Mapping knowledge domains for mine heat hazard
a bibliometric analysis of research trends and future needs

Zhao, Jiale; Yang, Fu Qiang; Guo, Yong; Ren, Xin

DOI
10.1007/s11356-023-25207-1

Publication date
2023

Document Version
Final published version

Published in
Environmental Science and Pollution Research

Environmental Science and Pollution Research
https://doi.org/10.1007/s11356-023-25207-1

REVIEW ARTICLE

Mapping knowledge domains for mine heat hazard: a bibliometric analysis of research trends and future needs

Jiale Zhao[1] · Fu-Qiang Yang[1] · Yong Guo[1] · Xin Ren[2]

Received: 14 November 2022 / Accepted: 4 January 2023

Abstract
As the shallow mineral resources are nearly depleted, the mining of deep resources has become an urgent problem to be studied. The increase in mine depth can lead to the increase of mine heat hazard, which is a critical concern for mining safety/occupational health and safety. However, there are limited review articles available regarding the prevention of mine heat hazard. To fill in this gap, a bibliometric analysis and knowledge mapping of the field of mine heat hazard prevention are presented in this paper. A total of 314 papers from the Web of Science (WOS) core collection database that published between January 1998 and July 2022 were analyzed using VOSviewer and CiteSpace. China, South Africa, Poland, USA, and Australia are the top five countries in this field. The important journals are *Applied Thermal Engineering*, *Applied Energy*, *Energies*, and *International Journal of Mining Science and Technology*. In addition, the research focal points and two research fronts were identified and discussed. The knowledge base of mine heat hazard research focuses on mine cooling technology, energy efficiency optimization of cooling systems, thermodynamic theory, and occupational health. There are two research fronts. One is to use the numerical simulation method to study various problems such as simulate the performance of refrigeration systems and thermal comfort in mines. The second is to study the occupational health impact of climate change on miners. Therefore, this paper provides readers and academics with an overview of the intellectual structure and knowledge body that have been developed on the subject of mine heat hazard.

Keywords Mine heat hazard · Mine cooling · Occupational health and safety · Bibliometrics · Knowledge mapping

Introduction

Due to the depletion of shallow mineral resources (Xie et al. 2021) and the increased mining depth of existing mines, mine heat hazard has become an important problem limiting deep shaft mining. Currently, more than 100 mines have been exploited at a depth of over 700 m in China (Li et al. 2021a), eighty of these mines are over 1000-m deep (Xie 2021a). The mining rate of deep coal wells is approximately 5–10m per year (Xie 2021b). When the mine depth exceeds 700m, the rock temperature reaches above 35°C, and the highest temperature is nearly 50°C (Cai et al. 2019). High temperature is a serious heat stress that threatens the life and health, of mine workers, let alone their working efficiency (Zhu et al. 2015). Constant exposure to heat stress may lead to health concerns such as heat exhaustion and heat stroke (Ryan and Euler 2017). The symptoms of heat stroke are characterized by fatigue, sweating, and thirst. Moreover, heat stroke can cause neurological damage to workers, resulting in hallucinations, and in extreme cases, may cause workers to die of organ failure (BOUCHAMA and KNOCHEL 2002). High temperature may also lead to severe disasters such as gas protrusion and spontaneous ore combustion (Kong et al. 2017; Xia et al. 2016; Pan et al. 2019). For example, in 2004, a major gas explosion occurred in the Chenjiashan coal mine in China, which killed 166 people; in 2010, the Pike River mine disaster in New Zealand killed 29 people (Cheng et al. 2012); and in the same year, a gas explosion at the Upper Big Branch Mine in the USA left 29 people dead (Davis et al. 2015).

Responsible Editor: Philippe Garrigues

✉ Fu-Qiang Yang
yangfuqiang@fzu.edu.cn

1 College of Environment and Safety Engineering, Fuzhou University, Fuzhou 350116, China

2 Safety and Security Science Group, Faculty of Technology, Policy and Management, TU Delft, 2628, BX, Delft, The Netherlands

Published online: 11 January 2023

Geothermal is not the only heat source that contributes to the high temperature environment in mines. The other heat sources include the heat released by the compression of the underground air, the heat generated by mining machinery, and the heat produced by the oxidation of ores (Shi et al. 2015). Some studies have pointed out that the most significant heat sources are surrounding rock (Xu et al. 2022) and seasonal high temperatures (Feng et al. 2018). Wei et al. (2020) found that surrounding rock heat release contributes to 52.57% of the total heat release in the mine. Głuch (2018) stated that it is incorrect to use equivalent climate temperature as the only parameter for assessing underground microclimate based on the theory of human thermal balance. Moreover， Chu et al. (2022) investigated the airflow thermodynamic parameters of a deep underground long distance tunnel and proposed a method to calculate the cumulative heat load. According to Yang et al. (2020) noted that stratum characteristics, geological structure, and groundwater characteristics are the main causes of anomalous thermal damage with a case study. Li et al. (2021b) suggested that moisture has a critical influence on mine heat exchange and proposed a new numerical model to describe heat and mass transfer processes at a high-temperature and humidity roadway. Han et al. (2019) conducted research on thermal comfort in mines and evaluated the working effectiveness of cooling systems.

In addition to these theoretical studies, researchers have also looked into the technical and engineering aspects of this subject. Modern mine heat damage control techniques mainly focus on non-mechanical cooling methods and mechanical cooling methods. Non-mechanical cooling methods are mainly used in shallow mines where the heat damage is relatively mild, e.g., ventilation cooling (Peng et al. 2014), individual protection (Ngô et al. 2020), and ice-concrete technology (Wang et al. 2018; Shen et al. 2022). As the increase of mine depths and heat hazard, mechanical cooling methods emerged, such as the split-type vapor compression refrigerator (SVCR) (Chen et al. 2016), the high-temperature exchange machinery system (HEMS) (HE 2009), and the central air conditioning cooling system (CACS) (Yang et al. 2011). In recent years, scholars have come to realize that the heat in mines is an available energy source; thus, various types of technology combining cooling and heating have been developed, for example, the recovery of heat from mine water (Bao et al. 2019) and geothermal recycling systems that combine cooling and heating (Guo et al. 2017).

Although research on mine heat hazard is flourishing, there are limited reviews on the status of research regarding mine heat hazard. The Mapping Knowledge Domain (MKD) method is an effective way to process large amounts of literature using computer aid and visualization techniques (Zou et al. 2018). The MKD method belongs to the category of scientometrics. The earliest scientific knowledge maps were graphs of the laws of scientific development after equations had been run. Through the development of technology, scientific knowledge mapping has evolved from two-dimensional to three-dimensional (KRETSCHMER 1994) and even multi-dimensional. In the 1950s, the concept of "citation analysis" (Garfield 2006) became the basis of scientometric (MCCAIN 1998). Since then, clustering analysis of large volumes of literature has become a hot topic in scientometrics. The clusters of articles resulting from cluster analysis show the frontiers and hotspots of the under studied research area. Apart from this, citation analysis is of great help for the scientific community to identify important contributions to the related research field (Börner et al. 2003). In recent years, this method has been widely used to explore research hotspots, development status, and research frontiers in various disciplines, such as coal spontaneous combustion (Liu et al., 2020), mine water inrush (Wu et al. 2022), urban mining (Zhang et al. 2019), mining waste management (Aznar-Sánchez et al. 2018), oxidation studies of sulfide ores (Hong et al. 2020), road safety(Zou et al. 2018), construction safety (Akinlolu et al. 2020), medicine (Qin et al. 2020), and occupational health (Wang et al. 2020). Herein, we attempt to use MKD to conduct a bibliometrics review in the field of mine heat hazard based on a wide range of relevant literature. In this study, we depicted the current research status by mapping the intellectual structure of the mine heat hazard topic. Additionally, future research trends were explored.

Data and methods

Data source

The data in this article comes from the core collection of WOS. To make a comprehensive collection of the relevant research records, several search terms were used. We used ("mine heat" * "mine thermal" * "mine cooling") AND (hazard * hazards * risk * risks) as the search strategy for the topic search. By screening the title, abstract, keywords, and other parts, we got the content related to mine heat hazard prevention and, a total of 314 papers were kept as the dataset for this bibliometrics review. Some basic information of the collected data are shown in Table 1. The search results were saved as "plain txt file" and "full record and cited references."

Table 1 Basic literature information

Data source	Publication time	Number of documents of each document type		
		Article	Conference proceedings	Review
WOS core collection	1998.1–2022.7	204	117	6

Analytical tools and method

The vast literature forms the basis of scientific research, but the huge volume of literature also raises the difficulty to access the knowledge one needs. To deal with this problem, various bibliometric techniques have been developed (Shiffrin and Borner 2004). Early tools for producing knowledge maps were SPSS and Pajek, which produced satisfactory visualization for a small body of literature. However, they could only produce a few simple graphs (van Eck and Waltman 2010), and the resulting maps suffered from serious label overlap when faced with many entries. VOSviewer is a bibliometric analysis tool for quantitative analysis of large volumes of bibliographic data at an aggregate level (van Eck and Waltman 2017). Adopting a unique distance mapping technique, VOSviewer enables users to view the details of bibliometric maps by zooming in and searching, which provides great convenience to researchers who work with a large amount of data. In the field of bibliometrics, the basic methods for analyzing literature include the analysis of citation relations and word relations (van Eck and Waltman 2014). Citespace is another widely used visual bibliometric software. It can be used to generate and analyze the co-occurrence network of keywords and subject categories, as well as the co-citation network of authors, literature, and journals. More importantly, it can build a bibliometric network of different time periods and identify burst keywords, which is helpful to analyze the changing trend of a certain discipline (Liu et al. 2015). Citation relations include direct citation relations, bibliographic coupling relations, and co-citation relations (Klavans and Boyack 2017), of which co-citation relations are obtained by counting the number of times two documents are cited by other documents together. Researchers can construct a knowledge base of a discipline base on co-citation relations to discover the key literature and research frontiers of that discipline. Word relationship is analyzed for words that appear together in the title and abstract of each document (Boyack et al. 2011), from which it is possible to derive keywords that appear with high frequency and that coalesce the author's ideas, research direction. Burst detection analysis can be used to analyze research trends in a particular field (Swar and Khan 2014; Yu et al. 2020), which is achieved by detecting changes in the keywords frequency. A sudden increase in the frequency of an emerging keyword at a certain time may herald a major change in research direction. In addition, this review has also applied frequency analysis and co-authorship analysis to study the key research areas as well as top contributing researchers and their collaborations in the field of mine heat hazard.

