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An overview of fuzzy research with bibliometric indicators

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ABSTRACT

Bibliometrics is a discipline that analyzes bibliographic material from a quantitative perspective. It is very useful for classifying information according to different variables, including journals, institutions and countries. This paper presents a general overview of research in the fuzzy sciences using bibliometric indicators. The main advantage is that these indicators provide a general picture, identifying some of the most influential research in this area. The analysis is divided into key sections focused on relevant journals, papers, authors, institutions and countries. Most of the results are in accordance with our common knowledge, although some unexpected results are also found. Note that the aim of this paper is to be informative, and these indicators identify most of the fundamental research in this field. However, some very influential issues may be omitted if they are not included in the Web of Science database, which is used for carrying out the bibliometric analysis.

1. Introduction

Research in the fuzzy sciences originated almost 50 years ago with the seminal paper of Lotfi A. Zadeh [1] published in Information and Control. This paper analyzed the concept of fuzzy sets, allowing classical Boolean sets to use a multi-valued logic. Initially, this research did not attract very much attention, and it received many criticisms in the scientific community. In the mid-1970s, and after much skepticism about this new theory, an increased number of scientists started to analyze the work of Zadeh more seriously. This group of researchers consolidated the field in 1978 with the creation of Fuzzy Sets and Systems in 1978, the first international journal exclusively devoted to fuzzy theories. Later, they started to organize in professional associations, such as the North American Fuzzy Information Processing Society (NAFIPS), created in 1982 by James Bezdek, Piero Bonissone, King Sun Fu, Enrique Ruspini, Richard Tong, Ronald Yager and Lotfi Zadeh. The first NAFIPS conference was held in Utah (USA) on May 18–20, 1982.

This group grew very quickly because it was especially motivated by the increased attention received by Asian and European researchers since the 1970s. The fuzzy community became a world entity with the creation of the International Fuzzy Systems Association (IFSA), which held its first conference in Palma de Mallorca (Spain) on July 1–6, 1985. Since then, many other associations have appeared, and many other journals with a strong focus on fuzzy research or being strictly dedicated to it have been launched, including the Journal of Japan Society for Fuzzy Theory and Intelligent Informatics (1989); the IEEE Transactions on Fuzzy Systems (1993); the International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems (1993); the Journal of Intelligent & Fuzzy Systems (1993); the Fuzzy Economic Review (1995); the International Journal of Fuzzy Systems (1999); Fuzzy Optimization and Decision Making (2002); and the Iranian Journal of Fuzzy Systems (2003). For an overview of fuzzy theories, see [2–6].

A strong consolidation process was performed in the 1990s with the creation of the Institute of Electrical and Electronics Engineers Computational Intelligence Society (IEEE CIS), which included fuzzy research as one of its three main branches. This implied the official recognition by the IEEE of the acceptance of fuzzy research as a strong entity in the scientific community. Today, it has over 7000 members. It is worth noting that this research field is also known as Soft Computing [7–9]. Briefly, it is composed of fuzzy systems, neural networks, evolutionary computation, probabilistic reasoning and other related areas, such as chaos theory. Currently, there is significant growth in this area with the creation and consolidation of new associations, including the World Federation on Soft Computing (WFSC), and journals, such as Mathware & Soft Computing

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(1994), the Journal of Multiple-Valued Logic and Soft Computing (1995), Intelligent Automation and Soft Computing (1995), Soft Computing (1997), Applied Soft Computing (2001) and the International Journal of Computational Intelligence Systems (2008).

Today, fuzzy research is a very general and established scientific field, with thousands of researchers studying different theoretical or practical aspects of this theory. The present organization of fuzzy sciences can be divided into two main blocks. The first block is based on the IEEE CIS society, and the second block has its nucleus in the IFSA association. IFSA is divided into 17 other associations that encompass researchers from a specific region or topic.

Bibliometric analysis is a research field that analyzes publications, citations and their sources of information. Currently, it is receiving more attention due to the strong development of computers and the internet. There have been many definitions and discussions concerning bibliometrics [10,11]. One of the key advantages is that it permits one to analyze a specific research field by considering papers, journals, authors, institutions and countries. Thus, it is possible to construct a general picture of a research field. However, there are many limitations, especially because of the particular research style followed by each researcher, which may imply a different volume of self-citations and co-authored papers.

In the literature, many studies have provided a general bibliometric overview of a research field. Among others, it is worth noting some key areas, including management [12], econometrics [13], health economics [14], marketing [15], statistics [16], ecological economics [17], ant colony optimization [18], pricing research [19], entrepreneurship [20], production and operations management [21–23], data envelopment analysis [24], gray systems [25] and innovation [26]. However, no paper has been published providing a general overview of fuzzy research. Some authors have studied some specific aspects, including a bibliometric mapping in computational intelligence that included fuzzy systems as one of its main components [27,28], tools for analyzing the evolution of topics in fuzzy research [29] and an application in the Spanish region [30].

The aim of this paper is to present a general overview of fuzzy research from its inception 50 years ago using bibliometric techniques. The objective is to show the most productive and influential research in the scientific community according to information found in the Web of Science (WoS). The information is classified by articles, authors, journals, institutions and countries. Most of the results found are in accordance with our common knowledge, whereby Zadeh is the most influential author in fuzzy research and most of the main leaders are also found in the first author positions, including Yager, Sugeno, Dubois, Prade, Bezdek, Pedrycz and Mendel. Fuzzy Sets and Systems and the IEEE Transactions on Fuzzy Systems are the main outlets for the dissemination of fuzzy theories, and the USA is the most influential country, although Asian countries have shown a substantial increase in publications during the last years. However, it is worth noting that many limitations may appear in the classification process because the focus is on the WoS; however, to provide a complete picture, many other factors should be considered, including editorial appointments in main journals and involvement in associations and conferences. Therefore, the aim of the paper is to be informative to show the current results found in the WoS regarding fuzzy research, although fundamental research developed in this field may be omitted if it is not included in this database.

The paper is organized as follows. Section 2 describes the methodology to be used. Section 3 presents the 50 most cited papers of all time in fuzzy research, and Section 4 presents the most productive and influential authors. Section 5 analyzes the main institutions in this area, and Section 6 presents the most relevant countries. Section 7 discusses the main conclusions of the paper.

2. Methodology

An important issue when analyzing the information is to select the methods and tools that are going to be used. To be informative and neutral with the information, the search process is based on the results found in the WoS database, which is currently owned by Thomson & Reuters. The WoS includes many databases for addressing this information. In this paper, the main focus is on the Web of Science Core Collection, which considers several sub databases, including the Conference Proceedings Citation Index. It includes research from almost all the known sciences and currently covers information from more than 15,000 journals and 50,000,000 papers. It classifies the information in 251 subject categories and in 151 research areas. Note that there are many other databases that could be considered, including SCOPUS and Google Scholar. However, in this paper, the focus will be given to the WoS.

To develop the search process, we have used the keyword "fuzzy" in the "topic" section. Therefore, the query should provide all the papers related to fuzzy research. One of the main limitations of this analysis is that many papers that address fuzzy sciences do not use the keyword "fuzzy". This problem is relevant because during the last few years, fuzzy research has become part of a more general field known as soft computing. Thus, the interaction of its subfields may bring about this limitation. Note that an additional manual search process with the "Cited Reference Search" has been developed to avoid the omission of key research in this field. However, when analyzing all the production in this area, it is very easy to omit papers, in particular, because it is not clear where the boundaries between fuzzy research and related fields are. Additionally, some papers that use the keyword "fuzzy" are not related to fuzzy research. The most relevant papers with this problem have been omitted to avoid relevant disequilibrium in the citation count. From a general perspective, it has been assumed that the general numbers representing the total production are valid because these two limitations should be approximately compensated between them. Note that this can also be proved by observing Table 2. The percentage of fuzzy papers in Fuzzy Sets and Systems and in the IEEE Transactions on Fuzzy Systems is over 90%, clearly indicating that all papers focused on fuzzy research are included. The percentage is not 100% because some papers may be at the intersection between fuzzy research and other general areas, such as soft computing and computational intelligence. Observe that in this paper, the aim is to focus strictly on fuzzy research.

In February 2013, there were 115,000 papers that used the keyword "fuzzy". Note that this number includes all the publications covered by the WoS. Currently, it considers 15 different types of publications, including journal articles, proceedings, book reviews, notes, comments, reviews and editorial material. To focus on the main articles, this information has been filtered by only looking for journal articles and reviews. Thus, the total number of publications found has been reduced to 56,500 papers. Note that most of these publications come from the last decade, with 78,300 papers between 2003 and 2012, which is reduced to 45,700 papers if only journal articles and reviews are considered. Observe that this represents 68% and 80.8% of the total volume. More specifically, it is clear that fuzzy research is becoming more influential in the scientific community by looking to the strong increase found in the last years as shown in Fig. 1. Obviously, this increase is also explained by the increase in the number of researchers worldwide and by the expansion of the WoS, which now includes more journals. However, the increasing influence of fuzzy research is demonstrated by the creation of new fuzzy journals and other related ones that have recently been indexed in the WoS. As observed in Fig. 1, the percentage of fuzzy papers out of the total number of papers included in the database each year has increased. Specifically, the ratio

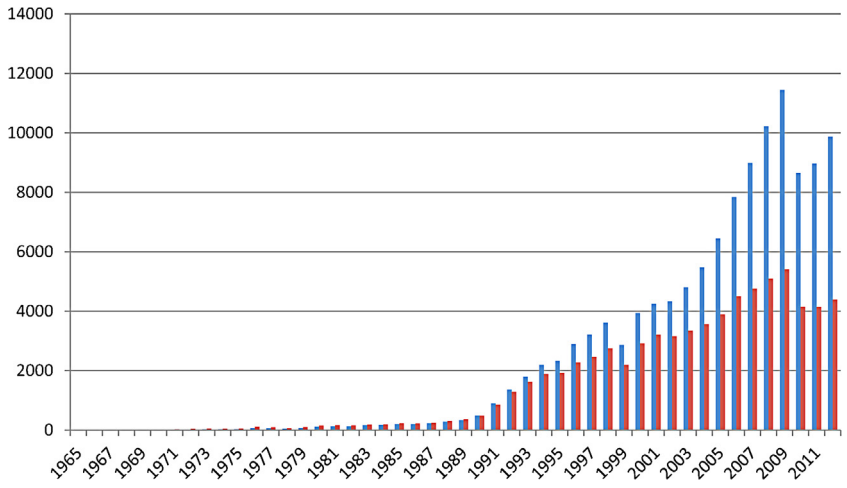

Fig. 1. Number of annual publications in fuzzy research (articles + reviews) since 1965. The blue bars indicate the total number of fuzzy papers published each year in the WoS and the red bars indicate the ratio (NFP/TNP) × 1,000,000 where NFP is the number of fuzzy papers in year X and TNP is the total number of papers published in the WoS in year X. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Table 1
General citation structure in fuzzy research in WoS.

