A visual knowledge map analysis of mine fire research based on Citespace

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Abstract

Mine fire has always been a serious disaster in coal industry, many academic achievements have poured out in the past two decades for solving this problem. In this study, visual analysis was conducted to grasp the hotspots and development trend of mine fire research. Papers that published in 1999-2020 were retrieved as the data basis from Web of Science, and Citespace was used to carry out knowledge map analysis. The results shown that number of papers has increased steadily since 2005 and achieved explosive growth since 2014. DENG J is the first published author among many scholars. China, the US, Australia are active areas in mine fire research and China University of Mining and Technology ranks first in this field. The highest co-occurrence frequency key word is "spontaneous combustion".

"INTERNATIONAL JOURNAL OF COAL GEOLOGY" and "FUEL" provide guidance for mine fire research. Fire prevention technology, low carbon, ecology and sustainable development are the hot research in recent years.

1. Introduction

Nearly 90% coal mines in China adopt the well exploitation. The mining depth increase and the complex hydrogeological conditions of coal mines leads to a great threat for the coal mine. Mine fire produces a large number of toxic gases and smoke, which diffuses to the whole mine by air flow through the ventilation network. It is easy to reach the location far from the fire source and to cause wind reversal, which aggravates the miner's risk. Although the fire-related injuries and death decrease in the past few years, mine fires still pose a threat to the miners' safety.

So far, a large number of scholars and experts have done a lot of research on mine fire. The research content is wide and diverse, however, the sorting out of present achievements is few. Most of the traditional visualization methods involve explore and interpret the existing data by analysts. It uses people's vision and knowledge reserve to seek information, which has limitations and omissions inevitably. In the information explosion age, people are no longer satisfied with the traditional visualization method, which only reflects the surface information of data. The present visual analysis method helps us seeking data in high efficiency and evaluating the current research object progress, which discovers the following research direction and new rules.

Knowledge map has widely use in fires. Li. (2016) studies the characteristics and evolution of the structure of safety science by taking the scientific and technological texts accumulate for a long time as the research object. Based on Citespace, the application of FDS software in the field of fire simulation is analyzed. Lin et al. (2020), Fu et al. (2020) and other researchers (He et al., 2019; Cui et al., 2019; Wang et al., 2016) conduct visual analysis on FDS fire simulation, gas explosion, fire numerical simulation, forest fire and other fields based on Citespace software. Jin et al. (2019) uses VOSviewer to catch visual research on building safety. Citespace shows the evolution of a knowledge field on a network map, and is one of the most popular drawing tools of knowledge map Chen et al. (2015). Therefore, in order to analyze the dynamic, polymorphic and multi-source data in the field of mine fire, this paper uses

Citespace software to draw knowledge map from the perspectives of publication distribution, authors, institutions, countries and keywords, in order to provide valuable information for the academic research and development in this field.

2. Research Method

2.1. Citespace summarize

CiteSpace is a multi-view information visualization software based on Java platform developed by Chinese American bibliometrics professor Chen Chaomei in 2004. The main function is to show the evolution trend and knowledge association of the science frontier through the visualization analysis. Citespace transforms the data exported from the WOS database to draw various knowledge maps and display the research field details by node size, network connectivity and other factors Liu. (2020). Besides the wide range of applications, the algorithm and data mining function in Citespace is powerful that other software does not have, such as: Minimum spanning tree algorithm, path network simplification algorithm and expansion word mutation detection algorithm. They provide users with rigorous analysis process and accurate results of the map. This paper uses the visual bibliometric analysis tool Citespace 5.8.R3 to process and analyze the data.

2.2. Using and debugging

Users create a new project in Citespace and named "Mine Fire", importing data, and setting parameters. In the main screen, the settings of Citespace interface includes time zone division, node type, connection, threshold setting, path selection, and map generation description. In particular, the Time Slicing is to segment the time zone of the data to be analyzed. The analysis time in this paper is set as 1999-2020, and the Time Slicing is 1 year. The Text Processing is used to select the Term extraction location and supplementary selection of common word analysis types. Network configuration area includes Node Types, Links, and Selection Criteria and the Network types depends on the analysis object. Different nodes generate different types and functions networks. Author, Institution and Country generate cooperation map. Term and Keyword produce the corresponding network. Cited Reference, Cited Author, Cited Journal is a co-cited network analysis of guiding papers, authors and source journals, respectively. Threshold selection includes four algorithms and they are Top N per slice, Top N% per slice, Threshold Interpolation and Select Citers.