Bibliometric analyses

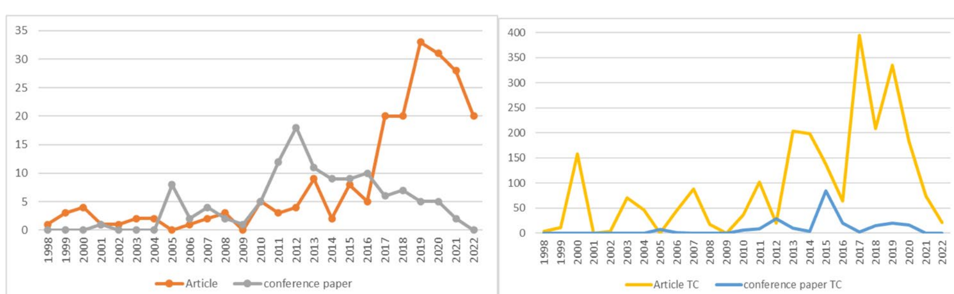
Temporal distribution of the literature

Temporal distribution of word literature

The temporal distribution of the literature related to mine heat hazard over the last 25 years is shown in Fig. 1. The average number of publications per year from 1998 to 2022 is approximately 13.

It can be seen from Fig. 1 that the number of articles published from 1998 to 2009 was low, with 37 articles in total and an average of 3.08 articles per year. These publications have a total of 406 citations, which leads to an average of 10.97 citations per publication. This period can be regarded as the initial stage of mine heat hazard research, and the number of journal articles and that of the conference papers in this period was roughly equal. The most cited article is "Heat exhaustion in a deep underground metalliferous mine" by Donoghue et al. (2000) published in *Occupational and Environmental Medicine* in 2000, with 109 citations. This article examined the incidence, clinical state, and personal risk factors of heat exhaustion among miners in metalliferous mines and noted that the incidence of heat exhaustion was significantly reduced when cooling power was above 250 W/m^2. Lowndes et al. (2004) "The application of exergy analysis to the cooling of a deep UK colliery," published in *Journal of The Southern African Institute of Mining and Metallurgy*, should be regarded as the representative article of this period in mine cooling technology (the most

Fig. 1 Distribution of the number of articles from 1998 to 2022. **a** Distribution of the number of articles. **b** Distribution of the number of citation



(a) Distribution of the number of articles (b) Distribution of the number ofcitation frequently cited). The article evaluates different mine cooling systems based on the concept of exergy to select the most cost-effective and efficient one.

The number of publications started to increase from 2010 to 2016, with 107 articles in total and an average of 15.29 articles per year. These publications have been cited 879 times in total, with an average of 8.21 citations per article. This phase can be considered the developmental stage of mine heat hazard research. The number of journal articles in this period is about half of the number of conference papers. The most cited article is "Health impacts of workplace heat exposure: an epidemiological review" by Xiang et al. (2014), published in *Industrial Health* with 179 citations. It is a review article in which the researchers collected 55 epidemiological studies conducted over a 15-year period on heat impacts at the workplace, pointing out the need for future quantitative studies on the physiological and psychological changes that induced by hot working environment for manual workers. During this period, new directions in technical research emerged. One study focus is the use of various heat recovery techniques to extract heat from the mine for other uses. The earliest searchable article in this direction is "The Analysis of the Cooling System with Gas-power-generation and Waste Heat Refrigeration," published in the proceedings of the 1st International Symposium on Mine Safety Science and Engineering (ISMSSE) by Jian et al. in 2011. The second research direction is the use of thermal insulation in mines. The earliest record on this direction is "Research on Thermal-insulating Material and Roadway Cooling with High Geotherm," (Liu et al. 2012) published in the Proceedings of the 1st International Conference on Energy and Environmental Protection (ICEEP 2012).

The number of articles published in 2017–2022 increased significantly from the previous two periods, with 169 articles in total and an average of 30.73 articles per year (the length of time is recorded as 5.5 years as the search date ends at July 2022). These publications have a total citation of 1126 and an average citation of 6.66 per article. During this period, journal articles greatly outnumbered conference papers. The most frequently cited of all articles is "Coupled cooling method and application of latent heat thermal energy storage combined with pre-cooling of envelope: method and model development" (Yuan et al. 2017). The article proposes a coupled cooling method based on ice storage cooling for the high temperature environment that can occur in a mine refuge after a mining disaster. Representative work in occupational health theory is "Heat stress management in underground mines" (Ryan and Euler 2017). This article proposed that underground temperatures should be detected by environmental monitoring stations placed throughout the mine and that different thermal management strategies should be selected depending on the actual situation. During this period, research on heat stress indices (Roghanchi and Kocsis 2018) began to grow. The heat stress index is a simple method to assess the thermal environment of workers through various personal, physiological, and thermal environment parameters. These parameters are known as Heat stress indices and can be divided into three categories: rational indices (calculated from the heat balance equation); empirical indices; and direct indices (obtained from direct measurements of environmental parameters) (Epstein and Moran 2006). Many parameters are now being invented, which makes it extremely difficult for specific industries to choose the right indices for heat stress assessment. Many heat stress indices have been developed for specific applications and they offer unique advantages in certain areas. The selection of suitable heat stress indices for miners for thermal environment assessment has therefore become an issue that must be investigated. A highly cited article in the WOS database, "Influence of mine shallow roadway on airflow temperature," appeared during this period (Zhang and Huang 2020). The article studied the heat exchange between the surface airflow and the tunnel surrounding rock. The main content was to summarize the surface temperature change law and to establish the mathematical relationship between the surface temperature and the mine temperature. It was pointed out that based on the surface temperature statistics, the surrounding rock of the shallow mine can be used to absorb heat from the summer airflow and release heat from the winter airflow to achieve the underground temperature regulation.

Spatial distribution of the literature

Country/region distribution

According to the dataset, a total of 27 countries have published research related to mine heat hazard, with countries mostly in Asia, Europe, and North America. The top 10 productive countries in terms of the number of publications are listed in Table 2. The data in the table include the number of publications, the percentage of publications of the total collected literature, and the average citations per item (ACI) for each country. The H-index is a hybrid quantitative indicator of the scholarly impact of a researcher. The H-index is usually defined as the number of citations of at least h articles in the data source being counted that do not fall below h.

From the bibliometric analysis, it was found that the four countries with the highest number of research output relating to mine heat hazard from 1998 to 2022 are China, South Africa, Poland, and USA. The temporal distribution of mine heat hazard research literature for these four countries is shown in Fig. 2, with the number of publications per year on the vertical axis and the year on the horizontal axis.

Table 2 Top 10 productive countries in mine heat hazard, 1998–2022

Rank	Country	Region	Numbers	Percentage	ACI	H-index
1	China	Asia	164	51.89%	5.43	17
2	South Africa	Africa	40	12.66%	6.68	7
3	Poland	Europe	24	7.59%	5.17	7
4	USA	North America	22	6.96%	12.55	7
5	Australia	Oceania	21	6.65%	25.62	10
6	Canada	North America	19	6.01%	11.16	7
7	England	Europe	12	3.79%	12.67	6
8	Ghana	Africa	7	2.22%	8.43	4
9	Germany	Europe	6	1.89%	18.17	4
10	India	Asia	5	1.58%	2.8	2

As can be seen in Fig. 2, the literature on mine heat hazard in China, although late in appearing, is far more numerous than that of the other countries. China has been the most active country in this research area since 2011. After forming the first research peak in 2012 and 2013, Chinese researchers started a new research boom in 2017. In 2012, the Chinese government reformed the coal market and abolished the long-standing dual-track system of electricity coal prices, which meant that the government no longer set a guide price for coal, and coal prices were completely regulated by the market. This greatly stimulated the vitality of the coal market and the development of the coal industry. In 2017, Chinese government implemented a policy to remove outdated technologies from the coal industry and vigorously promoting coal enterprises to implement new technologies. Since the industrial upgrading is inseparable from technological support, so a new research climax appeared. The research interests of Chinese researchers lie in mine cooling techniques. Only one of the top 20 most cited articles from China focus on occupational health theory. South Africa has the second highest number of publications on mine heat hazard, which is in part related to the mining of several famous deep shafts such as Mponeng, TauTona, and Driefontein mines. Researchers in South Africa are keen to optimize cooling systems or to optimize management strategies to achieve energy savings. Research on mine heat hazard in South Africa was concentrated in 2013–2019, with no new literature published in the last 2 years. Research on mine heat hazard in Poland peaked in 2010 and 2019, with a gradual decrease in the number of publications in recent years. Researchers in Poland prefer to use mathematical methods for their studies, and the most cited literature in the country is on the use of mathematical models to predict underground temperatures. The number of research publications in the USA started to increase more significantly in 2017. USA has a relatively high number of studies on heat strain models for miners.

China, the country with the highest number of publications, also ranks first in the H-index, but with an ACI of

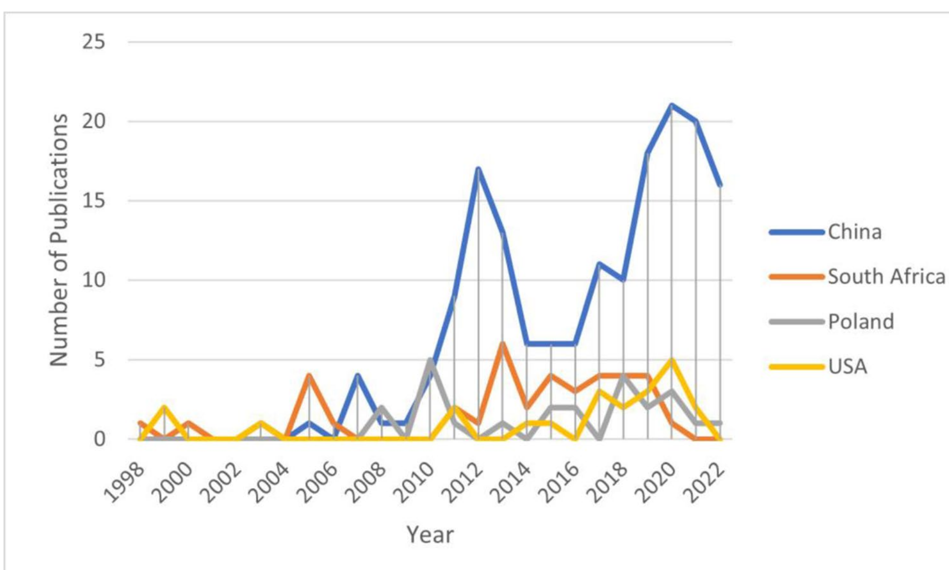


Fig. 2 Publication trend of the top 4 most productive countries (China, South Africa, Poland, and USA), 1998–2022

5.43. Australia, the fifth most published country, has the world's highest ACI and the world's second highest H-index. Australian academics focus their research on occupational health. It is found in Table 2 that the top 5 highest ACI countries are Australia, Germany, UK, USA, and Canada, and the top 6 highest H-index countries are China, Australia, South Africa, Poland, USA, and Canada. This shows that the overall quality of European and American articles is high, while the regions with the greatest academic impact are Asia and Australia. It is worth noting that, although Ghana is ranked eighth in terms of number of articles published, all their articles are published by or in collaboration with Australian universities.