Number of citations	Number of papers	% Papers
≥2000 citations	7 papers	0.008%
≥1000 citations	17 papers	0.021%
≥500 citations	50 papers	0.076%
≥250 citations	149 papers	0.270%
≥100 citations	812 papers	1.437%
≥50 citations	2553 papers	4.518%
≤50 citations	53,951 papers	95.481%
Total	56,504 papers	

[number of fuzzy papers in year X/number of papers published in year X in the WoS] has increased.

Currently, more than 5000 papers are being published in this field every year, with a record of 11,000 published in 2009. Regarding citation count, this area has a normal citation rate according to computer science and engineering standards. However, it is worth noting that the 1965 paper by Zadeh [1] has received more than 15,000 citations, and it is among the 50 most cited papers of all time in all scientific areas according to the WoS. Currently, it is in the 48th position, and it is the most cited paper of all time in computer science. Note that the average citation rate in computer science and engineering is very low compared to other fields such as physics, chemistry, biology and medicine. Thus, these results are even more remarkable. To evaluate the citation rate of papers in this field, in Table 1, the general citation structure of all the papers is presented, classified by several thresholds concerning number of citations. The percentage of papers in each section is also included.

Note, only seven papers have received more than 2000 citations, and 4.5% of the papers have received more than 50 citations. A further interesting activity is to analyze the global H-index (also known as H-classics [31]) found in fuzzy research. The H-index [32] is a measure that aims to represent the importance of a set of papers. For example, if a set of papers has an H-index of 25, then 25 of the papers included in the set have received at least 25 citations each. Moreover, this means that 26 papers with at least 26 citations each do not exist. For of the entire collection of papers in fuzzy research, the H-index (or H-Classics) is 208. Specifically, 208 papers have received at least 208 citations. Note that since its introduction, the H-index has been extended and generalized by many authors [33].

Research in the fuzzy sciences is published in a wide range of journals, which currently number in the hundreds. Some of these journals are strictly devoted to this field, whereas others are strongly influenced or simply publish some occasional paper. To classify the journals with fuzzy publications, the 30 most influential journals in this field and some smaller and newer journals but with a strong focus in this area are presented in Table 2.

According to the fuzzy H-index and to the percentage of fuzzy papers published in the journal, Fuzzy Sets and Systems and the IEEE Transactions on Fuzzy Systems are the most influential journals in this field. Some other key outlets are Information Sciences; the Int. J. Approximate Reasoning; the Int. J. Intelligent Systems; the Int. J. Uncertainty, Fuzziness and Knowledge Based Systems; the Int. J. General Systems; and Expert Systems with Applications. Moreover, some newer journals are becoming very popular, such as Applied Soft Computing and Soft Computing, and some of them are strictly dedicated to the field, such as the J. Intelligent & Fuzzy Systems, Fuzzy Optimization and Decision Making, the Int. J. Fuzzy Systems and the Iranian J. Fuzzy Systems. Furthermore, some other well-known journals regularly publish papers in this area and have become very influential, such as the IEEE Transactions on Systems, Man and Cybernetics, European J. Operational Research, the IEEE Transactions on Neural Networks, the J. Mathematical Analysis and Applications, IEEE Transactions on Industrial Electronics and Pattern Recognition.

Note that these journals are those covered in the WoS. However, there are many other journals worldwide publishing fuzzy research that are not indexed in the WoS. Table 3 presents a list of those journals with a strong focus on fuzzy research and soft computing.

The impact factor of each journal has been included in Table 2 as a measure of the quality of the journal. Note that this information is covered in the WoS in the Journal Citation Reports (JCR). It analyzes the value of a journal by dividing the number of citations received in the year $n-1$ and $n-2$ from year n by the total number of papers published in the year $n-1$ and $n-2$. Moreover, it is also possible to consider the impact factor for all the fuzzy papers published each year. The results are shown in Table 4.

In 2003, the impact factor was approximately 1, while in the last 3 years, it has increased, and it is usually approximately 2. Note that this increase can be explained due to the growth in fuzzy research in the last years and to the significant increase in publications in the WoS that has increased the impact factor of most of the material that was available earlier.

However, it is worth noting that the impact factor has received many criticisms during the last years because it has been argued that it has many limitations because it is easy to manipulate the

Table 2
Most influential journals in fuzzy research.[a]

R	Name	H-F	TCF	TPF	%PF	>500	>250	>100	>50	TP	TC	IF	T50	H
1	FSS	119	105,588	5703	91.7	4	24	176	517	6216	112,302	1.74	7	121
2	TFS	97	44,662	1306	96.9	5	28	94	231	1347	45,159	5.48	6	97
3	TSMC[b]	76	36,214	932	11.3	19	46	190	575	8199	160,981	2.65	7	128
4	IS	65	25619	1422	28.5	4	17	57	162	4984	59,206	3.64	4	80
5	EJOR	58	13,165	521	4.3	3	24	207	711	12,061	180,006	2.03	0	130
6	TNN	48	8642	202	7.2	14	44	156	436	2789	90,899	3.76	2	122
7	JMAA	46	10,741	275	1.3	8	32	147	515	20,812	169,496	1.05	5	114
8	TIE	43	7922	317	5.9	2	14	79	340	5348	90,102	5.16	0	94
9	PR	42	8428	315	5.3	10	33	133	407	5876	103,797	2.63	1	110
10	PRL	39	5726	290	6.1	2	8	45	165	4721	52,545	1.26	0	75
11	ESWA	38	11,475	1701	22.2	0	0	15	83	7641	44,242	1.85	0	59
12	IJAR	38	6769	436	42.3	0	0	14	35	1029	11,725	1.72	0	44
13	TPS	38	5251	230	3.9	0	10	138	509	5857	108,834	2.92	0	110
14	IJIS	35	5537	535	40.1	0	1	12	36	1331	11,232	1.41	0	43
15	IJPR	31	3545	294	4.2	0	4	47	234	6859	76,195	1.46	0	80
16	CMWA	30	4543	412	4.8	3	4	24	98	8475	49,672	2.06	1	63
17	IJUFKS	30	3934	556	65.4	1	2	5	23	849	6771	0.88	0	36
18	NN	30	3316	103	4.0	14	28	130	287	2527	72,737	1.92	1	112
19	TGRS	29	2682	113	1.6	7	51	229	688	6745	149,137	3.46	0	134
20	TPD	29	2206	129	1.9	1	4	47	242	6766	71,975	1.51	0	77
21	IJGS	28	4024	302	29.2	1	2	11	27	1031	8058	0.73	1	40
22	CSF	26	2408	220	3.2	1	8	61	238	6872	76,386	1.24	0	83
23	EAAI	25	2980	379	22.5	0	0	0	13	1679	11,610	1.62	0	37
24	JHEP	25	2706	174	1.2	18	66	352	1083	14,394	261,648	5.61	0	150
25	CAIE	25	2415	277	5.9	0	1	14	60	4667	28,230	1.51	0	53
26	ASC	24	3010	559	37.0	0	0	1	9	1510	7523	2.14	0	31
27	CEP	23	2348	204	8.1	1	4	11	46	2494	24,140	1.66	0	48
28	AMC	23	2136	212	1.6	0	4	26	137	12,853	71,279	1.34	0	69
29	NC	22	1988	282	13.6	13	28	123	295	2068	65,921	1.76	0	109
30	IJAMT	21	2221	356	5.6	0	0	2	22	6304	33,220	1.20	0	41
Other journals strongly influenced by fuzzy research[c]														
	SC	20	2618	510	44.1	0	0	4	11	1154	5421	1.12	0	28
	IJICIC	18	1816	404	15.9	0	0	2	15	2533	9317	–	0	30
	KBS	18	1617	157	11.7	0	1	3	7	1337	8635	4.10	0	33
	IC	16	17,619	25	0.7	5	29	83	218	3305	70,313	0.69	2	92
	JIFS	16	1361	384	71.3	0	0	0	1	538	1849	0.78	0	17
	CS	15	1025	184	16.5	0	0	1	7	1110	3857	0.97	0	22
	NCA	13	663	213	19.0	0	0	0	4	1118	3714	1.16	0	23
	FODM	13	520	118	87.4	0	0	0	1	135	609	1.48	0	15
	IJITDM	13	451	66	16.2	0	0	0	3	406	1958	–	0	17
	IJFS	9	488	204	90.6	0	0	0	0	225	499	1.50	0	9
	IJCIS	9	313	116	30.9	0	0	0	0	375	715	–	0	12
	IrJFS	7	199	148	98.0	0	0	0	0	151	200	–	0	7
	IASC	6	165	126	22.7	0	0	1	1	553	691	0.15	0	11
	JMVLSC	6	142	112	35.4	0	0	0	0	316	409	1.04	0	9

