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A bibliometric analysis of Iranian Journal of Fuzzy Systems (2007-2020)

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Abstract

Iranian Journal of Fuzzy Systems (IJFS) is an international journal, based on the WoS core collection, this paper uses bibliometric methods and tools (VOSviewer and Bibliometrix) to analyze the publications of IJFS from 2007 to 2020. A total of 716 publications are analyzed. Firstly, according to the basic information of the publications, including the type of publications, the number of publications, the number of citations, the average number of citations and the h-index, we conduct a general statistical analysis to explore the basic characteristics and internal structure of the publications. Afterwards, by studying the citation structure of publications, this paper analyzes which groups and fields the journal is more concerned about. For the journal itself, we combine the number of citations and the number of publications to identify the most popular publications, the most productive and influential authors/institutes/countries/regions. In the collaboration network analysis, we map the collaboration network of countries/regions, institutes and authors to explore the different levels of collaboration. The co-citation network of the journal is studied to explore the relationship between IJFS and other international academic journals. In the analysis of keywords, we discuss the development trend and hot topics of keywords over time through co-occurrence analysis, word growth graph and thematic evolution analysis. Finally, based on the above analysis, we discuss the problems and challenges that the journal may face, and some main conclusions are drawn. This study has certain reference value for the further development of the related researchers scientific research and the journal.

Keywords: *Iranian Journal of Fuzzy Systems*, bibliometric analysis, collaboration networks, thematic evolution.

1 Introduction

Iranian Journal of Fuzzy Systems (IJFS) is an international journal (print ISSN: 1735-0654, online ISSN: 2676-4334), aims to provide an international forum for refereed original research works in the theory and applications of fuzzy sets and systems in the areas of foundations, pure mathematics, artificial intelligence, control, robotics, data analysis, data mining, decision making, finance and management, information systems, operations research, pattern recognition and image processing, as introduced in the homepage of the journal [14]. IJFS is published and managed by the University of Sistan and Baluchistan. The honorary Editor-in-Chief, Editor-in-Chief, and managing editor are Prof. M. Mashinchi, Prof. M. M. Zahedi, and Prof. R. A. Borzooei, respectively, who are all outstanding researchers in mathematics. The first article of the journal was published in 2004, and more than 740 papers have been published by 2020. The journal has been available on Web of Science (WoS) since 2007, by the end of 2020, there are 716 articles that can be retrieved on the WoS, with an impact factor of 2.276 by Journal Citation Reports (2019). The main research direction of the journal is mathematics, involving two categories, namely mathematics (15/325) and applied mathematics (29/261). Therefore, a comprehensive bibliometric analysis of IJFS is necessary and meaningful. This research can explore the development of IJFS from multiple perspectives and understand the evolution of related research directions.

Bibliometrics, first named by Pritchard, mainly uses statistical and mathematical methods to analyze bibliography and explore the characteristics and rules of bibliography [25]. It can characterize the development in a research field or capture the changes of a specific journal [35]. The bibliometric method is a good aid for scholars who want to

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understand the relevant fields or journals. It can map the field of study without subjective bias by guiding researchers to their most influential work during the literature review, even before the reading begins [43].

At present, bibliometric analysis has been widely applied to research in different facets, including intuitionistic fuzzy sets [24], fuzzy decision making [3], support vector machines [42], deep learning [10], operations management [30], Covid-19 [6], etc. In addition, bibliometrics has been used in recent years to analyze specific journals, such as *Journal of Business Research* [22], *European Journal of Operational Research* [16], *European Journal of Marketing* [19], *Journal of Business & Industrial Marketing* [31], *International Journal of Intelligent Systems* [20], *Computers & Industrial Engineering* [5], *Production Planning & Control* [1], *Journal of Knowledge Management* [12], *International Journal of Logistics Research and Applications* [34] and *International Journal of Fuzzy Systems* [28].

In this paper, bibliometric techniques are employed to provide an overview of IJFS from 2007 to 2020. To be specific, this paper mainly makes the following contributions: (1) Through the general statistical analysis, the basic characteristics of periodical publications are explained, and the types, annual trends, citation structures of publications are provided. On this basis, the internal structure, development trend, popularity of articles, and productivity and influence of authors/sources/institutes/countries/regions are described. (2) According to the nodes, links and total link strength in the collaboration network, the collaboration network analysis is carried out on countries/regions, institutes and authors to explore the connection and cooperative relationship at different levels. And journal co-citation analysis is performed to find correlations between journals. (3) According to the co-occurrence network, word growth graph and thematic evolution of keywords in different periods, the development of hot topics and research themes of IJFS is discussed. (4) We debate the problems and challenges that IJFS may face, and summarize the research results of this journal from 2007 to 2020 for further research by scholars in relevant fields.

2 Bibliometric methods and data source

More and more research based on bibliometrics has been conducted in recent decades. Current popular bibliometric tools and techniques include CiteSpace [7], VOSviewer [32], Bibliometrix [2], Pajek [27], CitnetExplorer [33], HistCite [18], etc. Relying on these tools and methods, extensive bibliometric research has been carried out. In this study, VOSviewer and Bibliometrix are used. VOSviewer is used to implement collaboration network analysis, co-citation analysis and keyword co-occurrence analysis. It is a Java application developed by Van Eck, Nees Jan et al. VOSviewer pays special attention to the graphical representation of bibliometric maps, it can display large bibliometric maps in an easy-to-understand manner [32]. Bibliometrix is used to perform keyword co-occurrence analysis, word development and thematic evolution analysis, it is an R tool developed by Massimo Aria and Corrado Cuccurulol for performing comprehensive scientific map analysis [2].

For data source, in this paper, we collect data from the Web of Science, which is owned by the company Thomson & Reuters Corporation. WoS is one of the most widely used databases in academia [9]. Since IJFS's first publication in WoS was published in 2007, we analyze IJFS's publications from 2007 to 2020, and search for publication names by indexing Iranian Journal of Fuzzy Systems. Data are exported in plain text and tab-delimited (UTF-8) format with detailed information about publications, including authors, titles, sources, abstracts and references. The number of citations for all publications was retrieved from the WoS core collection on January 3, 2021.

3 Characteristics of publications in the journal

3.1 Basic information of publications in IJFS

As of 2020, IJFS has a total of 716 publications that can be retrieved in WoS, including 5 types, namely article, meeting, editorial, biology and review. It should be noted that here meetings (17, 2.374%) are also included in the article category. Specifically, among 716 publications, articles account for a large proportion (708, 98.89%), followed by editorial (5, 0.698%), biography (2, 0.279%) and review (1, 0.140%), as shown in Fig. 1. It reflects the various article types of IJFS, the proportion of which meets the requirements of article-based journals.