The country co-authorship networks obtained from the dataset are shown in Fig. 3. In Fig. 3a, the countries with larger nodes have more publications. The more lines a country has, the more collaborations this country has. In Fig. 3b, colors from green to yellow represent the frequency of occurrence of the analysis item from high to low. South Africa is not closely related to other countries in the field of mine heat damage, which may be related to that they focus on mine cooling system optimization research. It is clearly shown that China, USA, and Poland have established close cooperation relationship. Australia and Ghana are within one cluster, which is attributed to several papers by Australian academics on assessing the working environment of miners in Ghana.

Research focus distribution

The top 10 research areas in mine heat hazard research are listed in Table 3. Table 3 shows that the current research on mine heat hazard is dominated by mine cooling systems, which is reflected in the key topics of "Engineering," "Energy Fuels," and "Thermodynamics." However, the literature under "Energy Fuels" is not just on cooling systems, but also includes a significant part of the research on geothermal energy harvesting. Surprisingly, "Public Environmental Occupational Health" only ranks the seventh, which shows that few studies focus on the impact of mine heat hazard on mining workers.

Table 3 Top 10 research areas in mine heat hazard, 1998–2022

Rank	Research area	Quantity	Percentage
1	Engineering	117	37.025%
2	Mining Mineral Processing	91	28.797%
3	Energy Fuels	74	23.418%
4	Thermodynamics	42	13.291%
5	Environmental Sciences Ecology	32	10.127%
6	Construction Building Technology	24	7.595%
7	Public Environmental Occupational Health	23	7.278%
8	Materials Science	22	6.962%
9	Metallurgy Metallurgical Engineering	21	6.646%
10	Geology	19	6.013%

The research on occupational health theory did not get enough research attention in the past. However, most occupational health articles have been published in recent years, indicating a trend of research focus. "Materials Science" includes the research into the application of new materials for cooling in mine tunnels and the use of new materials for wearable cooling equipment, ranked eighth with a large proportion of its studies published in the last 5 years. In summary, the main research focal areas in mine heat hazard research are "Engineering," "Energy Fuels," and "Thermodynamics." Another observation is that the research branch in material science showed a growing trend.

Institute distribution of literature

The WOS database shows that 277 research institutions have published on the subject of mine heat hazard. However, most of these institutions have published less than 4 articles, only 31 institutions have published more than or equal to 4 articles. The top 12 productive institutions are listed in Table 4. It can be seen that these 12 institutions are mostly located in China, Australia, South Africa, and Poland, which verified the previous observation in Subsection "Country/region distribution." Among the top 12

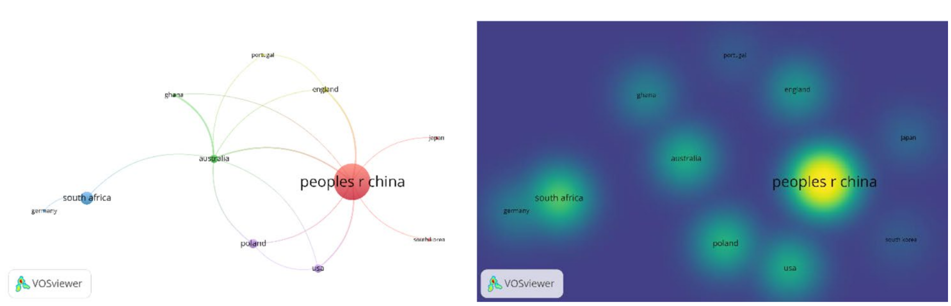


Fig. 3 The country co-authorship networks based on the WOS core collection. **a** Cooperation network. **b** The heat map of cooperation countries

(a) Cooperation network

(b)The heat map of cooperation Countries

Table 4 Top 12 research institutes in mine heat hazard, 1998–2022

Rank	Institute	Country	Quantity	Percentage	ACI	H-index
1	China University of Mining and Technology	China	44	13.924%	4.61	9
2	North West University South Africa	South Africa	25	7.911%	7.72	5
3	Shandong University of Science and Technology	China	24	7.595%	1.5	3
4	Agh University of Science and Technology	Poland	13	4.114%	5.08	5
5	Xi'an University of Science and Technology	China	12	3.797%	8.25	6
6	University Of Science and Technology Beijing	China	10	3.165%	5.9	4
7	McGill University	Canada	8	7.278%	15.88	5
8	Central South University	China	7	2.532%	2.71	2
9	Edith Cowan University	Australia	7	2.215%	8.43	4
10	Hunan University of Science Technology	China	7	2.215%	4.86	3
11	Ministry of Education China	China	7	2.215%	9.86	4
12	Takoradi Technical University	Ghana	7	2.215%	8.43	4

institutions, 7 institutions are from China. It is worth noting that the number of articles published by "China University of Mining and Technology" is significantly higher than that of the other institutions. Moreover, its H-index also ranks the first. However, the institution with the highest ACI is "McGill University."

The co-authorship network of the research institutions was constructed using VOSviewer and visualized in Fig. 4. The size of the nodes in the figure represents the number of published literature by the institutions. The collaboration between the research institutions in China is relatively close. In Fig. 4, the red, blue, and light blue clusters are all composed of Chinese research institutions. It can be seen that there is frequent collaborations between China University of Mining and Technology, Shandong University of Science and Technology, Xi'an University of Science and Technology, and Agh University of Science and Technology.

Publication distribution

The top 10 publications that have the most publications are listed in Table 5. *Applied Energy* published articles with the highest impact factor and the highest ACI, which indicates the high quality of the literature published in this journal on mine heat hazard research. The journal with the second highest ACI is *Advances in Civil Engineering*. *Case Studies in Thermal Engineering* has the fourth highest impact factor, but the ACI and h-index rankings are low, since the relevant literature have only appeared in this journal in the last 3 years.

Publication bibliographic coupling provides insights into the thematic similarity between articles published in various journals. A bibliographic coupling analysis was performed and the results are mapped out in science maps as shown in Fig. 5. Five distinct groups can be seen in this graph.

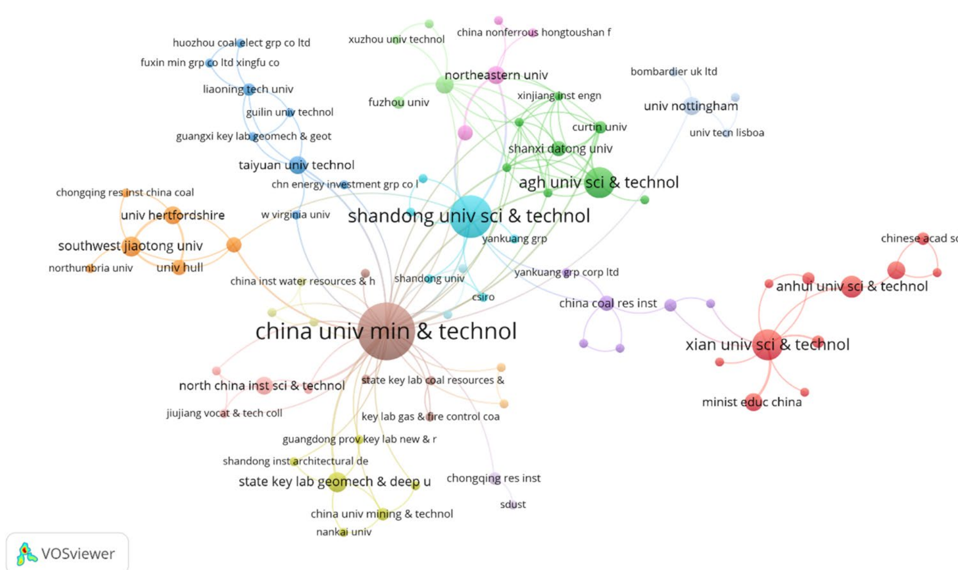
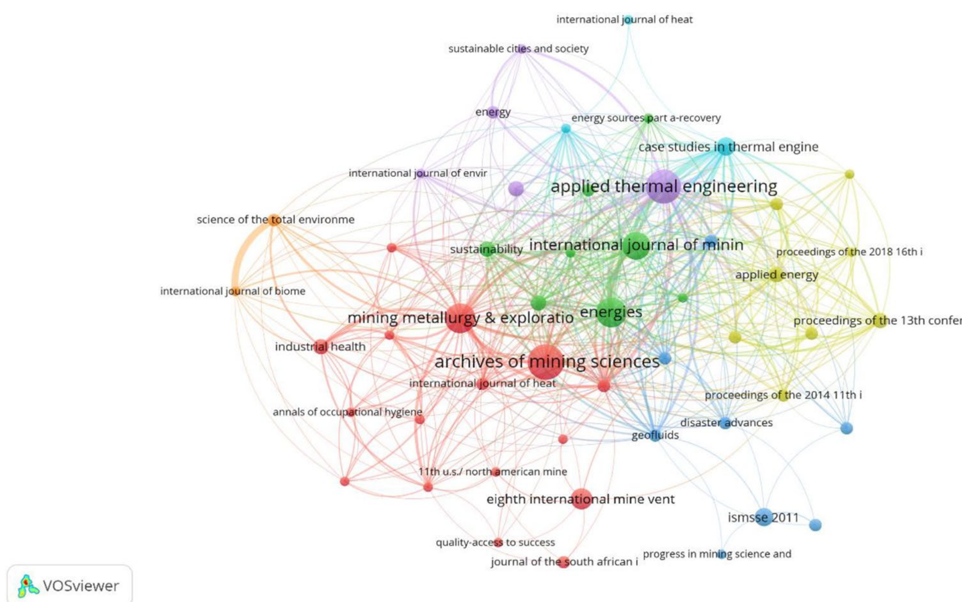


Fig. 4 The mine heat hazard research institution co-authorship networks

Table 5 Top 10 publications in mine heat hazard, 1998–2022

Rank	Journal	Number	Citation index	Impact factor (2021)	H-index	ACI
1	*Archives of Mining Sciences*	13	SCIE	1.435	5	4.69
2	*Applied Thermal Engineering*	12	SCIE	6.465	9	19.42
3	*Energies*	9	SCIE	3.252	3	2.89
4	*International journal of mining science and technology*	9	SCIE	7.67	6	13.56
5	*Mining Metallurgy & Exploration*	9	SCIE	1.695	2	1.78
6	*Case Studies in Thermal Engineering*	5	SCIE	6.268	2	3
7	*Advances in Civil Engineering*	4	SCIE	1.843	3	22.25
8	*Applied Energy*	4	SCIE	11.446	4	39.74
9	*Sustainability*	4	SCIE/SSCI	3.889	2	16
10	*Disaster Advances*	3	SCIE	2.272	2	6

Fig. 5 Cooperation network of main research journals for mine heat hazard, 1998–2022



Although these journals are divided into different colored groups, in general, they are interested in cooling technology. The red and green groups have a greater emphasis on occupational health research alongside cooling technology. The purple group focuses on both cooling technology and geothermal development. Journals in the blue cluster pay more attention to the theoretical studies of thermodynamics in mining environments.