Abbreviations: R, rank; H-F, H-index only with fuzzy; TCF and TPF, total citations and papers only with fuzzy; %PF, percentage of fuzzy papers in the journal; >500, >250, >100, >50, number of papers with more than 500, 250, 100 and 50 citations; TP and TC, total papers and citations; IF, impact factor 2012; T50, number of papers in the top 50 list shown in Table 4; H, H-index; FSS, Fuzzy Sets and Systems; TFS, IEEE Trans. Fuzzy Systems; SMC, IEEE Trans. Systems, Man and Cybernetics + A + B + C; IS, Information Sciences; EJOR, European J. Operational Research; TNN, IEEE Trans. Neural Networks; JMAA, J. Mathematical Analysis and Applications; TIE, IEEE Trans. Industrial Electronics; PR, Pattern Recognition; PRL, Pattern Recognition Letters; ESWA, Expert Systems with Applications; IJAR, Int. J. Approximate Reasoning; TPS, IEEE Trans. Power Systems; IJIS, Int. J. Intelligent Systems; IJPR, Int. J. Production Research; CMWA, Computers & Mathematics with Applications; IJUFKS, Int. J. Uncertainty, Fuzziness and Knowledge-Based Systems; NN, Neural Networks; TGRS, IEEE Trans. Geosciences and Remote Sensing; TPD, IEEE Trans. Power Delivery; IJGS, Int. J. General Systems; CSF, Chaos, Solitons and Fractals; EAAI, Engineering Applications of Artificial Intelligence; JHEP, J. High Energy Physics; CAIE, Computers & Industrial Engineering; ASC, Applied Soft Computing; CEP, Control Engineering Practice; AMC, Applied Mathematics and Computation; NC, Neural Computation; IJAMT, Int. J. Advanced Manufacturing Technology; SC, Soft Computing; IJICIC, Int. J. Innovative Computing, Information and Control; KBS, Knowledge Based Systems; IC, Information and Control (currently Information and Computation); JIFS, J. Intelligent & Fuzzy Systems; CS, Cybernetics and Systems; NCA, Neural Computing and Applications; FODM, Fuzzy Optimization and Decision Making; IJITDM, Int. J. Information Technology and Decision Making; IJFS, Int. J. Fuzzy Systems; IJCIS, Int. J. Computational Intelligence Systems; IrJFS, Iranian J. Fuzzy Systems; IASC, Intelligent Automation and Soft Computing; JMVLSC, J. Multiple Valued Logic and Soft Computing.

[a] The ranking is developed according to the H-index and a minimum of 100 papers in fuzzy research. In the case of a tie, the total fuzzy citations are considered.

[b] TSMC includes the original version published between 1971 and 1995 and the division in A, B and C that started on 1996. Its impact factor is calculated as an average of the impact factors of the three sections. Observe that between 1960 and 1970, it was published under different names. These earlier versions of the journal are not included here.

[c] The requirement to be included is to publish a high percentage of papers in fuzzy research (more than 10%). The only exception is IC, which is included because Zadeh published his first seminal work on fuzzy sets there.

general result using self-citations or related techniques [34,35]. Currently, the WoS has tried to solve this issue by introducing the 5-year impact factor that, instead of 2 years, considers five. However, many discussions are occurring regarding this issue, and further modifications are expected in the future.

As mentioned before, many other techniques have been suggested for addressing the value and influence of a set of papers, and there are many limitations that should be considered. For example, all the publications count as one paper and each of their citations as one unit [12]. However, it is not the same to publish a paper in the most popular journal of the field than in a less recognized journal. Therefore, if a researcher publishes five papers in the most popular journal in the area, the value is higher than publishing five papers in less popular journals. Obviously, each paper has a different value, but for a general perspective, this issue should be considered.

Table 3
List of some fuzzy journals not covered in WoS.

	Fuzzy journals	Soft computing and computational intelligence journals
1	Advances in Fuzzy Mathematics	Applied Computational Intelligence and Soft Computing
2	Advances in Fuzzy Sets & Systems	Archives for the Philosophy and History of Soft Computing
3	Advances in Fuzzy Systems	Computational Intelligence and Neuroscience
4	Annals of Fuzzy Mathematics and Informatics	Int. J. Advances in Soft Computing and Its Applications
5	Annals of Fuzzy Sets, Fuzzy Logic and Fuzzy Systems	Int. J. Artificial Intelligence and Soft Computing
6	Asian J. Fuzzy and Applied Mathematics	Int. J. Bioinformatics and Soft Computing
7	BUSEFAL	Int. J. Biomedical Soft Computing and Human Sciences
8	CiiT Int. J. Fuzzy Systems	Int. J. Computational Intelligence
9	Fuzzy Economic Review	Int. J. Computational Intelligence and Applications
10	Fuzzy Information and Engineering	Int. J. Computational Intelligence and Health Care Informatics
11	Fuzzy Sets, Rough Sets and Multivalued Operations and Applications	Int. J. Computational Intelligence and Organizations
12	Fuzzy Systems & AI Magazine	Int. J. Computational Intelligence and Telecom. Systems
13	Fuzzy Systems & Mathematics	Int. J. Computational Intelligence Bioinformatics and Systems Biology
14	Indian J. Fuzzy Mathematics and Systems	Int. J. Computational Intelligence in Control
15	Int. J. Applications of Fuzzy Sets and Artificial Intelligence	Int. J. Computational Intelligence Research
16	Int. J. Applications of Fuzzy Sets on General State Spaces	Int. J. Computational Intelligence Research & Applications
17	Int. J. Fuzzy Computation and Modeling	Int. J. Computational Intelligence Studies
18	Int. J. Fuzzy Logic and Intelligent Systems	Int. J. Computational Intelligence Systems
19	Int. J. Fuzzy Logic Systems	Int. J. Computational Intelligence Theory and Practice
20	Int. J. Fuzzy Mathematical Archive	Int. J. Computational Intelligence: Theory and Practice
21	Int. J. Fuzzy Mathematics and Systems	Int. J. Factory Automation, Robotics and Soft Computing
22	Int. J. Fuzzy System Applications	Int. J. Hybrid Computational Intelligence.
23	Int. J. Fuzzy Systems and Advanced Applications	Int. J. Mathematics and Soft Computing
24	Int. J. Fuzzy Systems and Rough Systems	Int. J. Research and Reviews in Soft and Intelligent Computing
25	Int. J. on Advances in Fuzzy Systems	Int. J. Soft Computing
26	Int. Review of Fuzzy Mathematics	Int. J. Soft Computing and Bioinformatics
27	Inventi Impact: Fuzzy Systems	Int. J. Soft Computing and Engineering
28	J. Advanced Research in Fuzzy and Uncertain Systems	Int. J. Soft Computing and Networking
29	J. Biomedical Fuzzy Systems Association	Int. J. Soft Computing and Applications
30	J. Fuzzy Mathematics	Int. J. Soft Computing Simulation and Software Engineering
31	J. Fuzzy Set Valued Analysis	Inventi Impact: Soft Computing
32	J. Japanese Society for Fuzzy Theory and Systems	J. Advances in Computational Intelligence and Intelligent Informatics
33	Neural and Fuzzy Modeling Technology in Economics	J. Artificial Intelligence and Soft Computing Research
34	Notes on Intuitionistic Fuzzy Sets	J. Soft Computing and Applications
35	Turkish Journal of Fuzzy Systems	Mathware and Soft Computing

3. Most influential articles in fuzzy research

An important issue when analyzing the research published in fuzzy sciences is to classify the papers according to the total number of citations received. Thus, it becomes possible to find papers that have received more citations in this field. Although many aspects may influence the value of a paper, the number of citations reflects the popularity and influence that each one has in the scientific community. Table 5 presents the 50 most cited papers of all time in fuzzy research.

Obviously, the 1965 paper by Zadeh is the most cited and influential one. Next, the classic paper by Takagi and Sugeno, with more than 5000 citations, is found. Zadeh dominates this list, with six papers in the top 10 and with 11 papers in the top 50. It is worth noting that some very well-known papers in fuzzy research did not immediately appear with the keyword "fuzzy". Therefore, a manual process was developed to find the citations of these papers. Among others, it is worth noting the papers on linguistic variables published in 1975 [36], the first paper in FSS by Zadeh [37] and the ordered weighted averaging aggregation operator published in 1988 by Yager [38]. Note that this list includes any type of publication and not only journal articles and reviews because the focus is on the number of citations.

Another important issue is to analyze influential books in this area. Unfortunately, the WoS did not include books until the last years. Therefore, the classical books on fuzzy research are not included there. However, it is possible to find the number of citations that they have received in the WoS using the "Cited Reference Search", which analyzes all the citations given by the publications included in the database. Thus, if any publication does not appear in the WoS, it is possible to find the number of citations that it has received using this tool. The main disadvantage of this method is that it requires a manual search process, and sometimes, it is not easy to find all the information. We analyzed all the well-known authors in fuzzy research to determine if some of their books were highly cited. Note that this process has many limitations because the references are not given correctly sometimes; therefore, the database has problems collecting all of them under the same section. Table 6 presents some influential books that were found using this technique and that had more than 1000 citations.

All these books are classical books and are very well known in the fuzzy community. The book by Bezdek, with more than 5000

Table 4
Impact factor in fuzzy research.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
TP	2341	2731	3159	3574	3120	3660	4198	4200	4919	5196
TC	35,296	39,957	37,533	38,779	38,659	33,445	29,677	18,743	10,551	2536
TC2	3914	4170	5398	7376	8048	11,358	14,785	14,153	16,478	16,669
TP2	4069	4330	5072	5890	6733	6694	6780	7858	8398	9119
IF	0.961	0.963	1.064	1.252	1.195	1.696	2.180	1.801	1.962	1.827

Abbreviations: TP, total number of paper published in year n; TC, total number of citations received from papers published in year n; TC2, total citations received in year $n-1$ and $n-2$ from year n; TP2, total number of papers published in year $n-1$ and $n-2$; IF, impact factor of year n.