Pruning parameters and functional areas work for the network Pruning, including PFNET (Path finding network) and MST (Minimum Spanning Tree) algorithms. Both of them are used to cut the connections in the network for the network density reduction and the network readability improvement. Finally, Visualization is adopted to set up Visualization results, including Cluster View, Timezone View and Timeline View.

3. Database

3.1. Data selection

Based on the research object and characteristics, all the data and information are from the Web of Science core database of ISI, which has the most authoritative data source in the world at present. It has more than 5500 kinds of scientific journals in this database. WOS contains the most influential and high-quality journal paper from all over the world, which ensures the accuracy of the data in this paper.

3.2. Data collection and processing

With the Web of Science Core Collection and the topic of "Mine Fire or Coal Spontaneous Combustion", 5181 papers are conducted from 1999 to 2020. 3048 papers are obtained by further refining the retrieval results. The data are imported into Citespace then 1334 papers are visualized through the de-merging and screening functions of the tool. "Pathfinder" is used to analyze author, institution, keyword, journal, country, citation and other contents, so as to obtain the corresponding knowledge map. Finally, measurement visualization analysis, tables and other tools, owned by WOS, are adopted to supplement and improve.

4. Data Analysis

4.1. Number of articles in different periods

The paper quantity is an important parameter to measure the quality in a certain field, which reflects the research results and active degree in a certain subject. By analyzing the temporal distribution and cumulative output of papers, it judges the social and academic attention degree to this field, which reveals the academic research and development trend Xue et al., (2020). Fig. 1 shows the amount of mine fire published in WOS from 1999 to 2020, presenting an obvious upward trend on the whole. In the initial period (1999-2005), the number of papers published in 1999 is Fig. 1. The possible reason is that due to the poor communication technology at that time, all papers cannot be uploaded. After that, with the rapid development of economy and the popularization of the Internet, the article number published begin to rise slowly. In stable transition period (2005-2014), the annual average number of papers published is about 28. The number of published papers increases from 68 in 2014 to 267 in 2020, which lies in booming growth period (2014-2020) (Tan et al., 2020a; Tan et al., 2019; Tan et al., 2020b; Tan et al., 2020c; Zhu et al., 2020). During this period, the academic community's understanding of mine fire rise to a new height, and the study of mine fire is still developing vigorously.

4.2. Author analysis

4.2.1. Author publication statistics

When analyzing the number of papers published by 682 authors, prolific authors are the analysis focus. Prolific authors are those who publish more papers in a certain field. According to Price's law, the specific formula is.

$$M=0.794 \times \sqrt{N_{max}} \quad (1)$$

Where M represents the minimum number of core authors in a certain field, and N_{max} represents the maximum number of core authors in a certain field. According to Price's law, the author who has a high number of papers includes DENG J, SHU CM, QIN BT, WANG DM, ZHU HQ. DENG J has published a large number of papers from 2015 to 2020, making great contributions to the research on mine fire. DENG J mainly engages in the theory and technology research of coal fire disaster prevention and control. In recent years, he has made a series of achievements in scientific issues such as nature of coal spontaneous combustion, characteristic information identification of coal spontaneous combustion and coal fire disaster prevention, which has published a lot of highly cited papers (Deng et al., 2015; Deng et al., 2016; Xiao et al., 2018; Deng et al., 2018; Deng et al., 2017). SHU CM, from National Yunlin University of Science & Technology, mainly studies the whole process of primary and secondary spontaneous combustion of coal and publishes some valuable papers from 2017 to 2020 (Zhao et al., 2019; Wang et al., 2016; Deng et al., 2017; Liu et al., 2015).

4.2.2. Author cooperation relationship

WOS paper data is imported into Citespace, setting the time span to 1999-2020 and time slice to 1 year. "Author" is chosen as "Node Types" analysis content after format transformation. Path algorithm conducts keyword frequency analysis for "Pathfinder, Pruning networks, pruning the merged network". Thus, an author collaboration map of "Nodes = 682", "Links = 797" and "Density=0.0031" is obtained.