Highly cited literature analysis

The highly cited literature represents the most concerned research topic in a certain field and the key contributions of the subject. The top 10 most cited publications are ranked in Table 6 according to total citation (TC). Besides, ACY stands for "average citations per year." These ten papers span from 2000 to 2017 and cover occupational health research related to heat radiation sickness (Donoghue et al. 2000), development of cooling technologies (Yuan et al. 2017), and thermal management of mines (Sasmito et al. 2015). Yuan et al. (2017) combined latent heat thermal energy storage (LHTES) with pre-cooling of envelope (PE); the principle of this method is to use forced-air to cool the PCM unit in the building at ordinary times, so that the PCM can cool the building through its own latent heat storage capacity at work time. The research results of Sasmito et al. (2015) show that the most significant factor affecting the tunnel temperature distribution is the temperature of the ventilation air flow, followed by the surrounding rock temperature and ventilation flow. The heat generated by the typical mining machinery increases the temperature of the roadway near the working face by about 5 °C, and at a distance of 30 m from the working face, the temperature rises to 10 °C. Obviously, when mining machinery is in active operation,

Table 6 The top 10 most cited papers, 2000–2020

Rank	TC	ACY	Title	Authors	Journal	Year
1	179	19.89	Health Impacts of Workplace Heat Exposure: An Epidemiological Review	Xiang et al	*Industrial Health*	2014
2	109	4.74	Heat exhaustion in a deep underground metalliferous mine	Donoghue et al	*Occupational and Environmental Medicine*	2000
3	87	7.25	Multi-objective optimization of HVAC system with an evolutionary computation algorithm	Kusiak et al	*Energy*	2011
4	70	11.67	Coupled cooling method and application of latent heat thermal energy storage combined with pre-cooling of envelope: Method and model development	Yuan et al	*Energy*	2017
5	70	4.38	The thermal work limit is a simple reliable heat index for the protection of workers in thermally stressful environments	Miller et al	*Annals of Occupational Hygiene*	2007
6	57	5.7	The use of variable speed drives for cost-effective energy savings in South African mine cooling systems	Du Plessis et al	*Applied Energy*	2013
7	53	2.65	Nonlinear control of mine ventilation networks	Hu et al	*Systems & Control Letters*	2003
8	49	4.9	Case study: The effects of a variable flow energy saving strategy on a deep-mine cooling system	Du Plessis et al	*Applied Energy*	2013
9	48	8	Sustainable Post-Mining Land Use: Are Closed Metal Mines Abandoned or Re-Used Space?	Kivinen	*Sustainability*	2017
10	47	5.88	Computational evaluation of thermal management strategies in an underground mine	Sasmito et al	*Applied Thermal Engineering*	2015

TC total citations, *AC* average citations per year

additional cooling is required. Eight of these ten articles were published before 2016, and to some extent depicted the key research directions in the beginning and development stages of mine heat damage research, i.e., heat exhaustion-related research and cooling system optimization. The two articles published after 2016 focused on new mine cooling technologies and the reuse of abandoned mines (Kivinen 2017). Kivinen (2017) points out that in addition to being turned into an industrial heritage site, abandoned mines can also be turned into sites for aquaculture, water sports, and other recreational activities.

Co-authorship analysis

A total of 919 scholars have published studies in the field of mine heat hazard. The authors with 5 or more publications are listed in Table 7. In Table 7, TLS stands for "total link strength," which indicates how often the author collaborates

Table 7 Top 13 productive authors in mine heat hazard, 1998–2022

Rank	Author	Organization	Country	Quantities	ACI	H-index	TLS
1	Liu, Lang	Xi'an Univ Sci & Technol	China	7	9.43	4	36
2	Nunfam, Victor Fanam	Edith Cowan Univ; Takoradi Tech Univ	Australia; Ghana	7	8.43	4	23
3	Kleingeld, M	Northwest Univ	South Africa	7	5.14	2	14
4	Wang, Mei	Xi'an Univ Sci & Technol	China	6	9.29	4	31
5	Ghoreishi-madiseh, seyed ali	Univ British Columbia	Canda	6	11.33	4	19
6	Mare, P	Northwest Univ	South Africa	6	5.5	2	13
7	Zhang, Xiao Yan	Xi'an Univ Sci & Technol	China	5	10.83	4	26
8	Adusei-asante, Kwadwo	Edith Cowan Univ	Australia	5	10.8	4	22
9	Frimpong, Kwasi	Edith Cowan Univ; Ghana Inst Management & Publ Adm	Australia; Ghana	5	10.8	4	22
10	Oosthuizen, Jacques	Edith Cowan Univ	Australia	5	10.8	4	22
11	Van Etten, Eddie John	Edith Cowan Univ	Australia	5	10.8	4	22
12	Sasmito, Agus P	McGill Univ	Canada	5	17.5	3	17
13	Schutte, A. J.	CRCED Pretoria	South Africa	5	0.67	1	11

with other authors. There are many Australian scholars who ranked 7–11 in the number of publications have published five papers together. These five papers are mainly about the risk of heat stress for miners in Ghana in high temperature environment. Table 7 shows that there was no noticeable mismatch in ACI and H-index of the top 13 productive authors. The TLS of two Chinese scholars is remarkably higher than the others, which indicates that these two scholars have more frequent collaborations.

The co-authorship network of mine heat hazard research constructed based on the collected dataset using VOSviewer is shown in Fig. 6. There are 60 authors who have published more than 3 papers on the topic. The larger the node in the graph, the higher the number of publications by the author. As seen in Fig. 6, there are several smaller collaborative clusters among scholars in the field of mine heat hazard research, and the top five authors represent four of the larger collaborative clusters. Such as the light blue cluster on the top that consists of Liu, Wang, Wang, W, the green cluster represented by Nunfam, Victor Fanam, the yellow cluster represented by Ghoreishi-madiseh, seyed ali, and the red clusters represented by Kleingeld, M. The main research direction of the light blue cluster is the development of new material-based mine cooling technologies (Wang et al. 2019). The main research direction of the yellow cluster is cooling systems using renewable energy sources (Ghoreishi-Madiseh et al. 2017). The main research direction of the red cluster is the optimization of mine cooling systems to improve performance (Pretorius et al. 2019).

Research knowledge base

Co-citation analysis is an important step in bibliometric analysis. Co-citation analysis refers to the analysis of the interrelationship between two documents that are cited together by a third document (Gou et al. 2022). It has the advantage of identifying the key foundational literature in a particular discipline. These literatures are usually repeatedly cited by scholars in the field and are essential for beginners to understand the basics of a research field. This literature, after a long period of validation, will become a widely recognized scientific paradigm and knowledge base in the corresponding field of research (Backhaus et al. 2011). Co-citation analysis is not only used to analyze the relationship between the literature, but also used to analyze the relationship between journals. Highly co-cited journals in a certain

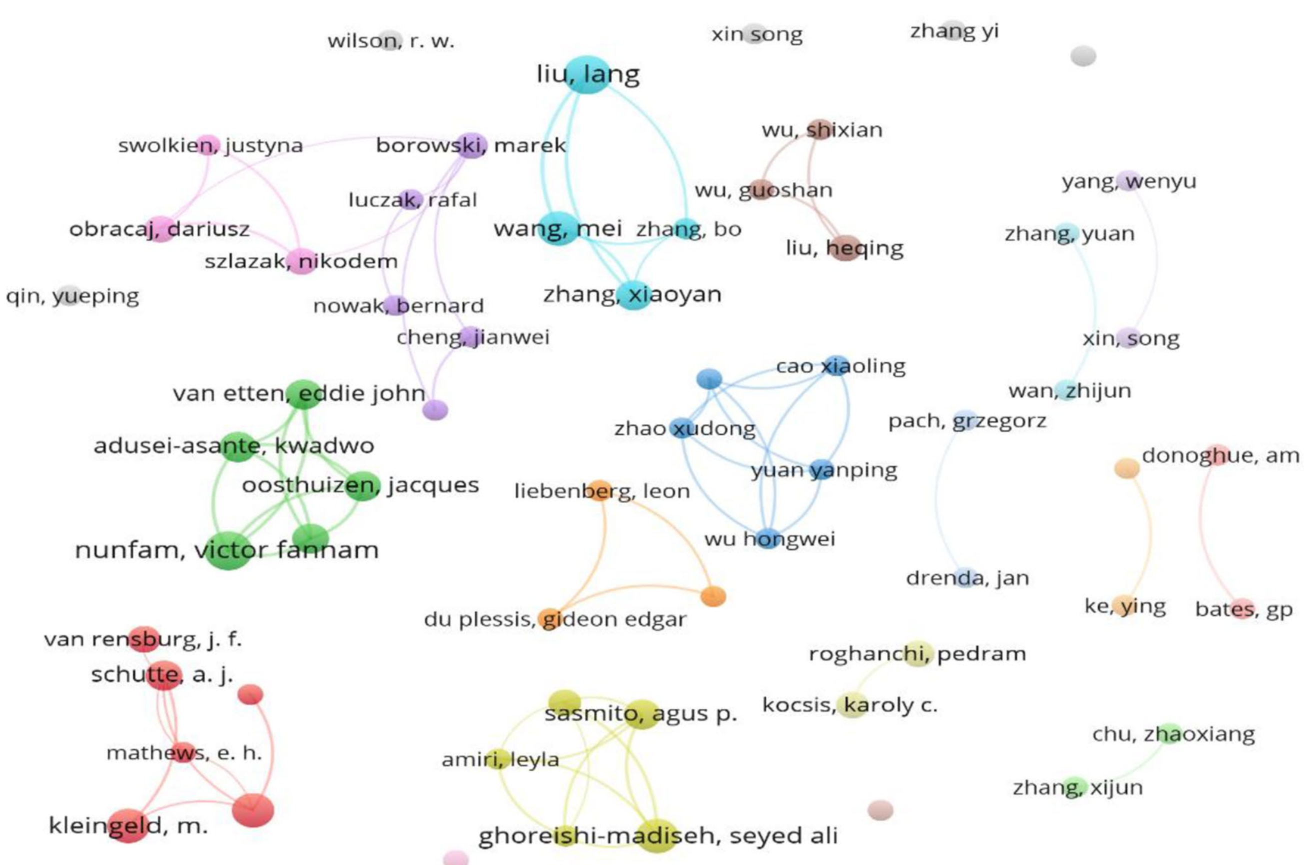


Fig. 6 Authors' cooperation network in mine heat hazard, 1998–2022

research area are often highly valued journals in the field and their publications often represent the frontiers and hotspots of research development. The analysis of co-cited journals can assist academics working on this topic to identify the high quality and high impact journals in the field.