Table 5
50 most cited papers in fuzzy research of all time.

R	J	TC	Title	Author/s	Year	C/Y
1	IC	15,519	Fuzzy sets	LA Zadeh	1965	330
2	SMC	5508	Fuzzy identification of systems and its applications to modeling and control	T Takagi, M Sugeno	1985	204
3	IS	3534	Concept of linguistic variable and its application to AR 1	LA Zadeh	1975	96
4	FSS	3130	Fuzzy sets as a basis for a theory of possibility	LA Zadeh	1978	92
5	SMC	3084	ANFIS: adaptive network based fuzzy inference system	JSR Jang	1993	106
6	SMC	2826	Outline of a new approach to analysis of complex systems and decision processes	LA Zadeh	1973	72
7	SMC	2151	Fuzzy logic in control systems: fuzzy logic controller 1	CC Lee	1990	97
8	IS	1820	Concept of linguistic variable and its application to AR 3	LA Zadeh	1975	49
9	IS	1757	Concept of linguistic variable and its application to AR 2	LA Zadeh	1975	47
10	SMC	1736	On ordered weighted averaging aggregation operators	RR Yager	1988	72
11	IJMMS	1568	Experiment in linguistic synthesis with a fuzzy logic controller	EH Mamdani, S Assilian	1975	42
12	PIEEL	1147	Applications of fuzzy algorithms for control of simple dynamic plant	EH Mamdani	1974	30
13	SMC	1142	Generating fuzzy rules by learning from examples	LX Wang, JM Mendel	1992	57
14	PR	1076	A review on image segmentation techniques	NR Pal, SK Pal	1993	56
15	TFS	1070	An approach to fuzzy control of nonlinear systems: stability and design issues	HO Wang, K Tanaka, MF Griffin	1996	67
16	FSS	1059	Stability analysis and design of fuzzy control systems	K Tanaka, M Sugeno	1992	53
17	FSS	1036	Intuitionistic fuzzy sets	KT Atanassov	1986	40
18	FSS	996	Structure identification of fuzzy model	M Sugeno, GT Kang	1988	41
19	TNN	921	Fuzzy basis functions, universal approximation and orthogonal least-squares learning	LX Wang, JM Mendel	1992	46
20	IS	899	Similarity relations and fuzzy orderings	LA Zadeh	1971	22
21	FSS	872	Fuzzy programming and linear programming with several objective functions	HJ Zimmermann	1978	26
22	JMAA	855	L-fuzzy sets	JA Goguen	1967	19
23	JMAA	813	Probability measures of fuzzy events	LA Zadeh	1968	18
24	TFS	798	Fuzzy logic equals computing with words	LA Zadeh	1996	50
25	TPAMI	779	A validity measure for fuzzy clustering	XLL Xie, G Beni	1991	37
26	TNN	757	Fuzzy ARTMAP: a neural network architecture for incremental supervised learning of analog multidimensional maps	GA Carpenter, S Grossberg, N Markuzon, et al.	1992	38
27	NN	748	Fuzzy ART: fast stable learning and categorization of analog patterns by an adaptive resonance system	GA Carpenter, S Grossberg, DB Rosen	1991	36
28	IJSS	724	Operations on fuzzy numbers	D Dubois, H Prade	1978	16
29	FSS	723	Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic	LA Zadeh	1997	48
30	CMWA	702	A computational approach to fuzzy quantifiers in natural languages	LA Zadeh	1983	24
31	JEI	699	Survey over image thresholding techniques and quantitative performance evaluation	M Sezgin, B Sankur	2004	87
32	AUT	677	Nonlinear black-box modeling in system identification: a unified overview	J Sjoberg, QH Zhang, L Ljung, et al.	1995	40
33	RSE	676	Status of land cover classification accuracy assessment	GM Foody	2002	68
34	JMAA	662	Fuzzy random variables	ML Puri, DA Ralescu	1986	25
35	TFS	658	Fuzzy regulators and fuzzy observers: relaxed stability conditions and LMI based designs	K Tanaka, T Ikeda, HO Wang	1998	47
36	TPAMI	653	Unsupervised optimal fuzzy clustering	I Gath, AB Geva	1989	28
37	PIEEE	645	Neuro-fuzzy modeling and control	JSR Jang, CT Sun	1995	38
38	JMAA	638	Fuzzy topological spaces	CL Chang	1968	14
39	TC	635	Neural network based fuzzy logic control and decision system	CT Lin, CSG Lee	1991	30
40	SMC	611	Fuzzy logic in control systems: fuzzy logic controller 2	CC Lee	1990	28
41	JMAA	594	Fuzzy groups	A Rosenfeld	1971	14
42	TFS	573	Robust stabilization of a class of uncertain nonlinear systems via fuzzy control	K Tanaka, T Ikeda, HO Wang	1996	36
43	IC	569	Definition of nonprobabilistic entropy in setting of fuzzy sets theory	A De Luca, S Termini	1972	14
44	TFS	560	Expected value of fuzzy variable and fuzzy expected value models	BD Liu, YK Liu	2002	56
45	CG	548	FCM: the fuzzy C-Means clustering algorithm	JC Bezdek, R Ehrlich, W Full	1984	20
46	IJGS	541	Rough fuzzy sets and fuzzy rough sets	D Dubois, H Prade	1990	25
47	TC	531	Application of fuzzy logic to approximate reasoning using linguistic synthesis	EH Mamdani	1977	15
48	IJMMS	516	Fuzzy cognitive maps	B Kosko	1986	20
49	FSS	513	Extensions of the TOPSIS for group decision making under fuzzy environment	CT Chen	2000	43
50	TFS	507	On cluster validity for the fuzzy C-means model	NR Pal, JC Bezdek	1995	30

Journal abbreviations are available in Table 2 except for: IJMMS, Int. J. Man-Machine Studies; PIEEL, Proc. of the Institution of Electrical Engineers of London; IJSS, Int. J. Systems Science; JEI, J. Electronic Imaging; AUT, Automatica; RSE, Remote Sensing of Environment; PIEEE, Proc. of the IEEE; TC, IEEE Trans. Computers; CG, Computers & Geosciences.

Table 6
Some influential books in fuzzy research with more than 1000 citations in WoS.

R	TC	Title	Author/s	Year	C/Y
1	5700	Pattern recognition with fuzzy objective function algorithms	JC Bezdek	1981	184
2	3500	Fuzzy set theory and its applications	HJ Zimmermann	1985	139
3	3350	Fuzzy sets and fuzzy logic: theory and applications	GJ Klir, B Yuan	1995	197
4	3200	Fuzzy sets and systems: theory and applications	D Dubois, H Prade	1980	62
5	2850	Neural networks and fuzzy systems	B Kosko	1991	136
6	2100	Possibility theory	D Dubois, H Prade	1988	65
7	1622	Fuzzy sets, uncertainty and information	GJ Klir, TA Folger	1988	68
8	1570	Fuzzy logic for engineering applications	TJ Ross	1995	92
9	1320	Introduction to fuzzy arithmetic: theory and applications	A Kaufmann, MM Gupta	1985	49
10	1120	Theory of fuzzy integrals and its applications (PhD thesis)	M Sugeno	1974	29
11	1080	Introduction to the theory of fuzzy subsets	A Kaufmann	1975	29
12	1030	Essentials of fuzzy modeling and control	RR Yager, DP Filev	1994	57

Same abbreviations than Table 5.

citations, is worth noting. Its great impact is a result of it being at the intersection of pattern recognition and fuzzy systems, two important disciplines. Note that many other well-known books have received several hundreds of citations, but in this section, the focus was to show only those that have a great impact on the fuzzy community by overcoming the 1000 citation threshold.

4. An overview of the most productive and influential authors

Since the introduction of fuzzy set theory by Zadeh, many other important contributions have been made by him and by many other authors. An important issue for obtaining an overview of fuzzy research is to determine the authors with the highest presence and influence. To do so, Table 7 presents a list with the 40 authors with the greatest number of papers in the fuzzy community. An additional list includes authors with smaller numbers of papers but who are highly cited. The aim of these two sections is to see the most active researchers in the fuzzy sciences without forgetting the most influential ones. Note that the number of papers is only indicative because, as mentioned in Section 2, numerous limitations must be considered, such as the size of each paper, the quality of the journal and the number of authors per paper. Therefore, many other indicators are shown in the remainder of the columns to obtain a general overview of each of these very well-known researchers.

As we can see, Zadeh is the most influential author in fuzzy research, with more than 23,000 citations. Moreover, by looking at his entire publication record, we observe that he has received more than 34,000 citations, three times that of the second author. However, he has not published as many papers compared to other authors. Some key issues that explain this is that in the 1960s, 1970s and 1980s, it was not as common to publish many papers, and most of the authors preferred to publish fewer papers but with more content. Moreover, co-authorship was not as common, and most of the papers written by Zadeh were single authored. Thus, if we assume an average of three authors per paper, his publication record (articles + reviews) would be well above 200 and close to the first positions.

Focusing on authors with the highest number of fuzzy papers, Pedrycz obtains the first position, with almost 400 papers; Yager obtains the second one, with 233; and Huang obtains the third one, with 189. Far behind come the next authors in the list, with Herrera in the fourth position, with 143 papers; Chen in the fifth one, with 134; and so on. Looking to the citation record, Sugeno obtains the second position after Zadeh, with 9700 citations, followed by Herrera, Dubois, Prade, Yager and Pedrycz. It is worth noting that many papers in the fuzzy sciences do not use the word fuzzy, and therefore, their citations are not included in the list. However, to provide a complete view, an additional column analyzes the total citations received by each author. Because most of them are strongly focused on fuzzy research and on related issues, this column can also be considered as indicative of the influence of these key authors in this field. In this case, Yager obtains the second position after Zadeh with 11,600 citations, followed by Sugeno, Rosenfeld, Herrera, Prade, Mendel, Dubois and Pedrycz. Excluding Rosenfeld and Mendel, who have also made fundamental contributions in other areas, the remainders of the authors are mainly focused on fuzzy issues.