Fig. 2 shows the trends in the number of publications (NP) and the number of citations (NC) of IJFS from 2007 to 2020. In Fig. 2(a), overall, NP presents a steady and slow upward trend. To be more specific, NP before 2011 was less than 30, and NP from 2011 to 2017 remained at around 55. In the past three years, NP has further increased, reaching a maximum of 84 in 2019.

In Fig. 2(b), NC shows an upward trend as a whole. Specifically, NC has gone through two stages of growth. From 2007 to 2015, it presented a stable and slow growth trend. NC stabilized at around 180 from 2012 to 2015, and then entered the second rising stage, showed a steady and rapid upward trend from 2015 to 2020, reached a maximum of 830

in 2019. Combining the development trends of NP and NC, IJFS focuses on the quality of manuscripts and controls NP every year. Besides, with the growth of the number of citations in recent years, more and more scholars have begun to pay attention to IJFS.

The authors h-index is an author-level metric that can be used to measure both the productivity and citation impact of publications within a scientist or scholar [13]. The average number of citations (AC) and h-index reflect the influence and recognition of publications in the journal [36]. Fig. 3 reflects the changes in h-index and AC of publications in IJFS from 2007 to 2020. As far as the h-index is concerned, the h-index in 2012 was the highest at 12, followed by 11 in 2009 and 2011. As for AC, it peaked at 10.48 in 2009, followed by 9.93 in 2010 and 9.09 in 2008. Based on the h-index and AC, publications from 2008 to 2012 are more influential and recognizable. On the other hand, the low h-index and AC in the past two years did not mean that there are no excellent studies. The number of citations is dynamic, and it takes some time for publications to be widely recognized and cited [17].

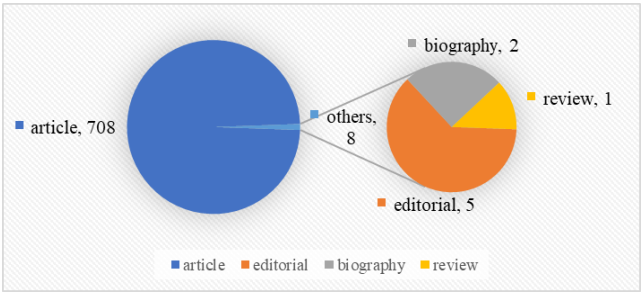


Figure 1: The type of distribution of documents in IJFS

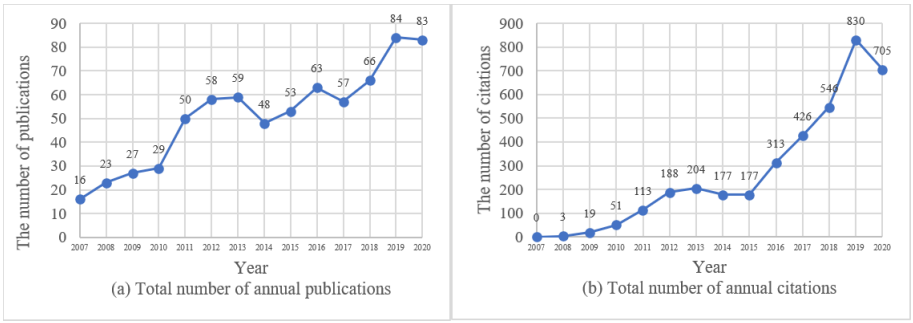


Figure 2: The number of publications and citations from 2007 to 2019

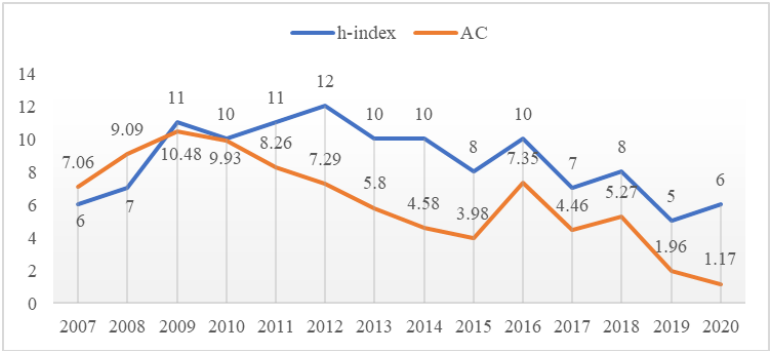


Figure 3: The h-index and AC of publications in IJFS

Table 1 provides the number of citations to articles per year and lists the number of publications exceeding a certain threshold, which is a way to identify the number of publications that have a certain level of influence [21]. According

Table 1: Citation structure in IJFS according to WoS

Year	NP	NC	AC	h-index	100	50	20	10	5	1
2007	16	0	7.06	6	0	0	1	5	6	15
2008	23	3	9.09	7	0	0	4	6	15	23
2009	27	19	10.48	11	0	0	3	12	18	24
2010	29	51	9.93	10	0	0	4	10	23	28
2011	50	113	8.26	11	0	1	4	12	26	48
2012	58	188	7.29	12	0	0	4	16	31	50
2013	59	204	5.8	10	0	0	5	10	22	52
2014	48	177	4.58	10	0	0	0	10	18	36
2015	53	177	3.98	8	0	0	1	6	16	43
2016	63	313	7.35	10	1	2	6	11	18	50
2017	57	426	4.46	7	0	0	2	5	17	44
2018	66	546	5.27	8	1	2	3	7	9	48
2019	84	830	1.96	5	0	1	2	2	5	40
2020	83	705	1.17	6	0	0	0	0	2	17
total	716	3752			2	6	39	112	226	518
percentage	100%				0.28%	0.84%	5.45%	15.64%	31.56%	72.35%

to the citation report on WoS, from 2007 to 2020, IJFS published 716 papers, with a total citation frequency of 3763, h-index of 25, and AC of 5.26. It is worth noting that two publications receive more than 100 citations, and both are high-cited papers. In addition, 0.84% of publications receive more than 50 citations, and 31.56% receive more than 5 citations. More than 70% of publications are cited at least once.