The reference co-citation analysis

The stronger the co-citation relationship between the publications, the more relevant their research contents are (Mustafee et al. 2013). A total of 60 records were obtained by setting the minimum number of co-citations to 7. The co-citation network of the collected publications is illustrated in Fig. 7. The node size in this figure denotes the citing frequency of the publication. The references in Fig. 7 were divided into four clear clusters, with 22 documents in the red cluster, 15 documents in the green cluster, 12 documents in the blue cluster, and 11 documents in the yellow cluster. A detailed analysis of the most cited literature in these four clusters by year of publication is presented below.

The Red Group: The Red Group represents the occupational health study in the field of mine heat hazard. In 2000, Donoghue et al. (2000) studied 106 heat exhaustion cases in mines, counted patients' changes in key physiological indicators, and concluded that heat exhaustion is inextricably linked to symptoms such as dehydration, eosinopenia, and metabolic acidosis. Following this, Donoghue, after counting 538 cases in the US mining industry, noted that the incidence is less in coal mines than that in metal mines. Moreover, the incidence is significantly higher in summer than in other seasons, and lower in open pit mining than in underground mining (Donoghue 2004). Kalkowsky et al. (2006) studied the increasingly hot working environment in German coal mines, stating that workers should be provided with drinking water at the workplace and changes should be made to the working regimes. Apart from this, heat exposure indices have been used to assess the effects of climate change on human occupational health (Kjellstrom et al. 2009). Kenny et al. (2012) studied the effects of different underground tasks on the physiological changes of workers, noting that the energy expenditure by different tasks, although different, has little effect on the changes in miners' body temperature. Ryan et al. (2017) pointed out that mine managers need to install suitable facilities for environmental temperature detection and improve the underground thermal environment

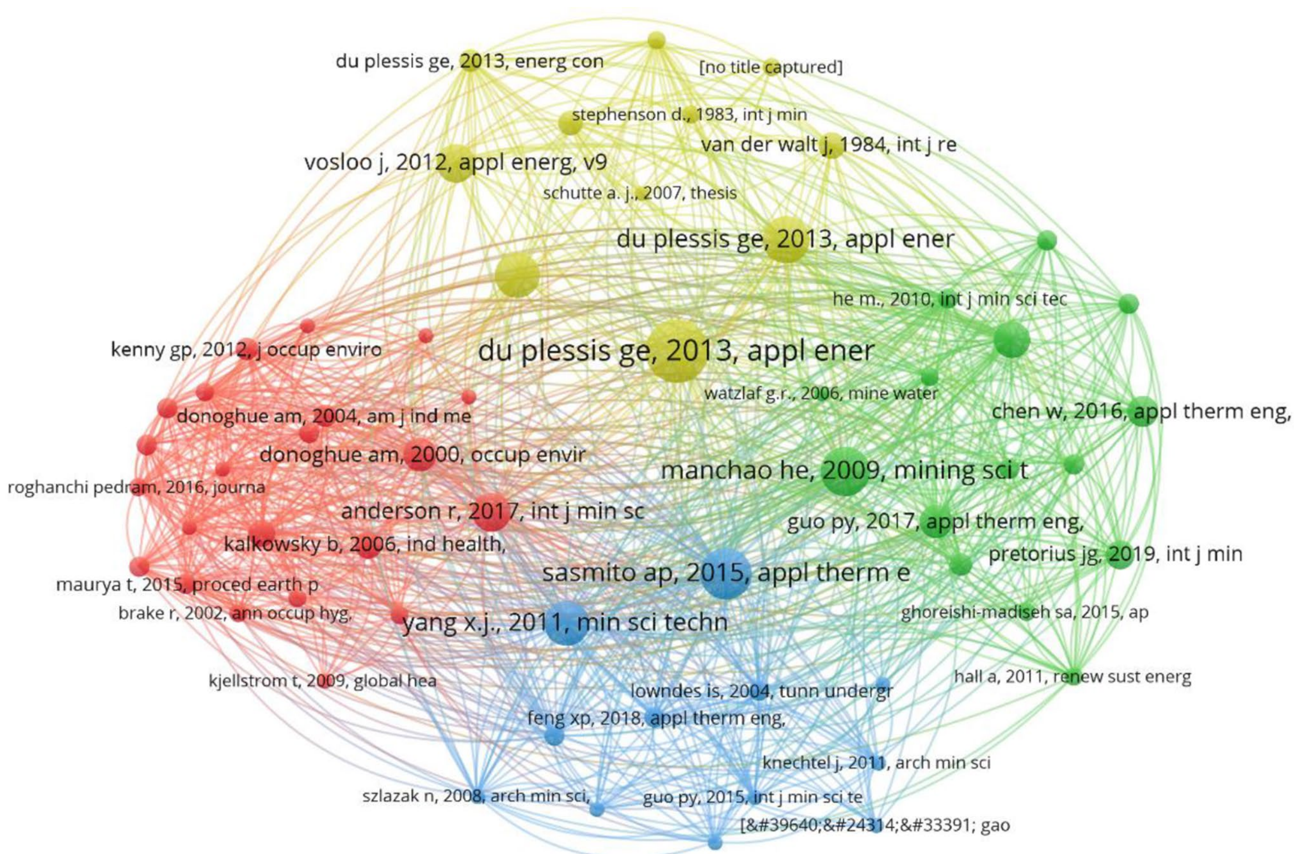


Fig. 7 The reference co-citation network of mine heat hazard publications, 1998–2022

through ventilation systems. In summary, the occupational health in the field of mine heat hazard has gradually evolved from case investigations to the change in work regime and work environment, relying on case and experimental results. This change indicates that mine thermal hazards cannot be addressed by management tools alone, and reasonable mine cooling systems must be developed.

Green Group: The research direction of Green Group is mine cooling system. He (2009) invented the HEMS (the high-temperature exchange machinery system) that uses mine surge water as a cooling source, which has been successfully applied in the jiahe Mine, and it is found out that this system can reduce the working surface temperature by 4–6°C. Chen et al. (2016) developed the SVCR (split-type vapor compression refrigerator) system. This system relies on the evaporation of a specially formulated refrigerant to cool down the mine, and it outperforms the cooling water system. Guo et al. (2017) developed the Geothermal Recycling System for Mines (GRSM) by combining geothermal recovery with refrigeration, and the effectiveness of this system is greatly improved compared to traditional cooling systems such as water cooling and air cooling. It can be seen that the newly developed cooling system is not only pursuing better refrigeration effects but also pursuing higher energy efficiency.

Blue Group: The Blue Group focused on theoretical studies of mine heat hazard. Yang et al. (2011) summarized previous studies and attributed the causes of heat damage to climate, geological, and mining factors, of which geological factors are the primary ones. Sasmito et al. (2015) concluded that ventilation temperature has the greatest influence on the temperature distribution in the mine channel and pointed out the need to further optimize the thermal management strategies to reduce energy consumption.

Yellow Group: The Yellow Group's research focus on energy saving in refrigeration systems. Vosloo et al. successfully saved 13% of the operating costs of a deep well water network system using Real-Time Energy Management System™ (REMS) (Vosloo et al. 2012). With the same technique, du Plessis et al. (2013a) developed an energy saving strategy that can reduce the power consumption by 31.5%. In addition, variable speed drive (VSD) technology has been applied to optimize energy savings in cooling systems (Du Plessis et al. 2013b).

In summary, there are four main research directions in the field of mine heat damage research. Except for the occupational health direction, the remaining three directions are more closely related to each other, especially the principal study of mine cooling systems (the blue group) and the energy conservation study (the yellow group).