To observe the influence of the publications of these authors on the nucleus of the fuzzy community, a classification of their papers according to eight journals that are believed to be the main outlets of the fuzzy sciences is presented in Table 8. Note that other very well-known journals could have also been included, such as EJOR and TNN, but because these journals may include papers in other fields, the selection of journals is based on the percentage of papers published on fuzzy research, as shown in Table 3.

As we can see, most of the authors have published more or less in all of these journals. It is worth noting that almost everybody has published in FSS and IS. Only Huang, Kahraman, Reyna, FJ Lin and HO Wang have not published in FSS, and only Huang, Linkens, CT Lin, Reyna, FJ Lin, Juang, Bezdek, Atanassov and Klir have not published in IS. It is worth noting the case whereby Huang and Reyna have not published in any of these eight journals. The main reason is because their research is not focused on the nucleus of fuzzy research, although they use it a lot. As shown, Huang mainly publishes mainly in environmental and engineering journals, and Reyna publishes in psychological journals. Note that although Reyna has been included in the list, it is questionable to what extend her research can be considered inside the fuzzy community. It is also worth mentioning that Zadeh has published in TFS, FSS, SMC, IS, IJIS and IJGS but not in IJAR and IJUFKS.

To obtain a better picture of the authors with the highest numbers of papers in these journals, Table 9 presents a list with the 30 authors with the highest numbers of papers published for each journal. Note that in the case of the tie in the 30th position, how many authors are tied in this position with the same number of papers is indicated.

Yager is the author with the most complete profile in these eight journals, being the author with the highest number of papers in IS, IJAR, IJIS and IJUFKS. Moreover, he obtains the second position in IJGS, third in TFS and TSMC and fifth in FSS. Pedrycz also obtains very remarkable results, being the first one in FSS, second in TFS, fifth in TSMC, eighth in IS and IJIS, thirteenth in IJAR, fourteenth in IJGS and twenty-eighth in IJUFKS. Mendel obtains the first position in TFS, although he only appears in IS in the fourteenth position. A similar problem occurs to Klir, who is the author with the highest number of papers in IJGS but who does not appear in any other journal. Other authors worth noting are Herrera and Dubois, who appear in six journals, Mesiar in five and Prade, Kandel, De Baets and Delgado in four. Note that in this table, all the publications have

Table 7
The most productive and influential authors in fuzzy research.

R	Name	Country	TP-F	TC-F	H-F	H	TP10	TC10	T50	TP	TC
1	W Pedrycz	CAN	395	6173	39	39	301	2263	0	473	6707
2	RR Yager	USA	233	6555	38	48	119	1494	1	377	11,633
3	GH Huang	CAN	189	2130	24	37	457	4003	0	508	6040
4	F. Herrera	SPA	143	7434	46	51	153	3814	0	223	9267
5	SM Chen	TWN	134	2862	28	26	96	937	0	141	2767
6	A Kandel	USA	127	1692	21	22	39	222	0	170	1995
7	D Dubois	FRA	121	7293	46	47	80	1072	2	204	7775
8	EE Kerre	BEL	120	2342	24	24	80	1418	0	132	2379
9	M Sakawa	JAP	115	1542	24	26	42	307	0	192	2131
10	H Prade	FRA	111	6734	42	47	72	626	2	204	8174
11	SK Pal	IND	102	3303	27	32	73	710	1	210	4710
12	ES Lee	USA	101	1394	21	21	60	387	0	151	1650
13	SK Oh	S.K	101	725	13	14	120	510	0	132	749
14	C Kahraman	TUR	98	1852	23	23	97	1771	0	104	1891
15	YB Jun	S.K	98	866	16	16	107	813	0	137	962
16	JJ Buckley	USA	97	3096	28	29	21	181	0	118	3297
17	SC Tong	CHN	97	1904	29	29	93	1623	0	107	2030
18	B De Baets	BEL	97	1272	20	25	245	2174	0	275	2791
19	R Mesiar	SLK	93	1107	20	22	124	1108	0	183	1983
20	B Davvaz	IRAN	89	928	17	20	151	1216	0	156	1365
21	DA Linkens	UK	85	1343	20	25	53	566	0	193	2445
22	ZS Xu	CHN	84	1841	23	32	122	2900	0	127	3188
23	D Ruan	BEL	84	1416	19	21	85	1267	0	109	1647
24	E Herrera-Viedma	SPA	83	4249	34	36	85	1927	0	105	4763
25	K Hirota	JAP	80	1126	18	19	51	253	0	106	1319
26	IB Turksen	TUR	79	1806	22	23	36	353	0	92	1949
27	G Feng	CHN	78	2837	29	34	172	2764	0	235	4435
28	MS Yang	TWN	78	1287	19	19	65	622	0	86	1365
29	CX Wu	CHN	77	666	14	16	46	333	0	102	857
30	M Delgado	SPA	75	1448	18	21	41	240	0	102	1861
31	CT Lin	TWN	74	2841	24	26	72	634	0	127	3170
32	VF Reyna	USA	71	3443	35	38	52	1197	0	99	4064
33	C Quek	SGP	70	1124	20	22	69	813	0	92	1291
34	FJ Lin	TWN	69	1453	22	28	86	896	0	163	2755
35	JM Mendel	USA	67	5130	31	40	46	1288	2	149	7923
36	CF Juang	TWN	67	1836	18	18	60	871	0	69	1840
37	J Kacprzyk	POL	67	1789	21	21	37	368	0	83	1835
38	MA Vila	SPA	67	1290	18	19	33	273	0	73	1518
39	GH Tzeng	TWN	66	1453	24	32	116	2401	0	155	3361
40	JL Verdegay	SPA	63	2320	21	23	23	166	0	70	2638
Other influential authors – ordered by total citations in fuzzy research and a minimum of 20 papers and 1000 citations											
1	LA Zadeh	USA	44	23,436	28	38	12	883	11	95	34,460
2	M Sugeno	JAP	41	9742	22	23	9	27	3	53	9859
3	JC Bezdek	USA	61	4181	29	37	25	367	2	110	6119
4	HO Wang	CHN	30	3560	19	28	131	1069	3	202	4917
5	K Tanaka	JAP	46	3098	29	31	7	63	4	64	3875
6	H Ishibuchi	JAP	53	2996	28	31	44	1020	0	91	4409
7	HJ Zimmermann	GER	37	2793	19	22	4	4	1	53	3466
8	NR Pal	IND	50	2317	18	26	44	567	2	110	3731
9	BD Liu	CHN	44	2167	22	26	51	753	1	81	2483
10	KT Atanassov	BUL	28	1931	11	12	19	103	1	55	1987
11	JM Keller	USA	46	1858	19	23	29	342	0	76	2582
12	O Cordon	SPA	43	1620	21	23	55	887	0	81	1916
13	B Kosko	USA	22	1547	13	21	16	238	1	45	3091
14	DA Ralescu	USA	22	1471	11	16	12	90	1	34	1805
15	R Lowen	BEL	41	1465	18	22	29	78	0	125	2009
16	A Rosenfeld	USA	20	1209	11	41	11	1511	1	337	9373
17	GJ Klir	USA	50	1129	21	28	15	131	0	99	1947
18	L Godó	SPA	47	1119	17	18	34	317	0	68	1234
19	EP Klement	AUT	39	1025	19	21	30	412	0	60	1280

Abbreviations: R, rank; TP-F, TC-F and H-F, total papers, citations and H-index fuzzy; H, H-index; TP10 and TC10, total papers and citations in the last 10 years; T50, number of papers in the Top 50 list shown in Table 4; TP and TC, total papers and citations.

been included, and the table has not been restricted to articles and reviews because the objective of this table is to show the presence of each author in the journal.

5. Most productive and influential institutions

Institutions from all over the world have performed research in the fuzzy sciences. Some of them are very well-known universities, whereas others are more specialized universities with a strong focus on fuzzy research. Table 10 presents a list with of the 50 most influential institutions in fuzzy studies according to the H-index obtained in the 12 journals considered as the most influential ones. Note that only those papers with the keyword "fuzzy" in these journals are considered. In the case of a tie in the H-index, the total number of citations in these journals is considered.

To obtain a complete picture of the research of these institutions, their publications and citations are considered according to the 12 most influential journals and to the total volume of publications.

Table 8
Total papers classified by selected journals.