In Fig. 2, the author cooperation map of mine fire presents a relatively close distribution on the whole. On the left is a large cluster formed by four groups WANG DM, QI GS, PAN RK and YANG SQ, and on the right it is a small cluster represented by SHU CM (Lu et al., 2019; Lu et al., 2021; Luo et al., 2022; Pan et al., 2020). WANG DM and QIN BT, DOU GL, LI XB, LU XX, DONG SJ, SHI GQ, WANG YM, WANG Y, HU C, MA LY (Qin et al., 2018; Ma et al., 2017; Zhang et al., 2021; Yuan et al., 2018; Wen et al., 2020; Zhang et al., 2019; Sun et al., 2019; Li et al., 2020; Shao et al., 2018; Lee et al., 2020; Yan et al., 2019; Du et al., 2018) are a small team of 10 people. Most of them are from China University of Mining and Technology, Henan Polytechnic University, China University of Mining and Technology (Beijing), Xi 'an University of Science and Technology, etc. The internal cooperation among institutions represented by China University of Mining and Technology indicates that the academic research teams engage in mine fire research in China have gradually become mature, and academic exchanges between authoritative authors play a key role in the research of this field.

In addition, QI GS cooperates with LIANG YT, LI JL and QI XY frequently. PAN RK is closely associated with HU DM, WU MY, MA JW and WANG J. YANG SQ has a cooperative relationship with TANG ZQ, CAI JW and SONG WX (Cai et al., 2019; Xu et al., 2019; Song et al., 2019). SHU CM is closely related to four authors, WANG CP, DENG J, ZHAO JY, and ZHANG YN. This means that there are many scholars studying mine fire in the world, but most of their researches are scattered and there is no large-scale cooperation and exchange behavior. Most of them are organized in the form of small groups of three or four people. Therefore, the large-scale cooperation among authors in the mine fire field research needs to be

strengthened. At present, the cooperation between authors is affected by regional, economic, linguistic and cultural factors or other aspects.

4.3.3. Authors co-citation

Authors co-citation analysis refers to the situation where two or more authors are simultaneously cited by other authors' papers, which obtains the distribution of highly cited authors and understands the research topics in the field. On the micro level, it reveals the interweaving and dependence between some disciplines. On the macro level, it reflects the discipline composition and structural characteristics of the scientific system to a certain extent (Zuo et al., 2021).

"Cited Author" is used as "Node Types" and path algorithm is set as "Pathfinder" for Author analysis. Thus, an author co-cited network map of "Nodes = 880", "Links = 3090" and "Density (Density) = 0.0051" is obtained, as shown in Fig. 3. It can be seen from the map that some co-cited authors cooperate closely. DENG J, WANG HH, STRACHER GB, CARRAS JN and SONG ZY are highly cited authors. In this paper, it is found that DENG J is not only a prolific author, but also a highly cited author. His paper is abundant in quantity and is of good quality as well. WANG HH, from UNIVERSITY OF NEWCASTLE, mainly studies low temperature oxidation of coal Stracher Glenn B. of the University System of Georgia, who studies coal fires. CARRAS JN, from Commonwealth Scientific & Industrial Research Organisation (CSIRO), has made outstanding contributions in coal spontaneous combustion and CO₂ injection into coal seam fire prevention and control. Song ZY is from Xi'an University of Science and Technology and his research focuses on coal field fire, energy and fuel.

Combine with the analysis of prolific authors, it is found that the number of Chinese authors with high citation frequency on the list is significantly reduced. It indicates that Chinese authors have more paper in the mine fire but their citation frequency is not proportional. The citation frequency of an author's paper reflects the author's status and influence in a certain research field. Therefore, Chinese authors need to make efforts in this regard to maintain a high number papers, ensuring the quality of papers and improving their influence in their research.

4.3. Research institutions analysis

4.3.1. Institution publication statistics

The high-yield institutions with more than 13 publications are selected from 535 research institutions as the main research objects in Table. 1. China Univ Min & Technol from China ranks the first with 283 papers, with 26, 37, 57, 43, 45 paper distributed in the past five years. WANG DM, KONG B, Xin HH, Xia TQ and others from this institution make significant contributions to the study of mine fire related to three-phase foam, coal spontaneous combustion, gas extraction and so on. Meanwhile, 9 of the top 13 institutions in the number of publications are from China, they are China Univ Min & Technol, Xian Univ Sci & Technol, China Univ Min & Technol Beijing, Natl Yunlin Univ Sci & Technol, Henan Polytech Univ, Shandong Univ Sci & Technol, Taiyuan Univ Technol, Liaoning Tech Univ, Shaanxi Key Lab Prevent &

Control Coal Fire. It is found that Chinese research institutions have conducted extensive research on mine fire, which indicates that Chinese institutions have become effective forces in the mine fire research.