The journal co-citation analysis

Through the co-citation analysis of journals, it is possible to identify the journals that are more active and influential in the field of mine heat damage. Figure 8 is obtained through the journal co-citation analysis of the literature on mine heat hazard research by VOSviewer. The literature are divided

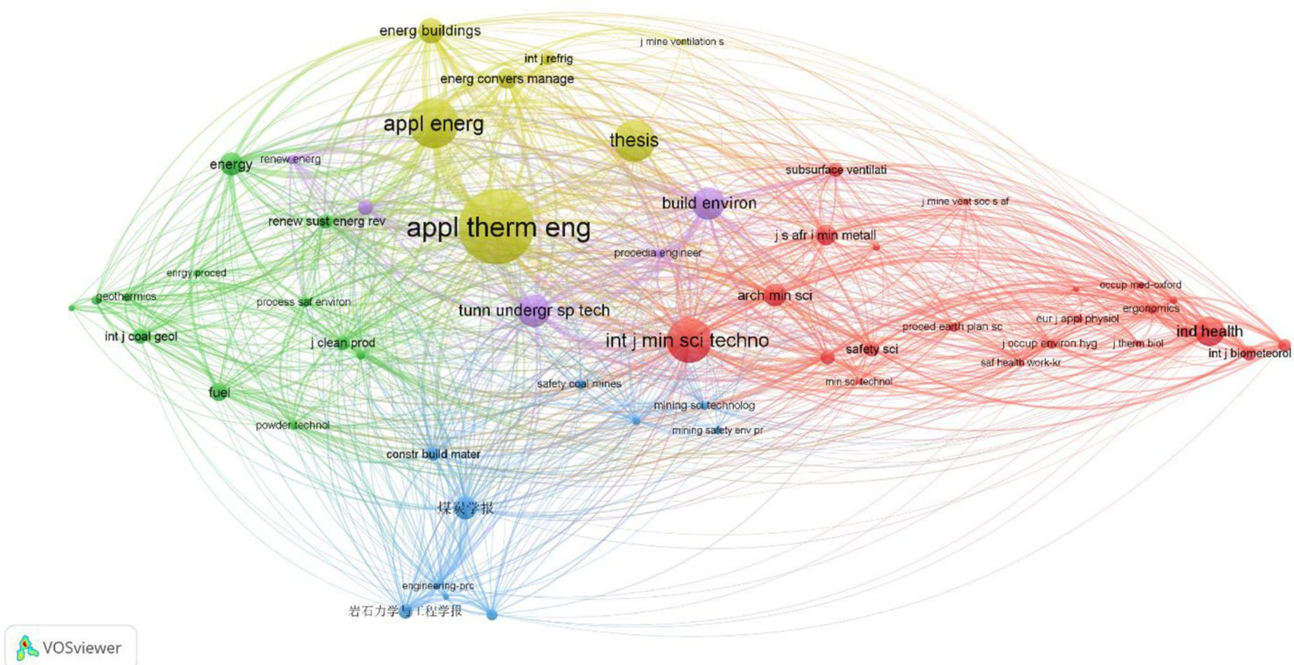


Fig. 8 The journal co-citation network of mine heat hazard publications, 1998–2022

Table 8 The top 10 keywords of mine heat hazard, 1998–2022

Rank	Keyword	Occurrence	TLS
1	Performance	25	76
2	System	20	50
3	Heat	18	45
4	Ventilation	18	38
5	Numerical Simulation	17	15
6	Temperature	15	49
7	Mine Cooling	15	40
8	Heat Stress	15	26
9	Model	15	25
10	Mine	14	43

into five clusters. The yellow cluster contains the most impactful journals. In addition to international journals, two journals from China are included in the blue cluster. The main research field of these journals is engineering technology. However, some medical journals are included in the red cluster. Referring to the analysis in Subsection publication distribution, we can broadly identify the most impactful journals in the field of mine heat hazard, which are *Applied Thermal Engineering*, *Applied Energy*, *Energies*, and *International Journal of Mining Science and Technology*.

Research hotspots and frontiers

Research hotspot analysis

Keywords are credible representations of the research topic and content, as well as the working domain of the scholar. When a keyword appears frequently in the literature of a research field, the keyword represents the hotspot and focus of the scientific community. Therefore, the keyword co-occurrence analysis can effectively identify the important research directions in mine heat hazard. After importing the collected data into VOSviewer, the software identified a total of 1200 keywords. In the end, 54 keywords were included in the network by setting the minimum occurrence frequency to 5. The top ten most frequent appeared keywords are listed in Table 8.

The keyword co-occurrence network of mine heat hazard research is presented in Fig. 9. The larger the node is in the figure, the more frequent this keyword appears in studies. The terms with high relevance form clusters in the same color. As can be seen in Fig. 9, there are six keyword clusters. The blue cluster is at the center of the network, and this cluster focuses on system and optimization. Highlighted

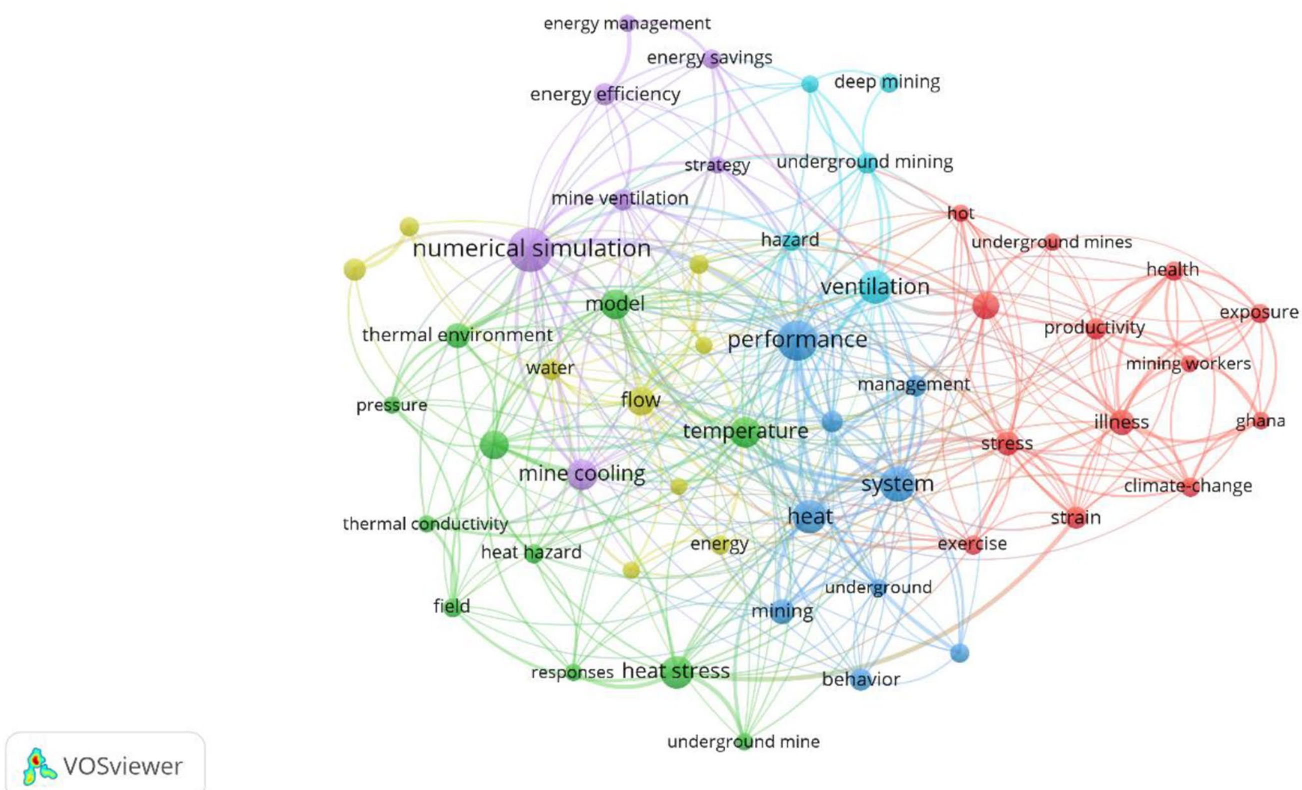


Fig. 9 Keywords co-occurrence network of mine heat hazard, 1998–2022

keywords in the red cluster are Illness, Health, and Exposure. Clearly, the red cluster focuses on occupational health research. The research direction of the shallow blue cluster is ventilation technology, using Ventilation to cool down against underground heat sources. The focus of the yellow cluster is to study various heat transfers in the mine, including the heat transfer between the external wind flow and the surrounding rock of the mine, and the extraction of geothermal energy through heat transfer. Purple cluster research focuses on finding more energy-efficient energy management strategies for deep wells and more effective cooling measures. Green clusters focus on exploring the distribution of downhole temperature field.

With the above observations, we attempt to merge these six clusters into three groups, namely the thermodynamic theory group, which includes the yellow cluster and the green cluster; the industry applications group, which consists the blue cluster, the purple cluster, and the shallow blue cluster; and the occupational health group, which has only the red cluster. The first two clusters are described below. The occupational health cluster has been discussed in Subsection "The reference co-citation analysis."

Thermodynamic theory group: In this group, many scholars have developed new cooling methods through heat transfer principles. For example, the use of the surrounding rock to save cold energy or heat (Ghoreishi-Madiseh et al. 2017), the cooling method of adding Phase Change Material (PCM) to backfill material (Wang et al. 2019a), and the employment of Ground Source Heat Pump (GSHP) (Athresh et al. 2016). There are also studies regarding mine temperature fields (Zhang et al. 2017) and applying numerical simulation methods to study the thermal environment (Wang et al. 2019b). In general, the research in this group is directed toward various theoretical explorations.

Industry applications group: In this cluster, many scholars have developed many cooling systems and system optimization techniques that are already in use, so we named this group as Industry applications, for example, HVAC optimization (Kusiak et al. 2011), optimization of ventilation network control (Zhai et al. 2019), energy-saving optimization of deep well cooling systems (Athresh et al. 2016), SVCR refrigeration systems (Chen et al. 2016), and HEMS refrigeration systems (HE 2009). In general, the research direction of this group focuses on the needs of the industry, from the early mine ventilation network research to the development and optimization of refrigeration systems for deep mines.

Research frontiers

The burst detection algorithm (BDA) was first proposed in 2003 with the original intention to deal with large amount of text, such as large amounts of emails and research results (Kleinberg 2003). BDA builds on the formulation of Markov sources that are used in modeling burst network traffic and the established hidden Markov models. BDA identifies burst keywords by detecting changes in their frequency of occurrence and ranks burst keywords according to their weights. Nowadays, BDA is applied to identify the research frontiers of a discipline in a certain period thanks to its ability to detect keyword surge within a period of time. This hotspot analysis was performed using Citespace. The top 10 burst keywords and their corresponding weights were derived. These keywords were further ordered by the occurrence year, as shown in Fig. 10.