		TFS	FSS	SMC	IS	IJAR	IJIS	IJUF	IJGS	Oth.F	Total
1	W Pedrycz	25	87	35	20	10	16	6	8	25	473
2	RR Yager	25	55	32	41	17	31	14	31	18	377
3	GH Huang	0	0	0	0	0	0	0	0	0	508
4	F. Herrera	18	30	9	14	10	16	6	0	24	223
5	SM Chen	11	16	14	2	0	1	0	0	2	141
6	A Kandel	6	54	14	24	1	17	2	0	1	170
7	D Dubois	14	32	6	10	14	13	7	8	4	204
8	EE Kerre	9	42	0	10	4	8	6	4	4	132
9	M Sakawa	0	38	8	3	1	0	0	0	1	192
10	H Prade	6	30	2	10	7	20	7	6	3	204
11	SK Pal	0	9	19	25	1	0	0	2	7	210
12	ES Lee	0	10	0	1	0	2	0	0	0	151
13	SK Oh	3	6	1	2	2	1	2	1	2	132
14	C Kahraman	0	0	0	8	0	8	2	1	26	104
15	YB Jun	0	12	0	22	0	0	1	0	15	137
16	JJ Buckley	0	71	0	2	1	3	4	0	17	118
17	SC Tong	9	23	7	8	0	0	0	0	2	107
18	B De Baets	13	38	0	12	6	0	12	0	8	275
19	R Mesiar	9	55	0	20	4	3	11	8	4	183
20	B Davvaz	0	3	0	23	0	0	2	2	36	156
21	DA Linkens	0	9	4	0	0	1	0	0	0	193
22	ZS Xu	3	1	4	12	3	15	7	7	11	127
23	D Ruan	1	8	0	19	2	15	5	2	16	109
24	E Herrera-Viedma	5	14	5	6	4	9	4	0	7	105
25	K Hirota	3	26	5	13	1	4	2	0	12	106
26	IB Turksen	4	24	5	13	5	2	0	0	3	92
27	G Feng	23	10	15	1	0	0	0	0	7	235
28	MS Yang	3	16	3	2	1	7	4	2	4	86
29	CX Wu	0	50	0	11	0	0	1	1	2	102
30	M Delgado	2	26	2	4	7	16	9	0	0	102
31	CT Lin	18	9	18	0	0	0	2	0	5	127
32	VF Reyna	0	0	0	0	0	0	0	0	0	99
33	C Quek	0	1	9	1	0	0	0	0	0	92
34	FJ Lin	7	0	1	0	0	0	0	0	0	163
35	JM Mendel	34	1	3	16	0	1	0	0	3	149
36	CF Juang	14	9	12	0	0	0	0	2	3	69
37	J Kacprzyk	1	12	0	5	1	8	5	3	2	83
38	MA Vila	3	20	0	5	2	15	5	0	1	73
39	GH Tzeng	0	5	3	4	0	0	6	0	8	155
40	JL Verdegay	2	29	1	6	3	8	2	1	3	70
1	LA Zadeh	1	4	4	9	0	1	0	2	0	95
2	M Sugeno	1	26	2	2	1	1	8	0	0	53
3	JC Bezdek	14	4	9	0	2	6	2	1	2	110
4	HO Wang	11	0	6	1	0	0	0	0	1	202
5	K Tanaka	14	6	7	15	0	0	0	0	0	64
6	H Ishibuchi	4	21	3	1	4	0	0	2	8	290
7	HJ Zimmermann	1	15	0	2	0	0	0	1	1	55
8	NR Pal	6	7	10	5	1	7	1	2	3	110
9	BD Liu	6	6	2	5	0	0	7	0	6	81
10	KT Atanassov	0	11	0	0	0	1	4	1	0	55
11	JM Keller	12	7	3	1	1	7	1	1	2	76
12	O Cordon	7	5	2	5	9	4	1	0	7	81
13	B Kosko	1	2	5	2	0	2	0	1	1	45
14	DA Ralescu	0	6	0	6	0	0	3	1	2	33
15	R Lowen	0	19	0	2	0	0	0	0	2	125
16	A Rosenfeld	0	1	21	19	0	0	0	0	0	337
17	GJ Klir	0	16	2	0	4	4	1	35	2	99
18	L Godó	1	10	0	2	7	4	4	0	4	68
19	EP Klement	1	19	0	2	1	1	3	1	1	60

Journal Abbreviations are available in Table 2. OthF = ASC + SC + JIFS + FODM + IJFS + IJCIS + IrJFS + JMVLSC.

The University of Granada obtains the most prominent results for any criteria considered, except for the total citations, where the University of California, Berkeley obtains the first position thanks to Zadeh. It is worth noting that only eight American institutions appear in the top 50, which is very surprising when compared with other disciplines, where the USA sometimes obtains almost all the top 50 positions. China also has eight institutions in the list, and Taiwan has seven. European institutions are very well positioned in this field, with 17 institutions in the top 50, Spain being the most remarkable one with four institutions. Observe that the reason for ranking the institutions according to these 12 journals is because it permits an analysis of the publication and citation record in the most influential journals, avoiding excessive publications and citations in less relevant journals for fuzzy research.

Because this information is very general, it is also interesting to analyze it from a more specific perspective. To do so, Table 11 presents a list of the 30 institutions with the highest number of papers in eight selected journals strongly devoted to the fuzzy sciences. Note that these eight selected journals are the same those in Table 9.

The University of Granada is the most influential institution, with the highest number of publications in FSS, IJAR, IJIS and IJUFKS.

Table 9
Authors with the highest number of papers in eight selected journals.

R	TFS		FSS		TSMC		IS		IJAR		IJIS		IJUFKS		IJGS	
	Author	TP	Author	TP	Author	TP	Author	TP	Author	TP	Author	TP	Author	TP	Author	TP
1	JM Mendel	39	W Pedrycz	105	MC Zhou	71	RR Yager	41	RR Yager	17	RR Yager	31	RR Yager	14	GJ Klir	35
2	W Pedrycz	26	JJ Buckley	79	A Rosenfeld	60	CC Chang	31	S Moral	15	V Kreinovich	20	B De Baets	12	RR Yager	31
3	RR Yager	26	R Mesiar	67	RR Yager	50	K Inoue	25	D Dubois	14	H Prade	20	V Kreinovich	11	Y Takahara	17
4	G Feng	23	A Kandel	58	WB Rouse	49	SK Pal	25	S Zaffalon	12	A Kandel	17	R Mesiar	11	R Belohlavek	11
5	BS Chen	22	RR Yager	57	W Pedrycz	44	A Kandel	24	G De Cooman	11	V Torra	17	M Delgado	9	FE Cellier	11
6	CT Lin	20	D Dubois	54	KR Pattipati	41	B Davvaz	22	PP Shenoy	11	M Delgado	16	WL Hung	9	J Abellan	9
7	JC Bezdek	19	CX Wu	53	BJ Oommen	39	YB Jun	22	LM De Campos	10	F Herrera	16	L Martinez	9	B Jones	9
8	F Herrera	19	H Prade	48	AP Sage	37	W Pedrycz	20	F Herrera	10	W Pedrycz	16	J Torrens	9	Y Lin	9
9	JM Keller	18	DH Hong	42	XL Li	30	R Mesiar	19	B Vantaggi	10	D Ruan	15	T Murofushi	8	G Resconi	9
10	D Dubois	16	EE Kerre	42	SK Pal	30	A Rosenfeld	19	I Couso	9	MA Vila	15	M Sugeno	8	R Rosen	9
11	HX Li	16	B De Baets	41	GM Siouris	29	D Ruan	19	FG Cozman	9	ZS Xu	15	D Dubois	7	J Iijima	8
12	P Shi	15	JX Fang	40	YY Haimes	26	YM Li	18	M Delgado	9	D Dubois	13	J Lawry	7	R Mesiar	8
13	K Tanaka	15	M Sakawa	38	A Kandel	25	I Takanami	17	W Pedrycz	9	T Tambouratzis	13	DF Li	7	RL Oldershaw	8
14	CF Juang	14	NN Morsi	37	CC White	25	JM Mendel	16	A Salmeron	9	J Lee	10	BD Liu	7	W Pedrycz	8
15	E Kim	14	R Fuller	35	D Zhang	24	JN Mordeson	16	P Smets	9	HB Mitchell	10	HT Nguyen	7	A Ramer	8
16	B De Baets	13	F Herrera	32	KS Fu	23	Y Xu	16	M Studeny	9	S Moral	10	H Prade	7	G Sirbiladze	8
17	ZQ Liu	13	E Pap	31	JN Warfield	23	YY Yao	16	O Cordon	8	G Antoniou	9	V Torra	7	BP Zeigler	8
18	SM Chen	12	JL Verdegay	31	CT Lin	22	F Herrera	15	T Denoeux	8	Herrera-Viedma	9	ZS Xu	7	M Zeleny	8
19	HJ Gao	12	K Hirota	30	TH Lee	21	P Shi	15	V Kreinovich	8	HT Nguyen	9	K Fujimoto	6	RC Conant	7
20	HO Wang	12	M Sugeno	30	TT Lee	21	K Tanaka	15	P Vicig	8	G Pasi	9	M Grabisch	6	D Dubois	7
21	NR Pal	11	EP Klement	29	DC Tao	21	O Castillo	13	L Godo	7	G De Tre	8	F Herrera	6	LJ Kohout	7
22	SC Tong	11	V Novak	28	X Yao	21	K Hirota	13	P Larrañaga	7	J Kacprzyk	8	DH Hong	6	I Kramosil	7
23	CS Tseng	11	FG Shi	28	SM Chen	20	A Jaoua	13	J Lawry	7	C Kahraman	8	EE Kerre	6	V Kreinovich	7
24	YC Chang	10	H Tanaka	28	ZW Li	20	S Lee	13	V Loia	7	EE Kerre	8	A Kolesarova	6	YH Ma	7
25	P Gader	10	M Delgado	27	AKC Wong	20	P Melin	13	E Miranda	7	ZM Ma	8	I Kramosil	6	A Nebot	7
26	R Krishnapuram	10	IB Turksen	26	H Hemami	19	IB Turksen	13	TD Nielsen	7	O Pons	8	G Mayor	6	V Novak	7
27	R Mesiar	10	E Czogala	25	KW Hipel	19	J Aoe	12	H Prade	7	JL Verdegay	8	E Pap	6	ZS Xu	7
28	XJ Zeng	10	JN Mordeson	24	WA Gruver	18	GR Chen	12	E Trillas	7	JF Baldwin	7	W Pedrycz	6	M Bunge	6
29	O Cordon	9	DX Zhang	24	KM Sim	18	B De Baets	12	Y Xiang	7	P Bosc	7	J Recasens	6	M Higashi	6
30	6 authors	9	6 authors	23	3 authors	17	5 authors	12	7 authors	6	6 authors	7	GH Tzeng	6	5 authors	6

Abbreviations are available in Table 2.