3.2 The citation structure of publications in IJFS

Table 2: Top 15 journal/institute/country/region of cited publications in IJFS

R	Journal	N	Country/ Region	N	Institute	N
1	Journal of Intelligent Fuzzy Systems	394	China	941	Islamic Azad Univ.	132
2	Iranian Journal of Fuzzy Systems	297	Iran	621	Sichuan Normal Univ.	98
3	Soft Computing	117	India	378	Beijing Inst. of Technology	84
4	Fuzzy Sets and Systems	88	Turkey	220	Shahid Bahonar Univ. of Kerman Sbuk	75
5	Mathematics	63	Pakistan	188	Univ. of Yazd	71
6	IEEE Access	50	Saudi Arabia	124	King Abdulaziz Univ.	55
7	International Journal of Fuzzy Systems	48	Spain	91	Univ. of Tehran	55
8	Symmetry Basel	46	South Korea	82	Ton Duc Thang Univ.	49
9	Applied Soft Computing	35	The U. S.	75	Univ. of Punjab	45
10	IEEE Transactions on Fuzzy Systems	32	Malaysia	68	Ferdowsi Univ. Mashhad	39
11	Neural Computing Applications	31	Vietnam	64	Payame Noor Univ.	38
12	Computational Applied Mathematics	28	Romania	61	Univ. of Electronic Science Technology	36
13	International Journal of Knowledge Based and Intelligent Engineering Systems	27	Taiwan	43	Vidyasagar Univ.	35
14	Mathematical Problems in Engineering	25	Italy	42	Univ. Birjand	34
15	Filomat	24	Egypt	39	Shahed Univ.	32

Table 2 describes the top 15 journals, institutes, countries/regions and authors that cite IJFS. The number 1 is *Journal of Intelligent Fuzzy Systems*, followed by the *Iranian Journal of Fuzzy Systems*, *Soft Computing*, *Fuzzy Sets and Systems and Mathematics*, with 394, 297, 117, 88 and 63 publications, respectively. It can be seen from Table 2 that most journals that frequently refer to IJFS are related to fuzzy systems and mathematics.

Among the top 15 countries/regions, China (941) is ranked first, followed by Iran (621), India (378), Turkey (220) and Pakistan (188). In terms of the institute, these 15 institutes are all from Asia, with Islamic Azad University in the leading position, citing 132 publications of IJFS, followed by Sichuan Normal University and Beijing Institution of Technology. Note that 8 of the top 15 institutes are from Iran and 2 of the top 3 are from China. This means that Iranian and Chinese scholars pay more attention to IJFS.

3.3 The most popular publications in IJFS

Table 3 shows the top 10 most popular publications in IJFS since 2007. The most cited publication is *Hesitant fuzzy linguistic arithmetic aggregation operators in multiple attribute decision making*, published in 2016, written by Hayat, T. et al. [39]. In this paper, they proposed some methods to solve the problem of multi-attribute decision-making under hesitant fuzzy linguistic environment. The second most cited publication is Wei, G. W.'s paper on some similarity measures and applications of picture fuzzy sets [38]. In this paper, the cosine similarity metric and set theory similarity metric were introduced to measure the similarity between picture fuzzy sets. *Fuzzy Soft Set Theory and Its Applications* authored by Cagman, N. et al. ranked third [4], a fuzzy soft set and its related properties were defined in their work. Moreover, they gave the fuzzy soft aggregation operator, which can construct more efficient decision-making methods. The top 3 publications are cited 110, 104 and 87, respectively. Only the first two publications are cited more than 100 times, which corresponds to what we mentioned in Subsection 3.1.

From Table 3, we can find that among the top 10 most cited publications, Xiu, Z. Y. and Pang, B. have two papers respectively. Also, six of the top 10 papers are high-cited papers, and all of the six papers were published in the last five years, indicating that publications in IJFS are of higher quality and are increasingly recognized by experts and researchers.

Table 3: The top 10 most popular publications in IJFS from 2007-2020

R	Title	Author(s)	Year	NC	Is it a high-cited paper
1	Hesitant fuzzy linguistic arithmetic aggregation operators in multiple attribute decision making	Wei, G.; Alsaadi, F. E.; Hayat, T.; Alsaedi, A.	2016	110	✓
2	Some similarity measures for picture fuzzy sets and their applications	Wei, G. W.	2018	104	✓
3	Fuzzy soft set theory and its applications	Cagman, N.; Enginoglu, S.; Citak, F.	2011	87	
4	A new vector valued similarity measure for intuitionistic fuzzy sets based on OWA operators	Fei, L.; Wang, H.; Chen, L.; Deng, Y.	2019	64	✓
5	Characterizations of L-convex spaces	Pang, B.; Zhao, Y.	2016	55	✓
6	Base axioms and subbase axioms in M-fuzzifying convex spaces	Xiu, Z. Y.; Pang, B.	2018	50	✓
7	M-fuzzifying interval spaces	Xiu, Z. Y.; Shi, F. G.	2017	43	✓
8	Estimating the parameters of a fuzzy linear regression model	Arabpour, A. R.; Tata, M.	2008	43	
9	Fuzzy linear regression based on least absolutes deviations	Taheri, S. M.; Kelkinnama, M.	2012	40	
10	Fuzzy pseudotopological hypergroupoids	Cristea, I.; Hoskova, S.	2009	40	

3.4 The most productive authors/institutes/countries/regions of IJFS

Table 4 lists the top 10 authors in IJFS who published the most. To compare who is more productive, we also consider the number of citations, the average number of citations per paper and the h-index in Table 4. Shi, F. G. not only ranks the first with 18 publications but also has been cited 161 times, making him the most productive and influential author in IJFS. Beyond that, Shi, F. G.'s h-index is 7, which is the highest among the top 10 authors. Additionally, we can note that Pang, B. has the highest AC, suggesting that his papers have been cited an average of 19 times per paper.

Table 4: The most productive and influential authors in IJFS

R	Author	NP	NC	AC	H-index
1	Shi, F. G.	18	161	8.94	7
2	Zahedi, M. M.	16	47	2.94	5
3	Davvaz, B.	12	102	8.5	6
4	Jun, Y. B.	11	93	8.45	6
5	Allahviranloo, T.	9	64	7.11	4
6	Jager, G.	9	20	2.22	3
7	Fang, J.	8	46	5.75	4
8	Pang, B.	8	152	19	5
9	Taheri, S. M.	8	100	12.5	4
10	Ameri, R.	7	48	6.86	5

Highly cited scholars and high-yield scholars are the elites of national and regional researchers. They are representative and reflect the commanding heights of national or regional knowledge innovation [40]. Fig. 4 shows the top authors production over time. On the left side of the figure, authors are ranked from high to low in line with Table 4. The larger the circle is, the more papers the authors have published, and the darker the circle is, the more citations the authors have received.