Table 1
Statistics of high-yield institutions' publications

Number	Counts	Centrality	Institutions
1	283	0.09	China Univ Min & Technol
2	91	0.03	Xian Univ Sci & Technol
3	87	0.04	China Univ Min & Technol Beijing
4	46	0.04	Natl Yunlin Univ Sci & Technol
5	42	0.12	Henan Polytech Univ
6	42	0.07	Shandong Univ Sci & Technol
7	37	0.25	Taiyuan Univ Technol
8	30	0.08	Liaoning Tech Univ
9	26	0.00	Shaanxi Key Lab Prevent & Control Coal Fire
10	23	0.01	Univ Queensland
11	21	0.01	Hunan Univ Sci & Technol
12	18	0.04	Monash Univ
13	17	0.07	Univ Witwatersrand
14	17	0.00	Cent Min Inst
15	15	0.00	Selcuk Univ
16	15	0.12	Anhui Univ Sci & Technol
17	14	0.00	Indian Sch Mines
18	14	0.02	Univ Sci & Technol Beijing
19	14	0.01	Chinese Acad Sci
20	13	0.01	Chongqing Univ
21	13	0.00	North China Inst Sci & Technol
22	13	0.05	Minist Educ

4.3.2. Institution cooperation relationship

Citespace is used to determine relevant parameters after several debugging. And generates a cooperation map of research institutions with 535 nodes and 544 links, as shown in Fig. 4. Each node and its size

represent an institution and cooperation frequency, meanwhile the links between nodes represent the cooperation relationship (Liu et al., 2020). China Univ Min & Technol establishes the largest node and close cooperation with 15 institutions. For example, China Univ Min & Technol Beijing, Henan Polytech Univ, Univ Sci & Technol Beijing and other institutions. This presents a cooperative network radiating outward from the center of China Univ Min & Technol. In Australia, Univ Queensland, Monash Univ, Curtin Univ, CSIRO Energy CSIRO, Univ Wollongong work closely. Univ Kentucky, NIOSH, Penn State Univ, Morehead State Univ and West Virginia Univ have frequent contact in the United States. It is found that the cooperation between institutions is regional, and the cooperation between countries or continents is rare. Fig. 4 roughly divides the cooperative relationship into three parts. They are the American cooperative network centered on Univ Kentucky, the Chinese cooperative network centered on China Univ Min & Technol and the Australian cooperative network centered on Univ Queensland.

4.4. Country analysis

4.4.1. Country publication statistics

According to the statistical analysis of the 94 countries publications, price's law calculation demonstrates that the minimum publications among 11 high-yielding countries is 21, as shown in Table. 2 and Fig. 5. China ranks the top with 678 papers, accounting for 50.82% and the US ranks second with 140 papers, accounting for 10.49%. From 2 papers in 2008 to 164 papers in 2020, China shows a rapid progress and becomes one of the high-yielding countries in the world. China's research achievements in the mine fire field and the degree of concern far exceeds other countries, which has become the backbone of all countries in this field. The US has been publishing papers on mine fires since 1999, which is a pioneer in the field. The number of papers, published in 2018, is 15 at most. Other high-yielding countries include Australia, India, Poland, South Korea, Turkey, Canada, Spain, etc. It is concluded that all high-yielding countries in mine fire are also recognized as big coal producers in the world.

Table 2
Statistics of high-yielding country publications

Number	Counts	Centrality	Country
1	678	0.25	PEOPLES R CHINA
2	140	0.58	USA
3	103	0.31	AUSTRALIA
4	58	0.18	INDIA.
5	46	0	POLAND
6	27	0	SOUTH KOREA
7	27	0.03	TURKEY
8	26	0.06	CANADA
9	25	0.3	SPAIN
10	24	0.17	SOUTH AFRICA
11	21	0.5	GERMANY

4.4.2. Country cooperation relationship

By using Citespace and adjusting parameters, the map of national research cooperation with 94 nodes and 116 links is obtained, as shown in Fig. 6. Nodes and its size represent countries and the cooperation frequency, meanwhile the line between nodes represents cooperation relationship (Xu et al., 2021). The USA has cooperative relations with 10 countries, such as PEOPLES R CHINA, NETHERLANDS, PERU, MEXICO, CANADA, PAKISTAN, etc. PEOPLES R CHINA has close cooperation with the USA, NORTH IRELAND and SOUTH KOREA. AUSTRALIA has close contact with PAKISTAN, U ARAB EMIRATES, GERMANY and SWEDEN. As two high-yielding countries, China and Australia carry out independent research and their cooperation intensity with other countries is much lower than that of the US.

