **Fig. 2** and **Fig. 3** aiming to see from a global perspective how fuzzy research is distributed in the world and how evolved throughout time. All the regions increased the number of publications with Southern Asia, Southeastern Asia and Eastern Asia leading after multiplying per 3.77 his publications in 10 years, going from 3,023 in 2013 to 11,411 in 2023. Northern America was leading before the 1990s, but its production has not increased at the same rhythm as the other regions changing from 795 in 2013 to 1,278 in 2023. Northern Africa and Iran holds second position, and their production is currently increasing significatively, especially in the last decade going from 1,231 to 3,891. Western Europe, which follows Northern America also increased its production significantly, but not enough to match Asia, Western Africa, and Iran.

Looking at individual countries, the conclusions are the same. The epicentre of the Fuzzy systems research production moved from the USA and England (with Canada and the rest of Europe being very important as well) to Asia with People's Republic of China, India and Iran leading the change. The expectations for the future are that Asia production will continue growing, and Western countries will not be able to match them. It is important to highlight that, even the epicenter of production is changing, the most important and influential papers are from the USA and England.

It should be underlined that this tendency change must not be seen as a rarity that happens just in the fuzzy systems field, as other science fields, especially the ones that are related to computer sciences are following the same path, where countries like People's Republic of China, India and Iran are surpassing USA and Western Europe, who were the traditional leaders in the field (Huang et al., 2015), and other countries start to match them. This is happening due to different reasons, but the governments of these countries are investing lots of resources into it to reduce their dependence on foreign countries as they develop (Ong, 2021).

Development priorities have aligned over the last years, with countries of all income levels prioritizing their transition to digital economies, convinced that their future economic competitiveness will depend upon how quickly they transition to digital. In order to achieve this development, countries need to improve their infrastructure and industrialization on a parallel path to its research, chronic underspending on research and development means they are largely a recipient of foreign scientific expertise and technology (Bonilla et al., 2015).

Although this work shows the tendencies and leading countries in fuzzy research, it has its limitations. As mentioned above in point 3, many authors work abroad and it's not easy to classify and evaluate the research of a country. English-speaking countries receive a large number of researchers from other countries, and that means that they can place higher in the rankings than other countries that count only on their citizens. If we

took the birth nationality as the main nationality to this study, some of the results will change, as some scholars prefers to work in more competitive institutions abroad.

Another important limitation related to this is that WoS gives each author only one country of reference. Some authors can work for different institutions in different countries in their lifetime, causing some deviations in the study. However, a country includes many researchers, and therefore, from a statistical point of view, the deviations should be equilibrated when considering a high volume of data and should not affect the final conclusions.

Also, the vast majority of the papers published in WoS are written in English, and non-English-speaking countries may also publish their research in other languages and therefore are not included in WoS. However, we must consider that the material included in WoS is sufficiently representative of the most important works so we can identify the trends and obtain conclusions.

We consider that the country and regional analysis provided in this article can be useful for different works that may be performed in the future, not only in the fuzzy research field, but also in other areas of study such as computer sciences. This article forms a preliminary stage to that may allow to identify trends in geopolitical studies, giving and overview of the focus and point of interest from different countries.

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