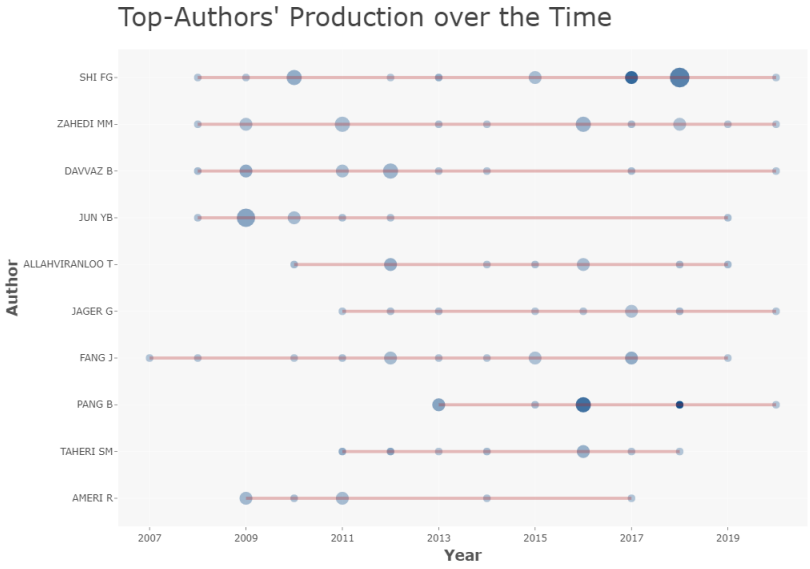


Figure 4: Top authors production over the time

According to Table 4 and Fig. 4, Shi, F. G. is the author with the highest productivity and influence. He published many papers in 2010 and 2018, and the most cited papers are mainly in 2017 and 2018. His high-cited paper, *M-Fuzzifying Interval Spaces*, published in 2017, introduced the notion of M-fuzzifying interval spaces. Under this framework, some of their fundamental properties were obtained [41]. Zahedi, M. M. has made a significant contribution to IJFS by publishing articles for 10 years. Pang, B. started late and published his first paper on IJFS in 2013, but his papers in 2016 and 2018 have received considerable attention, indicating that he is a promising author. Pang, B.'s main research direction is mathematics. For example, he introduced the concept of L-concave structures, concave L-interior operators and concave L-neighborhood systems in the article *characterizations of L-convex spaces* [23].

Table 5 lists the top 15 institutes and countries/regions with the most publications. Similarly, we refer to the number of citations and the average number of citations per paper. First, on the institute side, a total of 529 institutes have provided publications to IJFS to date. Of the top 15 institutes, eight are from Iran and four are from China. Islamic Azad University is one of the most famous universities in Iran. It shows its advantages in production and influence with 63 publications and 356 citations, followed by Shahid Bahonar University of Kerman Subk (Iran) and Beijing Institution of Technology (China). Interestingly, Beijing Institution of Technology ranks first in AC with 10.68

citations per paper, implying its high influence.

Table 5: The most productive and influential institutes/countries/regions in IJFS

R	Institute	NP	NC	AC	Country/Region	NP	NC	AC
1	Islamic Azad Univ.	63	356	5.65	Iran	261	1304	5
2	Shahid Bahonar Univ. of Kerman Sbuk	45	232	5.16	China	188	1217	6.47
3	Beijing Institute of Technology	25	267	10.68	India	90	420	4.67
4	Ferdowsi Univ. Mashhad	23	128	5.57	Turkey	37	341	9.22
5	Univ. of Tehran	17	88	5.18	South Korea	23	112	4.87
6	Amirkabir Univ. of Technology	15	69	4.6	The U. S.	23	76	3.3
7	Univ. of Yazd	15	126	8.4	Spain	18	91	5.06
8	Ocean Univ. of China	13	52	4	Romania	17	95	5.59
9	Gyeongsang National Univ.	12	98	8.17	Pakistan	16	223	13.94
10	India Institute of Technology System	11	32	2.91	Czech Republic	15	66	4.4
11	Shaanxi Normal Univ.	11	29	2.64	Egypt	11	14	1.27
12	Alexandru Ioan Cuza Univ.	10	68	6.8	Italy	11	161	14.64
13	Graduate Univ. of Advanced Technology	10	23	2.3	Slovakia	11	3	0.27
14	Nanjing Normal Univ.	10	13	1.3	South Africa	11	39	3.55
15	Semnan Univ.	10	29	2.9	Taiwan	11	15	1.36

Second, on the country/region side, Table 5 shows the 15 most productive countries/regions in IJFS. The top 5 most productive countries/regions are all from Asia, namely Iran (261), China (188), India (90), Turkey (37) and South Korea (23), which may be related to the fact that IJFS is from Iran (Asia). In particular, 7 of the top 15 most productive countries/regions are from Asia and five come from Europe, revealing that countries from Asia and Europe make a significant contribution. Italy, from Europe, is number one in terms of AC, so Italian publications get more attention.

4 Collaboration network analysis and co-citation analysis

Collaboration network is a very effective tool that can visually reflect the collaborative relationships among countries/regions, institutes and authors [37]. Co-citation analysis is a research method to measure the degree of relationship among papers. If the papers of two journals (or more than one journal) are cited by one or more papers at the same time, it is said that the two journals constitute co-citation relationship [29].

In this section, we use VOSviewer to analyze papers published between 2007 and 2020, including analysis of country/region collaboration network, institute collaboration network and author collaboration network. Furthermore, to explore the relationship among journals, compare similar types of journals and seek the development of IJFS itself, we also analyze the co-citation network of this journal.

4.1 The collaboration network at the level of country/region

Fig. 5 shows the country/region collaboration network of IJFS, where nodes represent countries/regions and links represent partnerships between countries/regions. The size of each node denotes the weight of the country/region (the number of publications), and the larger the node, the more publications. The distance between the two nodes depicts the affinity between the two countries/regions (the number of joint publications). The stronger the affinity, the shorter the distance, and the weaker the affinity, the farther the distance. The colors of nodes indicate their respective clusters.

We set the minimum number of documents of a country/region as 3, of the 51 countries/regions, 28 meet the threshold. In Fig. 5, there are 28 nodes, 8 clusters and 70 links, with a total link strength of 134. Calculating the total link strength of each country/region, China ranks first with a total link strength of 43 and cooperates with 12 countries/regions. Iran is next, with a total link strength of 42, and has publications in collaboration with 16 countries/regions. The United States ranks third, with a total link strength of 23, and has partnerships with 8 countries/regions. The above three countries show strong cooperation ability.