4.5. Journal co-citation analysis

Taking "Cited Journal" as the analysis content and path algorithm as "Pathfinder" for author analysis, a Journal co-citation map of "Nodes = 814", "Links = 2937" and "Density = 0.0089" is obtained, shown in Fig. 7. In addition, "Generate a Narrative" in "Export" is used to obtain an arrangement list of cited journals. The top 10 journals are listed, as shown in Table. 3 and Table. 4.

Table 3
Top ten cited journals ranking table

Counts	Centrality	Cited journal
535	0.07	INT J COAL GEOL
512	0.05	FUEL
339	0.02	SCI TOTAL ENVIRON
286	0.05	ENVIRON SCI TECHNOL
269	0.04	SCIENCE
240	0.04	NATURE
240	0.07	FUEL PROCESS TECHNOL
223	0.03	J HAZARD MATER
221	0.01	ATMOS ENVIRON
213	0.01	J LOSS PREVENT PROC

Table 4
Detailed information of highly cited journals

Abbreviation	Publishing country	Primary classification	Secondary classification	Average IF (2019~2021)	Citation frequency (2020-2021)
INT J COAL GEOL	Netherlands	Engineering technology Q2	Energy and Fuels Q2 Geoscience Q1	5.051	27351
FUEL	Netherlands	Engineering technology Q2	Energy and Fuels Q2 Engineering: Chemical Engineering Q2	5.205	137125
SCI TOTAL ENVIRON	Netherlands	Environmental Science and Ecology Q2	Environmental Science Q2	5.584	232429
ENVIRON SCI TECHNOL	The United States	Environmental Science and Ecology Q1	Engineering: Environment Q2 Environmental Science Q1	7.222	361186
SCIENCE	The United States	Comprehensive Q1	Comprehensive Q1	41.322	1380869
NATURE	England	Comprehensive Q1	Comprehensive Q1	42.475	1512938
FUEL PROCESS TECHNOL	Netherlands	Engineering technology Q2	Applied chemistry Q2 Energy and Fuels Q3 Engineering: Chemical Engineering Q2	4.482	40911
J HAZARD MATER	Netherlands	Environmental Science and Ecology Q1	Engineering: Environment Q2 Environmental Science Q1	7.707	206544
ATMOS ENVIRON	England	Environmental Science and Ecology Q2	Environmental Science Q3 Meteorology and Atmospheric Science Q2	3.92	115151

Abbreviation	Publishing country	Primary classification	Secondary classification	Average IF (2019~2021)	Citation frequency (2020-2021)
J LOSS PREVENT PROC	Netherlands	Engineering Technology Q3	Engineering: Chemical Engineering Q4	2.282	11964

In journal co-citation, INT J COAL GEOL, FUEL, SCIENCE OF TOTAL ENVIRONMENT, ENVIRON SCI TECHNOL., SCIENCE and NATURAE are frequently cited. INT J COAL GEOL, FUEL, FUEL PROCESS TECHNOL and J LOSS PREVENT PROC belong to engineering journals. SCI TOTAL ENVIRON, ENVIRON SCI TECHNOL, J HAZARD MATER, and ATMOS ENVIRON belong to the environmental science and ecology journals, while SCIENCE and NATURE belong to the general journals. On the whole, these journals are internationally famous and widely cited, which reflects that these journals are important knowledge supply in mine fire research, and also shows the importance of these journals in this field.

4.6. Research hotspots analysis

4.6.1. Key words co-occurrence

Keywords, representing the core and essence life-quintessence of the article, are a high-level summing-up to the article theme, so the keywords analysis examines the research focus of the papers (Zhu et al., 2021a). High frequency keywords are used to ensure the research hot pot in a certain field and 17 high frequency keywords are obtained through order statistics in mine fire research, which is listed in Table. 5. The top 10 keywords includes “spontaneous combustion”, “coal”, “low temperature oxidation”, “fire”, “oxidation”, “mechanism”, “temperature”, “mine”, “kinetics”, “model”(Zhu et al., 2021a; Zhu et al., 2021b; Zhu et al., 2021c; Zhu et al., 2021d).