Table 10
The most influential institutions in fuzzy research.

R	Name	Country	HF12	TPF12	TCF12	TPF	TCF	HF
1	Univ Granada	SPA	55	334	10,894	556	13,268	60
2	Nat Chiao Tung Univ	TWN	40	167	5739	516	9995	49
3	City Univ Hong Kong	CHN	39	158	4914	432	8394	46
4	Iona College	USA	36	182	7219	241	8118	38
5	Univ Toulouse III	FRA	36	81	5481	161	7271	47
6	Tsing Hua Univ	CHN	34	123	4024	459	6405	39
7	Univ Southern California	USA	33	75	5195	137	7209	39
8	Osaka Prefecture Univ	JAP	33	74	4234	133	4764	35
9	UC Berkeley	USA	32	66	20,952	193	31,492	52
10	Polish Academy Sciences	POL	31	155	3449	377	4955	35
11	Ghent Univ	BEL	30	208	3642	390	5533	36
12	Indian Statistical Inst	IND	28	113	2898	255	5570	34
13	Nat Cheng Kung Univ	TWN	28	97	2280	559	6660	39
14	SUNY Binghamton	USA	28	62	1129	100	2036	24
15	Tokyo Inst Tech	JAP	27	92	10,343	189	11,107	29
16	U Alabama Birmingham	USA	27	81	2822	111	3401	30
17	Univ Jaen	SPA	27	65	2771	157	3340	30
18	Univ Alberta	CAN	25	149	2297	370	4043	31
19	Delft Univ Tech	NET	25	45	2325	130	3956	31
20	Nat Univ Singapore	SGP	25	77	1355	349	4844	38
21	Harbin Inst Tech	CHN	24	142	1717	352	3049	30
22	Nat Central Univ	TWN	24	81	1670	299	3691	35
23	Chinese Univ Hong Kong	CHN	24	67	1420	134	2316	28
24	Nat Taiwan U Sci Tech	TWN	23	70	2026	420	4781	35
25	Univ Manchester	UK	23	64	1844	184	3488	32
26	Hong Kong Polytech Univ	CHN	23	102	1821	478	5329	34
27	Univ Toronto	CAN	23	62	1639	205	3708	30
28	Yonsei Univ	S.K	23	58	1560	195	2415	27
29	Univ Oviedo	SPA	23	113	1385	236	2385	29
30	Nat Tsing Hua Univ	TWN	22	61	2546	219	4346	32
31	Univ Manitoba	CAN	22	73	1862	154	2852	28
32	Univ Missouri Columbia	USA	22	54	1635	128	3215	33
33	Nanyang Tech Univ	SGP	22	73	1575	419	5324	36
34	Northeastern Univ China	CHN	22	79	1349	253	2676	27
35	RWTH Aachen Univ	GER	21	41	3022	96	3441	23
36	Chinese Academy Sciences	CHN	21	50	1472	422	3945	31
37	Czech Academy Sciences	CZE	21	87	1209	235	2334	25
38	Univ Southern Florida	USA	20	87	1682	165	3465	31
39	De Montfort Univ	UK	20	36	1653	79	2075	23
40	Korea Adv Inst Sci Tech	S.K	20	78	1372	256	2832	27
41	Hungarian Academy Sci	HUN	20	42	1341	95	2314	28
42	Hebei Univ	CHN	20	70	1241	146	1905	22
43	Univ Ostrava	CZE	20	83	1192	131	1660	22
44	Chung Yuan Christian U	TWN	20	66	1175	251	3681	34
45	Univ Publ Navarra	SPA	20	62	1167	84	1242	20
46	Slovak U Tech Bratislava	SLK	20	77	1124	121	1343	21
47	Kansas State Univ	USA	20	41	1079	169	2687	29
48	JK Univ Linz	AUT	20	50	1014	74	1217	21
49	Chinese Culture Univ	TWN	20	42	1001	92	1583	23
50	Vrije Univ Brussels	BEL	19	37	1525	93	2577	27

Abbreviations: HF12, TPF12 and TCF12 – H-index and total papers and citations in 12 selected journals in fuzzy research; TPF, TCF and HF – total papers, citations and H-index in fuzzy research. 12 journals = FSS + TFS + SMC + IS + EJOR + TNN + JMAA + IJAR + IJIS + IJUFKS + IJGS + JIFS = 12,657 papers.

Moreover, it obtains the second position in TFS, the sixth position in IJGS and the eighth position in IS. Some other very influential institutions are those linked to the most influential authors, such as Ghent University (De Baets and Kerre), Iona College (Yager) and the University of Alberta (Pedrycz). It is worth mentioning that there is a high degree of dispersion, and many countries are very influential in this field, especially USA, China, Taiwan and Spain. This is of great interest because it implies that there are very qualified researchers all over the world. Note that in other fields, the USA sometimes dominates all the top positions, such as in management [12] and economics [39].

6. Analysis by country

In a knowledge-intensive economy, research is a fundamental variable that determines the growth of a country. In this section, the objective is to analyze fuzzy research according to a geographical distribution. It is worth noting that several peculiarities may appear because some researchers move from one country to another. Therefore, an author in this situation will have publications from two different countries. This is of great relevance especially in the USA and in the UK because these countries have attracted many researchers from all over the world. Therefore, their publication record is much higher than it would be if only citizens from the country are considered. Because each institution is seen as a team inside the country, the focus is on publications signed under the name of the institution and not based on the original nationality of the researcher. The results are shown in Table 12. Note that the ranking is based on the H-index of the country in fuzzy research.

The USA is the most influential country and includes the father of fuzzy logic, Lotfi Zadeh. It has received more than twice the number of citations of the second country and has published about half of the most highly cited papers. In second place appears China, with a similar number of papers than the USA but with fewer citations and with a lower H-index. The main reason for this, apart from Zadeh, is that most of the publications from China have come from the

Table 11
Institutions with the highest number of papers in eight selected journals.

R	TFS		FSS		TSMC		IS		IJAR		IJIS		IJUFKS		IJGS	
	Institution	TP	Institution	TP	Institution	TP	Institution	TP	Institution	TP	Institution	TP	Institution	TP	Institution	TP
1	City UHK	62	U Granada	136	Purdue U	134	U Maryland	60	U Granada	61	U Granada	76	U Granada	41	SUNY	81
2	U Granada	43	Ghent U	124	U Virginia	117	N Ch Tung U	58	Ghent U	25	Iona Coll	33	Ghent U	26	Czech AS	34
3	U So Calif	40	U Alabama	99	Chinese AS	116	City UHK	57	U Oviedo	21	Polish AS	28	Czech AS	20	Iona Coll	32
4	N Ch Tung U	33	Slovak UT	90	Georgia IT	116	Indian Stat I	54	Czech AS	20	U Toulouse III	25	Slovak UT	17	Tokyo IT	19
5	U Missouri	32	Harbin IT	85	U Maryland-C	113	Indian IT	53	Sap U Rome	18	CSIC	23	New Mexic SU	16	PU Olomouc	17
6	U Alberta	31	Columbia U	85	MIT	110	Chinese AS	52	Iona Coll	17	U Texas	22	U Jaen	15	U Granada	14
7	HK Pol U	28	Czech AS	80	Ohio SU	103	Korea AIST	48	U Utrecht	17	Ghent U	21	U Pub Navarra	15	Ghent U	13
8	Ghent U	27	Indian IT	78	City UHK	99	U Granada	47	U Toulouse III	16	Southeast U	17	Iona Coll	14	U Ostrava	13
9	Yonsei U	27	Sichuan U	73	Nanyang TU	99	Ghent U	45	Aalborg U	15	U Pol Madrid	17	Tokyo IT	12	Louisiana SU	12
10	Iona Coll	26	U Delhi	69	N Ch Tung U	98	U Delhi	45	Polish AS	15	U So Florida	17	U Almeria	11	U Arizona	12
11	N Tsing H U	25	Shaanxi NU	68	HK Pol U	93	Shanghai JTU	43	U Salerno	15	Chinese UHK	15	U Texas	11	U Illinois	12
12	Harbin IT	20	Nat Ch Tung U	67	NJ IT	91	U Texas	43	U Kansas	13	New Mexic SU	15	U Oviedo	10	U Oklahoma	11
13	N Cheng K U	20	U Novi Sad	67	Rensselaer PI	91	Iona Coll	39	CNR	12	CNR	14	Columbia U	9	Chinese AS	10
14	N Taiwan UST	20	Tokyo IT	62	NU Singapore	87	N Tsing H U	37	U Bristol	12	N Central U	13	N Ch Tung U	9	Hiroshima U	8
15	Polish AS	18	U Ostrava	59	Chinese UHK	83	U So Calif	35	Carnegie M U	11	U Paris 6	13	Polish AS	9	N Cheng K U	8
16	Tsinghua U	18	Iona Coll.	57	U Michigan	83	Harbin IT	34	U Alberta	11	U Alberta	13	U Paris 6	9	Portland SU	8
17	UW Florida	18	Nanjing NU	57	Carnegie M U	81	SUNY	34	Euro Cent SC	10	U Bristol	13	U Bristol	9	Slippery Rock U	8
18	N Central U	17	Polish AS	57	Indian Stat I	79	U Illinois	34	U Sao Paulo	10	UC Berkeley	13	U Trieste	9	Slovak UT	8
19	Nanyang TU	16	U Alberta	53	U Connecticut	74	Xian JU	34	U Perugia	10	UP Catalunya	13	Amirkabir UT	8	Brunel U	7
20	Northeastern U	16	U Oviedo	47	U Illinois-Urb	74	Yonsei U	33	U Pol Madrid	10	CEN SCK	12	CSIC	8	C U Prague	7
21	U Manchester	16	U Manitoba	46	Indian IT	73	N Chung C U	31	U Trieste	10	U Missouri	12	U Pol Madrid	8	Fordham U	7
22	Chinese UHK	15	U Toulouse III	45	U Waterloo	73	Purdue U	31	CSIC	9	U Salerno	12	JK U Linz	7	IJ Tbilisi SU	7
23	N Chung H U	15	Hebei U	43	U Alberta	72	U Alberta	31	IDSIA	9	U Kansas	10	N Hsinchu	7	Tongji U	7
24	U Jaen	15	JK U Linz	43	UC Berkeley	70	Xidian U	31	Osaka Pref U	9	U N Carolina	10	U Balearic Isl	7	UC Berkeley	7
25	U So Florida	15	Osaka Pref U	43	Ben Gurion U	69	Feng Chia U	30	Southeast U	9	Czech AS	9	U Novi Sad	7	UP Catalunya	7
26	Chung Yuan U	14	U Calcutta	41	G Mason U	68	Nanyang TU	30	U Almeria	9	NU Singapore	9	U Montreal	7	Wroclaw UT	7
27	Delft UT	14	Eotvos Lor U	40	SUNY	67	N Sun Yat S U	29	U Castilla M	8	U Jaen	9	U Toulouse III	7	Dartmouth Coll	6
28	U Glamorgan	14	Florida SU	39	Xidian U	67	UC Berkeley	29	U Durham	8	U Maryland	9	Aalborg U	6	McGill U	6
29	UC Berkeley	14	Korea AIST	39	U Toronto	65	U Tokushima	29	U Jaen	8	U Ulster	9	Akdeniz U	6	Polish AS	6
30	U Toulouse III	14	Silesian UT	39	U So Calif	64	Yamaguchi U	29	2 institutions	8	3 institutions	9	10 institutions	6	7 institutions	6