As medical researchers pay more attention to mine heat hazards research, the first burst keyword was "Heat Exhaustion." In 2016, heat hazard in coal mines became a hot topic, together with new technologies such as geothermal

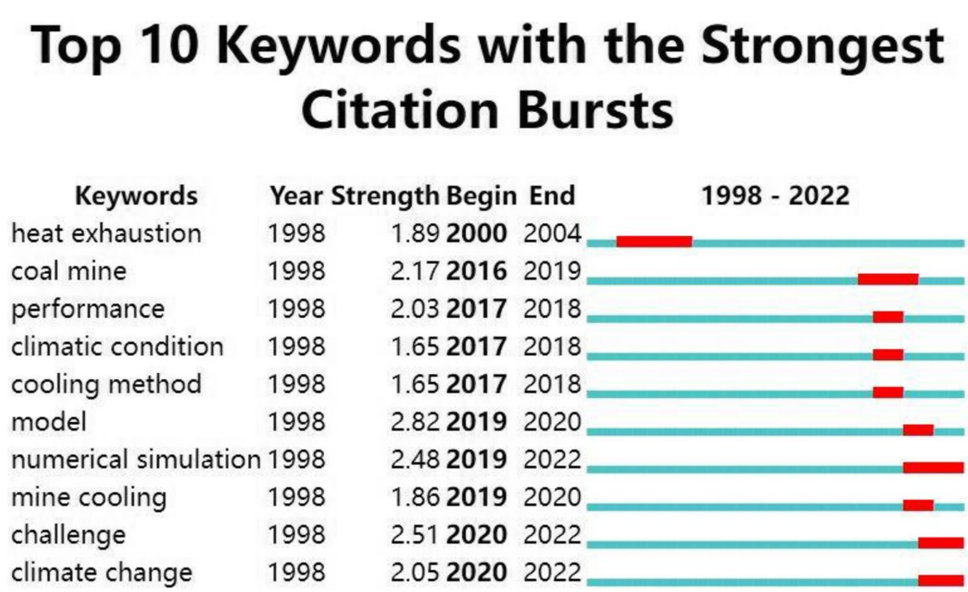


Fig. 10 Top 10 burst keywords of mine heat hazard, 1998–2022

recovery and envelope cooling emerged during this period, as described in the previous section. After 2019, the numerical simulation method become a new research hotspot, which is used to study thermal comfort in mines (Han et al. 2019), to simulate the performance of refrigeration systems (Zhai et al. 2019), and to investigate the oxidation of coal in thermal environments (Wang et al. 2013). After 2020, coping with climate change becomes a new research hotspot (Nunfam et al. 2019a; Nunfam et al. 2019b).

Discussion

Mine heat hazard prevention is a broad topic, including many studies, but its main body is mine cooling technology and occupational health research.

The most systematic research in this field is mine cooling technology, from ventilation technology to manual air conditioning technology. At present, with the development of artificial air conditioning technology tending to be mature, a variety of new cooling technologies have emerged. As a novel cooling technology, ice concrete technology adopts a different strategy from traditional cooling means, which provides a new idea for mine heat damage prevention by using cooling materials to absorb heat. As the depth of a mine increases, so does the energy consumed by the mine cooling system, meaning that finding reasonable and feasible energy saving strategies for ultra-deep shafts is a must, and South African researchers are at the forefront of the world in this regard. In addition, the heat pump technology, which can keep the temperature in the mine relatively constant, is a new technology rising from the traditional cooling method and has a certain development prospect.

In the early years of the twenty-first century, occupational health studies on heat stress in mines focused on the analysis of various symptoms that occur in miners. In recent years, such studies focused on the thermal comfort of miners to keep them working efficiently. Unlike other fields of safety science research, there is a lot of literature on quantitative analysis of mine thermal hazard levels, which may be due to the perfection of existing thermal hazard assessment standards, but these standards may need to be further revised when future mine depths are further deepened.

One contribution of this review is the identification of the research hotpots and research frontiers of mine heat hazard research in recent years. Undeniably, there are some limitations in this paper. The included literature from the WOS database is not an exhaustive collection of publications on mine heat hazard. And, the literature of mine heat hazard research contains fragmented keywords, and we may miss a very small number of articles with cold keywords. Nevertheless, this bibliometric review is believed to provide a strong reference concerning the research status and knowledge structure for scholars working in this field.

Conclusion

In this paper, two bibliometric tools, VOSviewer and Citespace, were used to develop the knowledge maps of mine heat hazard research. The obtained knowledge maps can effectively help researchers understand the current research trend and knowledge base of this field. In this study, the collected literature were analyzed concerning their spatial and temporal distributions. Moreover, co-authors networks, institution co-authorship networks, and journal co-citation networks were constructed. Furthermore, reference co-citation analysis and burst keyword analysis were performed. In the end, the main research conclusions are drawn as follows.

1. The current research on mine heat hazard has entered a booming period with a dramatict growth in the number of publications. The top 5 most active countries in this field are China, South Africa, Poland, USA, and Australia. Noticeably, the number of publications from China is significantly higher than other countries. The most productive research institutions in this field are China University of Mining and Technology, North West University of South Africa, and Shandong University of Science and Technology. The most influential journals in this field are *Applied Thermal Engineering*, *Applied Energy*, *Energies*, and *International Journal of Mining Science and Technology*. The top 3 authors with the most publications in this field are Liu Lang, Nunfam Victor Fanam, and Kleingeld M.
2. In the current research on heat damage in mines, the research attention distributed to occupational health theory is relatively low, with only two articles on this topic in the top ten highly cited articles. However, the articles on mine cooling technology accounts for most of the total publications. This research direction focuses on the development of new cooling technologies and the energy saving optimization of existing cooling systems. Through burst keyword analysis, we observed that the current research frontier is to apply numerical simulation methods to mine heat hazard research and to investigate the impact of climate change on mine heat damage.
3. We found that the current research on mine heat hazard presents small-scale collaboration, and researchers in each country prefer to collaborate domestically. This may be due to the differences in research directions among countries. For example, Chinese researchers focus on the development of new mine cooling technologies, while South African researchers concentrate on the optimization of energy efficiency in cooling systems.

Availability of data and materials Not applicable.

Authors' contributions Conceptualization, Jiale Zhao and Fuqiang Yang; formal analysis, Jiale Zhao; funding acquisition, Fuqiang Yang; investigation, Jiale Zhao; supervision, Fuqiang Yang; writing — original draft, Jiale Zhao; writing — review and editing, Fuqiang Yang, Yong Guo, and Xin Ren.

Funding This work was supported by the National Natural Science Foundation of China (52274181).

Declarations

Ethical approval Not applicable.

Consent to participate All authors have confirmed their participation.

Consent to publish All authors agree to publication.

Conflict of interest The authors declare no competing interests.

References

Akinlolu M, Haupt TC, Edwards DJ, Simpeh F (2020) A bibliometric review of the status and emerging research trends in construction safety management technologies. Int J Proj Manag:1–13. https://doi.org/10.1080/15623599.2020.1819584

Athresh AP, Al-Habaibeh A, Parker K (2016) The design and evaluation of an open loop ground source heat pump operating in an ochre-rich coal mine water environment. Int J Coal Geol 164:69–76. https://doi.org/10.1016/j.coal.2016.04.015

Aznar-Sánchez J, García-Gómez J, Velasco-Muñoz J, Carretero-Gómez A (2018) Mining waste and its sustainable management: advances in worldwide research. Minerals-Basel 8:284. https://doi.org/10.3390/min8070284

Backhaus K, Lügger K, Koch M (2011) The structure and evolution of business-to-business marketing: a citation and co-citation analysis. Ind Mark Manag 40:940–951. https://doi.org/10.1016/j.indmarman.2011.06.024

Bao T, Meldrum J, Green C, Vitton S, Liu Z, Bird K (2019) Geothermal energy recovery from deep flooded copper mines for heating. Energ Convers Manage 183:604–616. https://doi.org/10.1016/j.enconman.2019.01.007

Börner K, Chen C, Boyack KW (2003) Visualizing knowledge domains. Annu Rev Inf Sci Technol 37:179–255. https://doi.org/10.1002/aris.1440370106

Bouchama A, Knochel JP (2002) Medical progress: heat stroke. N Engl J Med 346:1978–1988

Boyack KW et al (2011) Clustering more than two million biomedical publications: comparing the accuracies of nine text-based similarity approaches. PLoS One 6:e18029. https://doi.org/10.1371/journal.pone.0018029

Cai M, Xue D, Ren F (2019) Current status and development strategy of metal mines. Chin J Eng 41:417–426. https://doi.org/10.13374/j.issn2095-9389.2019.04.001

Chen W, Liang S, Liu J (2016) Proposed split-type vapor compression refrigerator for heat hazard control in deep mines. Appl Therm Eng 105:425–435. https://doi.org/10.1016/j.applthermaleng.2016.03.014

Cheng J, Wang C, Zhang S (2012) Methods to determine the mine gas explosibility – an overview. J Loss Prevent Proc 25:425–435. https://doi.org/10.1016/j.jlp.2011.12.001

Chu Z, Zhou G, Rao Z, Wang Y, Zhao X (2022) Field measurement and assessment on airflow thermodynamic parameters in hot and humid underground tunnelling: a case study. Tunn Undergr Sp Tech 121:104341. https://doi.org/10.1016/j.tust.2021.104341

Davis SG, Engel D, van Wingerden K (2015) Complex explosion development in mines: case study-2010 upper big branch mine explosion. Process Saf Prog 34:286–303. https://doi.org/10.1002/prs.11710

Donoghue AM (2004) Heat illness in the U.S. mining industry. Am J Ind Med 45:351–356. https://doi.org/10.1002/ajim.10345

Donoghue A, Sinclair M, Bates G (2000) Heat exhaustion in a deep underground metalliferous mine. Occup Environ Med 57:165–174

du Plessis GE, Liebenberg L, Mathews EH (2013) Case study: the effects of a variable flow energy saving strategy on a deep-mine cooling system. Appl Energy 102:700–709. https://doi.org/10.1016/j.apenergy.2012.08.024

Du Plessis GE, Liebenberg L, Mathews EH (2013) The use of variable speed drives for cost-effective energy savings in South African mine cooling systems. Appl Energy 111:16–27. https://doi.org/10.1016/j.apenergy.2013.04.061

Epstein Y, Moran DS (2006) Thermal comfort and the heat stress indices. Ind Health 44:388–398. https://doi.org/10.2486/indhealth.44.388

Feng X et al (2018) A full air cooling and heating system based on mine water source. Appl Therm Eng 145:610–617. https://doi.org/10.1016/j.applthermaleng.2018.09.047

Garfield E (2006) Citation indexes for science. A new dimension in documentation through association of ideas†. Int J Epidemiol 35:1123–1127. https://doi.org/10.1093/ije/dyl189

Ghoreishi-Madiseh SA, Sasmito AP, Hassani FP, Amiri L (2017) Performance evaluation of large scale rock-pit seasonal thermal energy storage for application in underground mine ventilation. Appl Energy 185:1940–1947. https://doi.org/10.1016/j.apenergy.2016.01.062

Głuch B (2018) Equivalent Climate temperature analysis as a criterion of climate hazard evaluation in Polish underground mines. Arch Min Sci 63:975. https://doi.org/10.24425/ams.2018.124988