Table 5
Listing of high frequency keywords

Number	Counts	Centrality	Keywords
1	299	0.05	spontaneous combustion
2	191	0.05	coal
3	190	0.07	low temperature oxidation
4	148	0.18	fire
5	136	0.07	oxidation
6	93	0.01	mechanism
7	85	0.01	temperature
8	76	0.09	mine
9	76	0.03	kinetics
10	69	0.10	model
11	68	0.05	pyrolysis
12	67	0.08	behavior
13	66	0.04	bituminous coal
14	63	0.19	prevention
15	59	0.03	gas
16	56	0.07	emission
17	54	0.08	propensity

The WOS data is imported into Citespace and formatted transformation, the time span from 1998 to 2020, time slice is 1 year, "Keywords" is set as "Node Types" analysis content, and path algorithm is set as "Pathfinder" for author analysis. Thus, a keyword co-occurrence network map of "Nodes = 528" and "Links = 1853" is obtained, as shown in Fig. 8.

Nodes represent key words, and the number of nodes represents the key words number in the paper. The line reflects the relationship between keywords and the node size represents the keyword frequency. Centrality is one of the criteria to describe the nodes importance, indicating the possibility that a node becomes the "intermediary" of other nodes. The Citespace visual interface specializes the high intermediate centrality nodes. When the intermediate centrality is greater than 0.1, a purple circle appears on the outside of the node's annual ring (Liu et al., 2020).

According to the node radius in the map and the order in the table, the five keywords of "Spontaneous combustion", "coal", "low temperature oxidation", "fire" and "oxidation" are cited more than 100 times,

followed by "mechanism". "Temperature", "mine", "kinetics" and "Model" are all cited more than 50 times (Wen et al., 2017; Du et al., 2015; Yang et al., 2015; Kim et al., 2016; Wu et al., 2017).

4.6.2. Keywords Cluster

39 clusters are obtained from 528 keywords extraction and the main clusters are displayed in Fig. 9. According to #0, #1..... #20 sort, the map covers 21 clusters from #0 to #20. #0 india#1 model#2 restoration#3 thermoplastic powder#4 moisture#5 coal#6 composite inhibitor#7 vegetable oils#8 gas#9 fine particulate matter#10 product#11 coal stockpile#12 mechanical thermal expression#13 carbon nanotubes#14 discrimination#15 coalfield#16 emergency rescue#17 forest burned areas#18 emission#19 threatened species#20 foam stability (Jolanta et al., 2017; Qin et al., 2017; Jo et al., 2015; Qin et al., 2016; Lu et al., 2017).

Modularity Q and Mean Silhouette S are two indicators reflecting the definition of cluster boundary and cluster size. In the map, Modularity $Q=0.8057$ ($Q>0.3$) indicates clear boundaries between research topics and significant field differentiation. Mean Silhouette $S=0.91$ ($S > 0.7$) with good clustering effect. The labels and related descriptions of each cluster are shown in Table. 6 and Table. 7.

Table 6
Keywords cluster statistical analysis

Cluster	Keywords	Size	Silhouette	Mean year
#0	india	48	0.905	2010
#1	model	41	0.806	2010
#2	restoration	40	0.941	2005
#3	thermoplastic powder	30	0.975	2015
#4	moisture	29	0.929	2006
#5	coal	28	0.855	2013
#6	composite inhibitor	27	0.836	2016
#7	vegetable oils	27	0.994	2009
#8	gas	26	0.894	2011
#9	fine particulate matter	25	0.886	2016
#10	product	24	0.876	2010
#11	coal stockpile	23	0.817	2011
#12	mechanical thermal expression	21	1.000	2009
#13	carbon nanotubes	20	0.877	2016
#14	discrimination	20	0.965	2012
#15	coalfield	17	0.94	2006
#16	emergency rescue	14	0.989	2012
#17	forest burned areas	14	0.913	2012
#18	emission	10	0.996	2013
#19	threatened species	8	1.000	2010
#20	foam stability	6	0.983	2015