Abbreviations are available in Table 2.

Table 12
The most influential countries in fuzzy research.

Rank	Name	TP	TC	>500	>250	>100	>50	TP10	TC10	TP/I	TC/I	H
1	USA	8704	170,775	28	76	267	763	4186	43,683	27.6	541.69	143
2	PR China	8767	70,857	1	7	57	245	7179	48,587	6.47	52.33	86
3	UK	3037	48,364	4	13	67	199	1867	21,239	48.2	767.68	86
4	Taiwan	5387	62,252	2	9	61	250	3984	31,483	234.21	2706.6	84
5	Japan	2780	44,478	6	12	58	135	1157	8358	21.88	350.22	79
6	France	1952	35,606	4	11	50	128	1170	9423	30.03	547.78	75
7	Canada	2644	34,329	0	5	39	130	1792	15,319	75.54	980.82	74
8	Spain	2829	32,822	0	6	39	121	2043	16,626	61.5	713.52	68
9	Germany	2076	26,318	1	5	28	99	1032	8857	25.62	324.91	64
10	India	3006	26,058	1	3	25	85	2079	12,906	2.48	21.53	62
11	Belgium	827	13,772	0	1	16	65	492	5893	75.18	1252	57
12	Australia	1251	16,000	0	2	22	67	796	6203	56.86	727.27	56
13	S. Korea	2347	19,598	0	1	14	68	1641	9057	46.94	391.96	55
14	Italy	2077	21,849	0	3	15	61	1370	10,003	34.61	364.15	54
15	Netherlands	570	12,051	0	5	23	60	344	3911	35.62	753.18	54
16	Poland	1295	15,354	0	5	18	58	886	6189	34.07	404.05	52
17	Turkey	2225	17,394	1	0	9	38	2042	14,962	29.66	231.92	46
18	Singapore	789	10,097	0	0	7	37	481	5183	157.8	2019.4	45
19	Greece	880	10,600	0	1	7	37	634	5098	88	1060	44
20	Hungary	317	4959	0	0	7	28	169	2097	31.7	495.9	37
21	Austria	387	4896	0	0	1	18	231	2216	48.37	612	36
22	Iran	2417	10,528	0	0	0	17	2306	9460	31.38	136.72	34
23	Brazil	745	6878	0	2	10	19	570	4099	3.86	35.63	33
24	Finland	410	5055	0	1	9	19	219	1685	82	1011	33
25	Czech Rep.	564	5045	0	0	2	13	439	3102	56.4	504.5	33
26	Sweden	266	5294	1	2	12	19	157	1506	29.55	588.22	32
27	N. Zealand	203	3568	0	1	8	16	131	1676	50.75	892	32
28	Switzerland	300	3917	0	0	4	17	202	1783	37.5	489.62	31
29	Israel	292	3666	0	0	5	13	151	1358	36.5	458.25	27
30	Egypt	532	3516	0	1	3	7	311	1738	6.40	42.36	25

Abbreviations: TP and TC, total papers and citations; >500, >250, >100, >50, number of papers with more than 500, 250, 100 and 50 citations; TP10 and TC10, total papers and citations in the last 10 years; TP/I and TC/I, total number of papers and citations divided by the total number of inhabitants of the country; H, H-index of the country in fuzzy research.

last 10 years. As shown in the columns analyzing the last 10 years, China has published more papers than the USA and is receiving a higher number of citations, although the citations/papers ratio is lower. The third position goes to the UK, which is very close to China according to the H-index, although it has published fewer papers, and the differences seem to increase over time. Taiwan also appears very close in the fourth position, and it appears that it will soon surpass the UK because it is publishing a higher volume of papers and receiving more citations. Japan, France, Canada and Spain, all of which have a very remarkable publication and citation records, appear in the next positions.

7. Conclusions

A general overview of fuzzy research using bibliometric techniques has been presented. From a general perspective, the results are in accordance with our common knowledge. First, there is a high degree of dispersion in this research field, with many influential countries. Initially, the USA was the most influential country thanks to Lotfi Zadeh, the father of fuzzy logic. However, today, many countries are very influential thanks to newly emerging research groups that are appearing all over the world. It is clear that Zadeh has been the most influential author by far. His first fuzzy paper is among the most cited papers of all time in all the sciences, and currently, it is the most cited paper of all time in computer science. His importance has given the University of California, Berkeley the status as the most influential institution in this area, and it has produced some of the most popular researchers in the field. Today, the Berkeley Initiative for Soft Computing (BISC) is connected to thousands of researchers all over the world, and most fuzzy researchers are influenced by it in some way. Apart from Zadeh, many other influential researchers are from the USA, including Yager, Bezdek, Mendel and Kandel. They are very well positioned in the most influential journals in the field, although a higher dispersion compared to other research fields is found [12], where American universities almost have a monopoly.

However, an important issue to note is that most of the influential institutions working on fuzzy theories do not appear in the top 100 of general university rankings available for the general public, such as the Academic Ranking of World Universities (ARWU), with the exception of Berkeley in the top 10 and at a lower level, the University of Toronto, the University of Manchester, the University of Southern California and Ghent University in the top 100. Note that when focusing on more specialized rankings in engineering and computer science, some other Asian institutions appear in the top 100, including the City University of Hong Kong, the Tokyo Institute of Technology, the Korea Advanced Institute of Science and Technology, Tsinghua University, Hong Kong Polytechnic University, National Tsing Hua University, National Chiao Tung University, National Cheng Kung University, Nanyang Technological University, Harbin Institute of Technology and the Chinese University of Hong Kong. Therefore, it is clear that in Asia, fuzzy research is receiving a substantial amount of attention, whereas in Europe and especially in America, there seems to be more skepticism.

Focusing on European researchers, they have also exerted a strong influence in the fuzzy sciences, having 17 institutions in the top 50 and being responsible for Fuzzy Sets and Systems, most likely the most popular journal in this field. Currently, Spain is exhibiting the strongest increase since the 1990s, having four very influential institutions. Some other very influential institutions are those connected to key researchers in fuzzy theories, including the Paul Sabatier University of Toulouse III (Dubois and Prade), the Polish Academy of Sciences (Kacprzyk and, partially, Pedrycz) and Ghent University (De Baets and Kerre). It is also worth noting that many Western and Nordic countries have less influence than in other disciplines, while less developed countries, such as Eastern and Southern countries, obtain a better position.

Countries in the rest of the world are still lagging behind, although in fuzzy research, it appears that more developing countries are doing significant research compared to other fields, and some of them, including India, Turkey, Iran, Brazil and Egypt, are already obtaining remarkable results. Thus, it appears that they will continue increasing their presence in this area, reaching more significant positions in the scientific community. Moreover, the future of fuzzy theories seems to be very healthy and productive because many new developments are appearing in the scientific community and because many potential applications can be developed. Therefore, it is expected that the number of publications and citations will continue to grow, consolidating more journals in this area and involving more people all over the world.

Although this paper has provided a general bibliometric overview of fuzzy research, it is worth noting that there are some limitations that should be noted. First, the information presented here is only informative and only gives a general orientation of the most productive and influential research. However, many peculiar cases may appear due to the specific research nature considered. For example, some researchers may obtain a higher number of papers due to a high degree of co-authorship, while some others may usually publish single-authored papers. Therefore, the publication of 10 papers from the first type of author is not equivalent to the publication of 10 papers from the second one. In contrast, citations are also influenced by these issues because, for example, a research area may be more specific than another area and may therefore be less cited. This is very common in the fuzzy sciences because it is an interdisciplinary field that encompasses researchers from many disciplines, with different citation rates between them. Furthermore, a substantial amount of key information may be omitted when addressing bibliometric information based on publications and citations because a scientific field also depends on other issues that cannot be directly quantified, such as the involvement in journals, conferences and associations. Therefore, this paper attempts to identify some key research in fuzzy theories but with the only objective of being informative. However, it is worth noting that other relevant information could be included. In addition, inside the information provided in the paper, many differences regarding the rankings could appear, depending on the specific issues considered, that affect each paper, journal, author, institution and country.

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