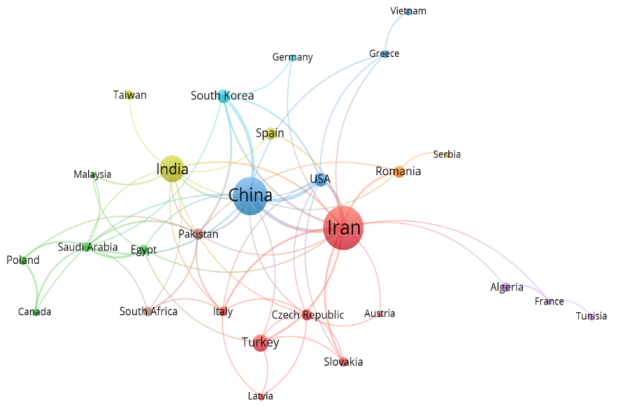


Figure 5: Country/region collaboration network

Among the 8 clusters, Cluster 1 is the largest cluster, indicated in red, including Iran, Austria, Czech, Republic, Italy, Latvia, Slovakia and Turkey. Cluster 2, represented in green, consists of five countries/regions: Canada, Egypt, Malaysia, Poland and Saudi Arabia. Cluster 3 includes four countries/regions: China, Greece, the United States and Vietnam. Cluster 4 consists of India, Spain and Taiwan. Cluster 5 includes Algeria, France and Tunisia. Cluster 6 includes Germany and South Korea. Cluster 7 includes Romania and Serbia. Cluster 8 is composed of Pakistan and South Africa. On the whole, Iran, the United States, China, India and other countries have demonstrated strong research cooperation.

4.2 The collaboration network at the level of institute

Likewise, the institute collaboration network is shown in Fig. 6. We let the minimum number of documents of an institute be 5, of the 540 institutes, 47 meet the threshold. Some of the 47 nodes in the network are not connected to each other. The largest set of connected items consists of 31 nodes, so we show this set of nodes instead of all nodes.

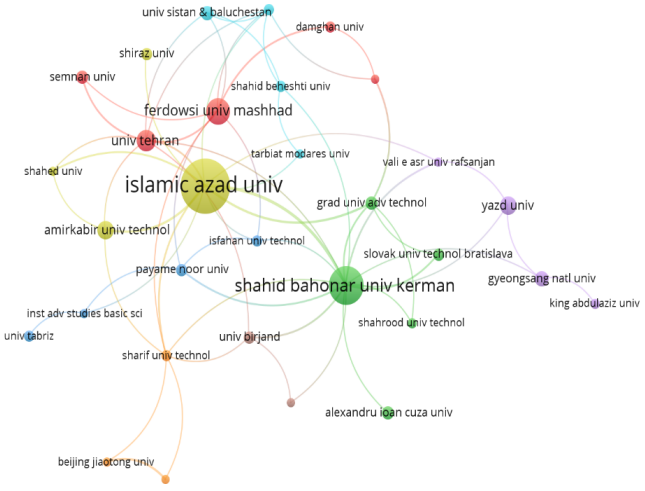


Figure 6: Institute collaboration network

Fig. 6 has 31 nodes, 62 links and a total link strength of 84. Based on the cluster analysis of VOSviewer, we get eight clusters. The most active institute is the Shahid Bahonar University of Kerman from Iran, which has a research

collaboration with 15 institutes with a total link strength of 24. It is followed by the Islamic Azad University, also from Iran, which has a research collaboration with 12 institutes with a total link strength of 23. It is worth noting that the top two most active institutions also have close partnerships with each other.

In Fig. 6, we can learn about the relationship between the institutes by the distance between the nodes. The largest cluster is green and contains 5 institutes, namely Shahid Bahonar University of Kerman Sbuk, Alexandru Ioan Cuza University, Graduate University of Advanced Technology, Shahrood University of Technology and Slovak University of Technology Bratislava. Cluster 2 consists of Damghan University, Ferdowsi University Mashhad, Iran University Science and Technology, Semnan University and University of Tehran. Cluster 3 includes 4 institutes: Institution of Adv Studies Basic Science, Isfahan University of Technology, Payame Noor University and University of Tabriz. Cluster 4 consists of Amirkabir University of Technology, Islamic Azad University, Shahed University and Shiraz University. In Cluster 5, there are Gyeongsang National University, King Abdulaziz University, Vali E Asr University Rafsanjan and University of Yazd. Cluster 6 contains Shahid Beheshti University, Tarbiat Modares University, University of Mazandaran and University Sistan and Baluchestan. Cluster 7 includes Beijing Jiaotong University, Sharif University of Technology and University of Cincinnati. The Shiraz University of Technology and the University of Birjand are from Cluster 8.

4.3 The collaboration network at the level of author

To present the author collaboration network, we set a minimum threshold of 2 publications, and out of 1,188 authors, 246 authors meet the threshold, forming 95 clusters, as shown in Fig. 7.

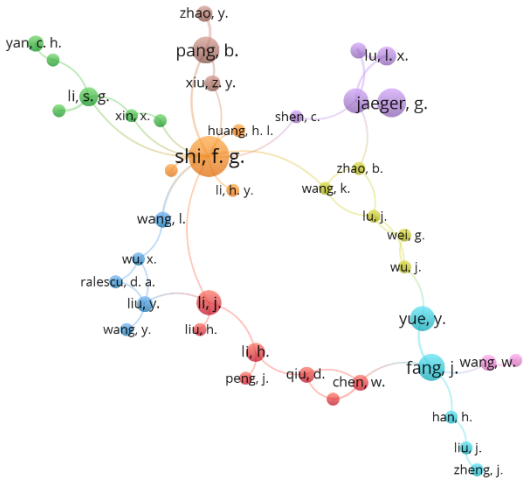


Figure 7: Author collaboration network with 246 authors

Some of the 246 nodes in the network are not connected to each other, so we show the largest set of connected nodes instead of all nodes, the details are shown in Fig. 8. The largest set of connected nodes is identified by 42 nodes and 52 links. The authors are divided into 9 clusters with a total link strength of 66. Shi, F. G., from Beijing Institution of Technology, is not only the author with the most citations, but also has the best performance in paper cooperation. He collaborated with 12 scholars on research, and his total link strength is 15. Pang, B. from Harbin Institution of Technology and Yao, W. from Beijing Institution of Technology also play an active role in paper cooperation. They both have a total link strength of 7. To be specific, Pang, B. has conducted cooperative research with 3 scholars, while Yao, W. has collaborations with 5 scholars.