Table 7
Keywords cluster information table

Cluster	Top terms
#0	spontaneous combustion; plugging property; temperature; mine fire; india; temperature; impact; mine fire; india; area; india; coal fire; jharia coalfield; wuda; aster.
#1	spontaneous combustion; activation energy; thermal analysis; analytical solution; ignition behavior; low temperature; self -heating; safety engineering; proactive inertisation; mine safety; model; low temperature oxidation; aliphatic hydrocarbon; unsaturated hydrocarbons; proactive inertisation.
#2	spontaneous combustion; situ fourier; surface characteristics; infrared spectroscopy; grey correlation analysis; low-temperature oxidation; functional group; inhibiting effect; thermal release intensity; thermogravimetric analysis; product; initial exothermic temperature; element occurrence; methane migration; surface characteristics.
#3	spontaneous combustion; free radical reaction; porosity changes; porous media; gangue hill; coal stockpile; temperature profile; coal oxidation; thermoplastic powder; extinguishing fire; coal stockpile; prevention; goaf; statistical model.
#4	spontaneous combustion; mechanical thermal expression; particle size; mineral matters; pore structure; forest fire; historical mining; environmental pollution; prescribed fire; water pollution; mechanical thermal expression; forest fire; lignite; prescribed fire; ash.
#5	spontaneous combustion; emission regularity; co-generation mechanism; advanced characterization; iron nanoparticles; carbon nanotubes; rare earth elements; colombian coals; spontaneous coal; analytical approach; carbon nanotubes; potential hazardous elements; nano-minerals; human exposure; advanced characterization.
#6	spontaneous combustion; inhibition characteristic; particle size; crustal structure; foaming agent; discrimination; crustal structure; quarry; anisotropy; mining explosion; discrimination; explosion; quarry blast; earthquake; daxing mine.
#7	spontaneous combustion; bi-point source; reverse dispersion modelling; emission factor; fire extinguishment; coalfield; coal fire; natural example; in situ gasification; depth; coalfield; depth; east basuria colliery; coal fire; back-calibration.
#8	numerical simulation; emergency rescue; smoke plume control; porous media; critical velocity; porous media; coal stockpile; natural convection; convection visualization; cooling area; emergency rescue; fds; cfd; porous media; numerical simulation.
#9	table mountain; pinus pungens; appalachian mountains; fire history; satellite data; forest fire; metal contamination; post-mining environment; water quality; mining disturbance; forest burned areas; gas chromatography-mass spectrometry (gc-ms); africa; serpentine barren; pinus virginiana.
#10	spontaneous combustion; underground coal mine; ambient temperature; toxicity; gangue hill; emission; toxicity; sampler; partition coefficient; deposition; emission (14.45, 0.001); pah; fluorine release; microbial remediation.
#11	bauxite mining; vegetation structure; tropical savannas; new caledonia; ultramafic substrates; new caledonia; ultramafic substrates; tropical savannas; bauxite mining; vegetation structure; threatened species; conifers; tropical savannas; ultramafic substrates; new caledonia.
#12	spontaneous combustion; mercury emission; gangue hill; coal oxidation; gaseous products; fire; rehabilitation; savanna; fuel; minesite; restoration; fire; mining; lampropholis; reptile.

Cluster	Top terms
#13	spontaneous combustion; carbon dioxide; temperature-sensitive retardant microcapsule; fire-retardant mechanism; coal mine fires; tendency; mathematical origin; coal spontaneous combustion; sulfide mineral; powder; foam stability; kinetic based simulation method; three-phase foams; mathematical origin; powder.
#14	spontaneous combustion; clay suspensions; alginate fluid gels; ash content; coal mining; thermoplastic powder; extinguishing fire; oxygen consumption; polymorphic foam clay; coal self-oxidation; thermoplastic powder; inert gas; flame retardant; convection; synergistic effect.
#15	spontaneous combustion; apparent activation energy; differential scanning calorimetry; mechanism function; particle size; low-temperature oxidation; functional group; cyclic reaction; oxidation; moisture; moisture; inversion temperature; crossing-point temperature; self-ignition; drying.
#16	spontaneous combustion; discrete particle swarm optimization; mine ventilation network; gob flow field; mineral matter; low-temperature oxidation; solid biofuels; co emissions; heavy metals; thermokinetic parameter; coal; gasification; basin; greenhouse gas; energy.
#17	spontaneous combustion; free radical reaction; porous material; ultra-wideband spectrum; densified coal; low-temperature oxidation; functional group; cyclic reaction; porous material; ultra-wideband spectrum; composite inhibitor; coal spontaneous combustion; prediction; inorganic matter; inhibition mechanism.
#18	spontaneous combustion; foam evolution; pickering foams; coal residues; microstructure; coal wastes; vegetable oils; oil agglomeration; coal residues; microstructure; vegetable oils; sewage sludge; coal wastes; adsorption; sorption
#19	spontaneous combustion; free radical reaction; dangerous area division; pollinator; apoidea; active site; oxidation; pyrolysis; bituminous coal; functional group; gas; active site; pyrolysis; pore structure; programmed heating.
#20	spontaneous combustion; systems-theoretic accident model; comprehensive evaluation; indicator; wetting time; low-temperature oxidation; coalification degree; pore development; coal-rock dynamic disaster; nuclear magnetic resonance; fine particulate matter; smoke exposure; time series; coal mine fire; risk.