4.4 The collaboration network at the level of author

Fig. 9 directly shows the co-citation network of IJFS. A basic assumption of co-citation analysis is that the higher the frequency of co-citation between two journals, the stronger the linkage between them [15]. The threshold for the minimum number of citations for journals is set at 20, and 96 of the 4,306 sources meet the threshold. Each node

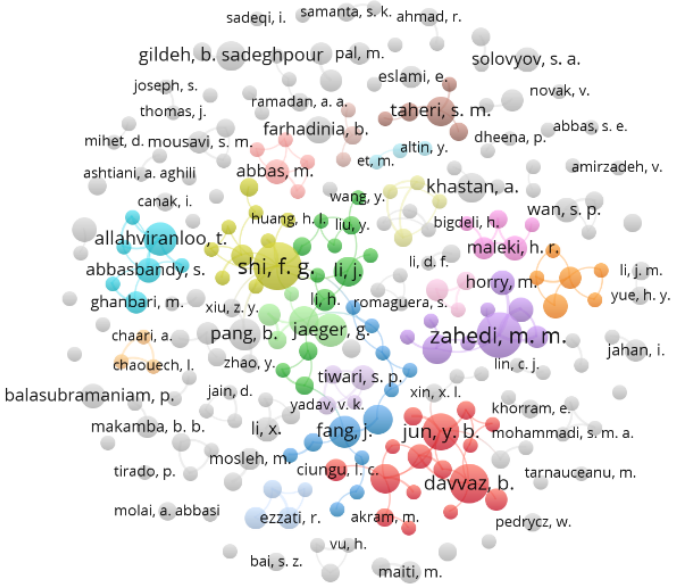


Figure 8: Author collaboration network with 42 authors

represents an author, and the size of the node represents the number of references. The links in the figure indicate that two linked journals are cited in the same paper. Table 6 lists the top 10 journals in terms of total link strength, along with some other indicators, including the number of citations and the number of links.

Table 6: The 10 most cited journals by IJFS

R	Institute	NP	NC	AC	Country/Region	NP	NC	AC
1	Islamic Azad Univ	63	356	5.65	Iran	261	1304	5
2	Shahid Bahonar Univ of Kerman Sbuk	45	232	5.16	China	188	1217	6.47
3	Beijing Institute of Technology	25	267	10.68	India	90	420	4.67
4	Ferdowsi Univ Mashhad	23	128	5.57	Turkey	37	341	9.22
5	Univ of Tehran	17	88	5.18	South Korea	23	112	4.87
6	Amirkabir Univ of Technology	15	69	4.6	The U. S.	23	76	3.3
7	Univ of Yazd	15	126	8.4	Spain	18	91	5.06
8	Ocean Univ of China	13	52	4	Romania	17	95	5.59
9	Gyeongsang National Univ	12	98	8.17	Pakistan	16	223	13.94
10	India Institute of Technology System	11	32	2.91	Czech Republic	15	66	4.4
11	Shaanxi Normal Univ	11	29	2.64	Egypt	11	14	1.27
12	Alexandru Ioan Cuza Univ	10	68	6.8	Italy	11	161	14.64
13	Graduate Univ of Advanced Technology	10	23	2.3	Slovakia	11	3	0.27
14	Nanjing Normal Univ	10	13	1.3	South Africa	11	39	3.55
15	Semnan Univ	10	29	2.9	Taiwan	11	15	1.36

Fuzzy Sets and Systems, located in the center of the figure, is the journal with the most attention, with 3,252 citations. It has the most links, co-cited with 229 journals, and also has the strongest total link strength (43,902), indicating a strong association with other journals. Next came *Information Sciences*, with 1,026 citations, 227 links and a total link strength of 21,718. In third place is the *Iranian Journal of Fuzzy Systems*, which is cited 701 times and co-cited with 226 journals, with a total link strength of 12,118. It is clear that excellent articles from these journals have a great impact on the publications of IJFS. Of course, some of the other journals listed in Table 6 also have a significant

impact on IJFS, such as *IEEE Transactions on Fuzzy Systems*, *Journal of Mathematical Analysis and Applications*, *Expert Systems with Applications*, *Journal of Intelligent Fuzzy Systems* and so on.

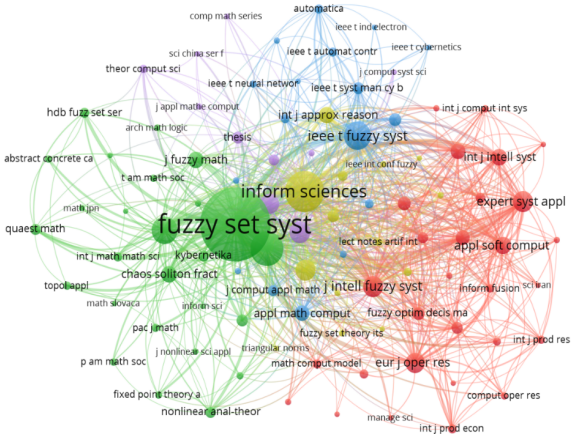


Figure 9: Co-citation network of IJFS

5 Thematic trend analysis

When keywords are used to identify thematic topics, their conceptual level is higher than the terms extracted from titles and abstracts generally [8]. Therefore, to study the themes of IJFS and its development trend, this section gives a detailed analysis of keywords in the publications. To be specific, we divide the period from 2007 to 2020 into three periods, namely, 2007-2010, 2011-2015 and 2016-2020, so that we can better grasp the change of hot topics over time.

5.1 Keyword descriptive analysis

Table 7 summarizes the top 20 keywords with the highest occurrence frequency in each period. Specifically, sets is the most frequently used keyword, with 57 times, followed by model (47), numbers (24), design (23) and systems (20), respectively. We find that in the first two periods, 2007-2010 and 2011-2015, the most frequently used keyword is sets. However, in the third period, from 2016 to 2020, the occurrence frequency of model increased significantly, and became the keyword with the highest frequency. This indicates that in recent years, IJFS is paying more and more attention to topics related to model building, such as soft computing [26] and uncertainty modeling [11]. In addition, we note that sets, systems and fuzzy have persisted for 14 years with high frequency, which reveals that these issues have been hot topics in IJFS for a long time.

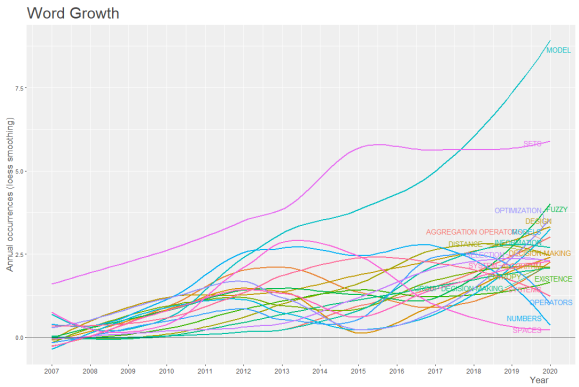


Figure 10: Word growth in IJFS, 2007-2020

In order to intuitively show the evolution of keywords over time from 2007 to 2020, we draw a word growth graph using Bibliometrix, as shown in Fig. 10. It can be seen that sets has always been a hot topic in this journal, and model has been attracting increasing attention since 2011. In addition, in recent years, keywords such as fuzzy, optimization, design and aggregation have been discussed frequently and become hot topics.

Table 7: Most frequently used keywords in IJFS

	2007-2020		2007-2010		2011-2015		2016-2020	
R	**Keyword**	**F**	**Keyword**	**F**	**Keyword**	**F**	**Keyword**	**F**
1	sets	57	sets	9	sets	20	model	33
2	model	47	ideals	5	model	13	sets	28
3	numbers	24	subgroups	4	spaces	12	design	13
4	design	23	fuzzy ideals	3	numbers	11	information	13
5	systems	20	relation equations	2	systems	9	distance	13
6	fuzzy	19	systems	2	algorithm	9	numbers	12
7	distance	18	equations	2	design	8	selection	11
8	algorithm	16	2-slit experiment	2	mappings	7	aggregation operators	11
9	entropy	16	approximation	2	differential-equations	6	fuzzy	11
10	spaces	16	metric-spaces	2	fuzzy	6	operators	11
11	optimization	16	fuzzy	2	optimization	6	entropy	10
12	system	15	compactness	2	system	6	systems	9
13	selection	14	design	2	calculus	5	system	9
14	information	14	ranking	2	existence	5	group decision-making	9
15	operators	14	shortest-path	1	ideals	5	optimization	9
16	decision-making	14	arc lengths	1	algorithms	5	models	8
17	stabilization	12	algorithms	1	distance	5	stabilization	8
18	Group decision-making	12	semirings	1	entropy	5	aggregation	8
19	aggregation operators	12	set	1	decision-making	5	decision-making	8
20	existence	12	resolution	1	metric-spaces	5	existence	7

5.2 The keyword co-occurrence network of publications in IJFS

In this part, we use VOSviewer to carry out a co-occurrence analysis of publications from 2007 to 2020, as shown in Fig.11.

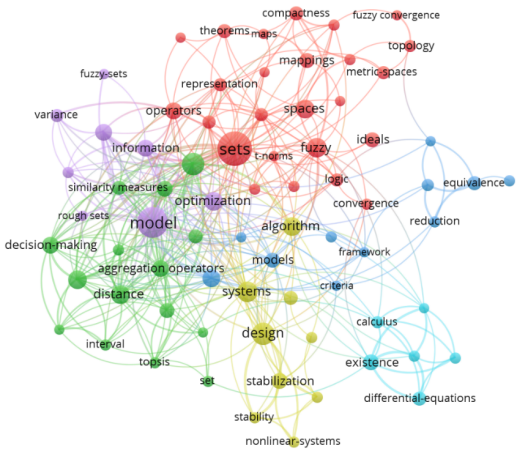


Figure 11: Keyword co-occurrence network

The minimum frequency of keyword occurrence is set to 5. 74 keywords reach the threshold, and all the keywords are divided into six major clusters. In the network, model has the highest total link strength (92), appearing 47 times in total, sets (58), distance (47), numbers (45) and entropy (40) are followed, which indicates that the publications of IJFS attach high importance to these words. Table 8 lists the detailed keywords for each cluster.

Specifically, Cluster 1 is marked in red and contains 25 keywords, among which sets, fuzzy and spaces are prominent. It mainly studies related issues of fuzzy system and topology structure. Cluster 2 consists of 15 keywords, identified in green, and focuses on issues related to decision making and sorting. The third cluster contains 11 keywords and focuses on the direction of administration and system simplification. Cluster 4 consists of 9 keywords, corresponding to the yellow part in the figure, which is more interested in the study of system stability. Cluster 5 includes 8 keywords, identified in purple in the figure, and the word model is the most obvious. This cluster pays more attention to fuzzy sets and model optimization. Cluster 6 consists of 6 keywords, and most of the research issues are related to the field of calculus.

Table 8: Main themes identified in the cluster analysis by VOSviewer

Cluster	**Keywords**
Cluster1	Approximation, compactness, construction, convergence, fixed-point theorems, foundations, fuzzy, fuzzy convergence, fuzzy topology, ideals, mappings, maps, metric-spaces, operations, operators, representation, set-theory, sets, spaces, theorems, t-norms, topological-spaces, topology, uninorms
Cluster2	Aggregation operators, decision-making, distance, entropy, equations, group decision-making, interval, numbers, ranking, reasonable properties, set, similarity measure, similarity measures, TOPSIS, variables
Cluster3	Criteria, equivalence, framework, machines, management, minimization, models, reduction subgroups, supervisory control, system
Cluster4	Algorithm, algorithms, design, h-infinity control, identification, nonlinear-systems, stability, stabilization, systems
Cluster5	Aggregation, fuzzy-sets, information, model, optimization, rough sets, selection, variance
Cluster6	Calculus, differential-equations, existence, integral-equations, number-valued functions, uniqueness

5.3 Thematic evolution in IJFS

Fig. 12 uses the Sanky chart to show the changes of thematic words in publications from 2007 to 2020. We set the occurrence frequency of the minimum keyword as 5, and take 2010 and 2015 as the time segmentation points to get three time periods. In the figure, the larger the number of publications on the corresponding theme, the larger the rectangle. The more containing indexes between two connected themes, the wider the rectangle's edge. Notice that the themes here are named with the maximum degree of keywords. In general, there are a lot of connections and transformations in the process of thematic evolution. By combining Table 7 and Fig. 12 for specific analysis, the following conclusions can be drawn:

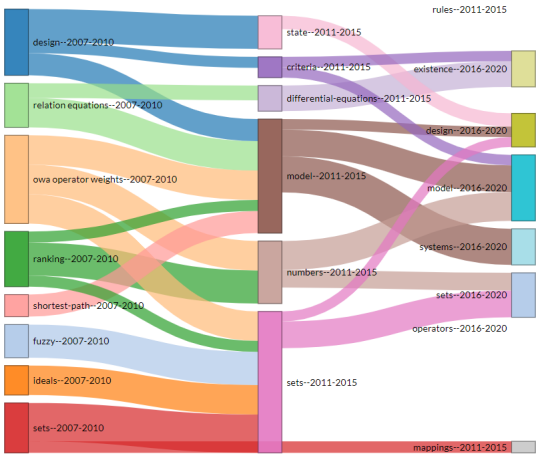


Figure 12: Mapping of thematic evolution in IJFS, 2007-2020

Themes with high frequency in each period mostly appear in all three sub-periods and develop stably and compactly from the first period (2007-2010) to the last period (2016-2020). It states that these themes are ongoing and highly focused in IJFS, such as sets, design, systems and fuzzy.

Many of the identified themes are continuations and developments of those identified in the previous period. Over time, the themes of publications become more focused and related to each other. On the one hand, themes such as relation equations and ideals become less and less popular between 2011 and 2015, showing a trend of gradual decline. On the other hand, themes such as model, numbers and existence begin to emerge in the period 2011-2015 and flourish in the period 2016-2020.

Furthermore, the way that many themes evolution shows an increasing trend in terms of the frequency of keywords in each theme. For example, the frequency of sets increases from 9 in the period 2007-2010 to 20 in the period 2011-2015, and then to 28 in the period 2016-2020. The frequency of design increases from 2 in 2007-2010 to 8 in 2011-2015, and then to 13 in 2016-2020. The frequency of models increases dramatically from 13 in 2011-2015 to 33 in 2016-2020.

6 Discussions

This research provides a bibliometric analysis of the publications of IJFS from 2007 to 2020 by collecting related indicators. The research results show that in recent years, the number of publications and the number of citations have been increasing. These publications have gained wide attention in the field of scientific research, and the influence of IJFS in the field of fuzzy systems has been increasing. However, with the development of academic research and technology, we find that IJFS may face some potential problems and challenges.

On the one hand, IJFS has received papers from 41 countries (based on the address of the corresponding author) between 2007 and 2020, but most of the authors who focus on the journal are from Asia and Europe, with Iran and China leading the way. How to expand the journal's international profile and attract more international researchers is a challenge. In addition, in recent years, as major journals are trying their best to give play to their own advantages, the number of publications in the entire retrieval database is increasing. How to ensure both the quality and the quantity of publications is another issue worth thinking about, so as to further improve the attention and scientific influence of IJFS.

On the other hand, the research directions of publications in this journal are mostly inclined to theoretical research, and its ranking in applied research direction (29/261) is relatively weak. Here we encourage more scholars to put forward more innovative and efficient methods or algorithms based on the original theoretical research. In the meantime, theories should also be connected with practice. Researchers can apply some advanced and practical methods or models to related fields, such as data mining, artificial intelligence, finance and management, to promote the development of related industries. In the future, we expect more papers to connect fuzzy systems to management, economics, engineering and other scientific fields.

7 Conclusions

Based on the WoS core collection, we analyzed 716 articles published in IJFS between 2007 and 2020 using bibliometric tools and methods (VOSviewer and Bibliometrix). We collected the basic information of the publications on the WoS and performed a general statistical analysis based on the basic information and citation structure of the publications. Collaboration network analysis explored the cooperative relationships between countries/regions/institutes/authors, and the co-citation networks of journals were studied. Finally, through the keyword co-occurrence analysis and other methods, the development trend and hot topics of thematic evolution over time were discussed. Based on the above analysis, the main conclusions are as follows:

(1) IJFS is an international journal with great development potential and influence. Since the first paper was published, the number of publications and citations has gradually increased, attracting more and more attention from domestic and foreign researchers. According to the statistical analysis of the data on WoS, *Journal of Intelligent Fuzzy Systems*, *Iranian Journal of Fuzzy Systems* and *Soft Computing* are the three journals that quote IJFS the most. Most of the countries citing IJFS are from Asia, with China showing the most interest and citing IJFS the most, followed by Iran. The most popular publication in IJFS, written by Wei, G. et al., is *Hesitant fuzzy linguistic arithmetic aggregation operators in multiple attribute decision making*. Shi F. G., from Beijing Institution of Technology, is the most productive and influential author. Pang, B., also from Beijing Institution of Technology, is a very potential author. His papers have gained wide attention since they were published. The top three most productive institutes are Islamic Azad University, Kerman Subk University and Beijing Institution of Technology. Iran, China and India are the top three producers.

(2) The analysis of collaboration network shows that China, Iran and the United States are the most active countries in paper cooperation. In terms of institutes, the most active collaborators are the Shahid Bahonar University of Kerman and Islamic Azad University from Iran, which also have close cooperation with each other. Shi, F. G., Pang, B. and Yao, W. are the most active authors involved in the collaborative study. The co-citation network of IJFS shows that *Fuzzy Sets and systems*, *Information Sciences*, *Iranian Journal of Fuzzy Systems* are the most popular journals of publications in IJFS, and they have a great influence on the publications of IJFS.

(3) The top three most frequently used keywords in IJFS are sets, model and numbers. Keywords such as sets, systems and fuzzy have persisted in this journal for the past 14 years, and have been the focus of IJFS's long-term attention. Keywords such as fuzzy, optimization, design and aggregation operators have become new hot topics in recent years. Keyword co-occurrence analysis shows that sets, distance and numbers are the three keywords with the highest total link strength, which indicates that IJFS attaches high importance to these keywords. Themes with high frequency in each period mostly appear in all three sub-periods and develop steadily and compactly, many of the themes continue and develop on the basis of the themes identified in the previous period. As time goes on, themes become more concentrated and interrelated, many themes are evolving in ways that show a growing trend.

In summary, this research applied bibliometric methods to explore the basic characteristics, collaboration networks, co-citation networks and thematic evolution of publications in IJFS, which will help researchers interested in this journal to understand its research status, hot topics and development trend. It has a certain contribution to promote scientific and technological progress in related fields at home and abroad. Besides, this will also make for attracting more outstanding researchers in related fields and contributing to the development of scientific research topics covered by IJFS. In the future, we will further collect research results, study advanced technologies related to bibliometric analysis and continue to pay attention to the development of IJFS.

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