4.6.3. Burst term map

Using the Burstdetection algorithm, the words with high frequency change rate in the subject words are detected from a large number of subject words as burst term. Combined with the change trend of word frequency, it predicts the research frontier and development trend of mine fire. In Citespace, burst term is refined with the parameter γ (range 0-1) of BURSTNESS. Generally, the breakout values can be easily found on the interface with a low γ value, as shown in Table. 8. When the parameter is set to $\gamma = 0.9$, a total of 25 emergent words are displayed, as shown in Fig. 10 in chronological order.

Table 8
Parameter γ Value range

γ value	Burst term number	γ value	Burst term number
0.1	129	0.6	53
0.2	127	0.7	40
0.3	126	0.8	30
0.4	99	0.9	25
0.5	69	1.0	10

The highest burst intensity is "coal", which started in 2000 and decreased sharply in 2015. Around 2000, the world entered the rapid economic development stage, coal was widely used for heating, iron smelting, oil refining and other aspects, gradually infiltrated into the national defense, industry, agriculture, medicine and other industries, so the world increased the mining of coal. With the excessive use of coal, the global temperature has deteriorated and heated up, causing great damage to the world's ecological environment. In 2003, the concept of "low-carbon economy" emerged to reduce energy consumption and carbon dioxide emissions, so as to resist climate change. The time of "coal" surge and stabilization keeps pace with the hot spot time of international coal policy. This indicates that the burst term intensity is influenced by the political and economic environment at that time and is closely related to relevant policies.

5. Conclusion

According to the published papers number, the research on mine fire can be divided into three stages: initial period (1999-2005), stable transition period (2005-2014), and vigorous growth period (2014-2020), with an overall upward trend.

In terms of research subjects, DENG J from Xi 'an University of Science and Technology in China ranks the top in the 67 prolific authors. In addition, Chinese authors occupy an increasing proportion in this field. There are many scholars studying mine fire in the world, but most of their researches are scattered and there is no large-scale cooperation and communication

From the research space, China Univ Min & Technol ranks first among high-yield institutions, and the cooperation between institutions is mainly in neighboring regions. There is also a strong regional distribution in the cooperation among countries, with China, the United States and Australia as the center of the cooperation network. The countries where the high-yield institutions are located have made significant contributions to the research on mine fire.

Based on the research knowledge, INT J COAL GEOL and FUEL are the most influential journals in COAL, and the paper published in the two journals have strong influence and recognition. Cheng WM, 2017, FUEL, V210, P826, DOI 10.1016/j.fuel.2017.09.007 is the highest cited papers. After 2015, the content of paper is more convincing, accounting for 90% of highly cited paper.

With the research hotspots, mine fire mainly involves basic research fields such as coal spontaneous combustion, goaf fire and low temperature oxidation. Affected by the economic and political environment at that time, the research hotspot lasts for at least two years, accompanied by the emergence and sharp decline of burst term. It is speculated that the research will focus on fire prevention, low carbon, ecology and sustainable development in this field.

Declarations

Ethical Approval

Not applicable.

Consent to Participate

Not applicable.

Consent to Publish

Not applicable.

Authors Contributions

Feiran Wang: Formal analysis, Writing-original draft, Visualization. Bo Tan: Methodology, Conceptualization, Writing-review & editing. Yue Chen: Writing-original draft, Visualization. Xiyang Fang: Formal analysis, Visualization. Guowei Jia: Investigation. Haiyan Wang: Methodology, Conceptualization, Writing-review & editing. Gang Cheng: Investigation. Zhuangzhuang Shao: Investigation.

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Competing interest

The authors declare no conflict of interest.

Availability of data and materials

The data and materials used to support the findings of this study are available from the corresponding author upon request.

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Figures

Figure 1

Chronological distribution of mine fire dispatch

Figure 3

The authors co-citation map

Figure 4

Cooperation relationship map of institutions and cooperative network

Figure 5

Comparison of the paper number between China and the US

Figure 6

A network of country cooperation relationship

Figure 7

Figure 8

Keywords co-occurrence map

Figure 9

Keywords cluster analysis map

Top 25 Keywords with the Strongest Citation Bursts

Figure 10

Keywords burst time analysis diagram