Gou X et al (2022) In-depth analysis on safety and security research based on system dynamics: a bibliometric mapping approach-based study. Saf Sci 147:105617. https://doi.org/10.1016/j.ssci.2021.105617

Guo P, He M, Zheng L, Zhang N (2017) A geothermal recycling system for cooling and heating in deep mines. Appl Therm Eng 116:833–839. https://doi.org/10.1016/j.applthermaleng.2017.01.116

Han Q, Zhang Y, Li K, Zou S (2019) Computational evaluation of cooling system under deep hot and humid coal mine in China: a thermal comfort study. Tunn Undergr Sp Tech 90:394–403. https://doi.org/10.1016/j.tust.2019.05.010

He M (2009) Application of HEMS cooling technology in deep mine heat hazard control. Min Sci Technol 19:269–275. https://doi.org/10.1016/S1674-5264(09)60051-X

Hong R, Liu H, Xiang C, Song Y, Lv C (2020) Visualization and analysis of mapping knowledge domain of oxidation studies of sulfide ores. Environ Sci Pollut R 27:5809–5824. https://doi.org/10.1007/s11356-019-07226-z

Kalkowsky B, Kampmann B (2006) Physiological strain of miners at hot working places in German coal mines. Ind Health 44:465–473. https://doi.org/10.2486/indhealth.44.465

Kenny GP, Vierula M, Maté J, Beaulieu F, Hardcastle SG, Reardon F (2012) A field evaluation of the physiological demands of miners in Canada's deep mechanized mines. J Occup Environ Hyg 9:491–501. https://doi.org/10.1080/15459624.2012.693880

Kivinen S (2017) Sustainable post-mining land use: are closed metal mines abandoned or re-used space? Sustainability-Basel 9:1705. https://doi.org/10.3390/su9101705

Kjellstrom T, Holmer I, Lemke B (2009) Workplace heat stress, health and productivity – an increasing challenge for low and middle-income countries during climate change. Glob Health Action 2:2047. https://doi.org/10.3402/gha.v2i0.2047

Klavans R, Boyack KW (2017) Which type of citation analysis generates the most accurate taxonomy of scientific and technical knowledge? J Am Soc Inf Sci Technol 68:984–998. https://doi.org/10.1002/asi.23734

Kleinberg J (2003) Bursty and hierarchical structure in streams. Data Min Knowl Disc 7:373–397. https://doi.org/10.1023/A:1024940629314

Kong B, Li Z, Yang Y, Liu Z, Yan D (2017) A review on the mechanism, risk evaluation, and prevention of coal spontaneous combustion in China. Environ Sci Pollut R 24:23453–23470. https://doi.org/10.1007/s11356-017-0209-6

Kretschmer H (1994) Coauthorship networks of invisible colleges and institutionalized communities. Springer, Dordrecht, pp 363–369. https://doi.org/10.1007/BF02017234

Kusiak A, Tang F, Xu GL (2011) Multi-objective optimization of HVAC system with an evolutionary computation algorithm. Energy 36(5):2440–2449. https://doi.org/10.1016/j.energy.2011.01.030

Li Z et al (2021a) Impact of the water evaporation on the heat and moisture transfer in a high-temperature underground roadway. Case Stud Therm Eng 28:101551. https://doi.org/10.1016/j.csite.2021.101551

Li Z, Xu N, Jia M, Liu H, Pan W, Deng Y (2021b) Numerical simulation on heat hazard control by collaborative geothermal exploitation in deep mine. J Cent South Univ 52:671–680. https://doi.org/10.11817/j.issn.1672-7207.2021.03.002

Liu YW, Li GF, Liu XY (2012) Research on thermal-insulating material and roadway cooling with high geotherm. Adv Mater Res 512–515:915–921. https://doi.org/10.4028/www.scientific.net/AMR.512-515.915

Liu Z, Yin Y, Liu W, Dunford M (2015) Visualizing the intellectual structure and evolution of innovation systems research: a bibliometric analysis. Scientometrics 103:135–158. https://doi.org/10.1007/s11192-014-1517-y

Liu H, Hong R, Xiang C, Lv C, Li H (2020) Visualization and analysis of mapping knowledge domains for spontaneous combustion studies. Fuel 262:116598. https://doi.org/10.1016/j.fuel.2019.116598

Lowndes I, Pickering S, Twort C (2004) The application of exergy analysis to the cooling of a deep UK colliery. J South Afr Inst Min Metall 104:381–396

McCain KW (1998) Neural networks research in context : a longitudinal journal cocitation analysis of an emerging interdisciplinary field. Scientometrics 41:389–410. https://doi.org/10.1007/BF02459053

Mustafee N, Bessis N, Taylor SJ, Sotiriadis S (2013) Exploring the e-science knowledgebase through co-citation analysis. Procedia Comput Sci 19:586–593

Ngô VTM, Nadeau S, Hallé S (2020) Validation of ergonomic criteria of a cooling vest for deep and ultra-deep mining. Int J Ind Ergon 78:102980. https://doi.org/10.1016/j.ergon.2020.102980

Nunfam VF, Oosthuizen J, Adusei-Asante K, Van Etten EJ, Frimpong K (2019a) Perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana. Sci Total Environ 657:365–378. https://doi.org/10.1016/j.scitotenv.2018.11.480

Nunfam VF, Van Etten EJ, Oosthuizen J, Adusei-Asante K, Frimpong K (2019b) Climate change and occupational heat stress risks and adaptation strategies of mining workers: perspectives of supervisors and other stakeholders in Ghana. Environ Res 169:147–155. https://doi.org/10.1016/j.envres.2018.11.004

Pan R, Li C, Fu D, Chen L, Xiao Z (2019) Micromechanism of spontaneous combustion and oxidation of an unloaded coal under repeated disturbance. Int J Energy Res 43:1303–1311. https://doi.org/10.1002/er.4362

Peng W, Kunlei Z, Yu Z, Jingxian L, Changyan S (2014) Research and application of controlled circulating ventilation in deep mining. Procedia Eng 84:758–763. https://doi.org/10.1016/j.proeng.2014.10.493

Pretorius JG, Mathews MJ, Maré P, Kleingeld M, van Rensburg J (2019) Implementing a DIKW model on a deep mine cooling system. Int J Min Sci Technol 29:319–326. https://doi.org/10.1016/j.ijmst.2018.07.004

Qin Y, Zhang Q, Liu Y (2020) Analysis of knowledge bases and research focuses of cerebral ischemia-reperfusion from the perspective of mapping knowledge domain Brain Res Bull 156:15-24 doi:https://doi.org/10.1016/j.brainresbull.2019.12.004

Roghanchi P, Kocsis KC (2018) Challenges in selecting an appropriate heat stress index to protect workers in hot and humid underground mines. Saf Health Work 9:10–16. https://doi.org/10.1016/j.shaw.2017.04.002

Ryan A, Euler DS (2017) Heat stress management in underground mines. Int J Min Sci Technol 27:651–655. https://doi.org/10.1016/j.ijmst.2017.05.020

Sasmito AP, Kurnia JC, Birgersson E, Mujumdar AS (2015) Computational evaluation of thermal management strategies in an underground mine. Appl Therm Eng 90:1144–1150. https://doi.org/10.1016/j.applthermaleng.2015.01.062

Shen Y, Lv Y, Yang H, Ma W, Zhang L, Pan J (2022) Effect of different ice contents on heat transfer and mechanical properties of concrete. Cold Reg Sci Technol 199:103570. https://doi.org/10.1016/j.coldregions.2022.103570

Shi B, Ma L, Dong W, Zhou F (2015) Application of a novel liquid nitrogen control technique for heat stress and fire prevention in underground mines. J Occup Environ Hyg 12:D168–D177. https://doi.org/10.1080/15459624.2015.1019074

Shiffrin R, Borner K (2004) Mapping knowledge domains. P Natl Acad Sci Usa 101:5138–5185. https://doi.org/10.1073/pnas.0307852100

Swar B, Khan GF (2014) Mapping ICT knowledge infrastructure in South Asia. Scientometrics 99:117–137. https://doi.org/10.1007/s11192-013-1099-0

van Eck NJ, Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84:523–538. https://doi.org/10.1007/s11192-009-0146-3

van Eck NJ, Waltman L (2014) Visualizing bibliometric networks. Springer International Publishing, Cham, pp 285–320. https://doi.org/10.1007/978-3-319-10377-8_13

van Eck NJ, Waltman L (2017) Citation-based clustering of publications using CitNetExplorer and VOSviewer. Scientometrics 111:1053–1070. https://doi.org/10.1007/s11192-017-2300-7

Vosloo J, Liebenberg L, Velleman D (2012) Case study: energy savings for a deep-mine water reticulation system. Appl Energy 92:328–335. https://doi.org/10.1016/j.apenergy.2011.10.024

Wang W et al (2019b) In situ measurements and CFD numerical simulations of thermal environment in blind headings of underground mines. Processes 7:313. https://doi.org/10.3390/pr7050313

Wang Y, Shi G, Wang D (2013) Numerical study on thermal environment in mine gob under coal oxidation condition. Ecol Chem Eng 20:567–578. https://doi.org/10.2478/eces-2013-0041

Wang M, Liu L, Chen L, Zhang X, Zhang B, Ji C (2018) Cold load and storage functional backfill for cooling deep mine. Adv Civ Eng 2018:1–8. https://doi.org/10.1155/2018/5435214

Wang M, Liu L, Zhang X, Chen L, Wang S, Jia Y (2019a) Experimental and numerical investigations of heat transfer and phase change characteristics of cemented paste backfill with PCM. Appl Therm Eng 150:121–131. https://doi.org/10.1016/j.applthermaleng.2018.12.103

Wang Y, Chen H, Liu B, Yang M, Long Q (2020) A systematic review on the research progress and evolving trends of occupational health and safety management: a bibliometric analysis of mapping knowledge domains. Front Public Health 8:81. https://doi.org/10.3389/fpubh.2020.00081

Wei D, Du C, Lin Y, Chang B, Wang Y (2020) Thermal environment assessment of deep mine based on analytic hierarchy process and fuzzy comprehensive evaluation. Case Stud Therm Eng 19:100618. https://doi.org/10.1016/j.csite.2020.100618

Wu M, Ye Y, Hu N, Wang Q, Tan W (2022) Visualization analysis and progress of mine water inrush disaster-related research. Mine Water Environ 41:599–613. https://doi.org/10.1007/s10230-022-00876-5

Xia T, Zhou F, Wang X, Zhang Y, Li Y, Kang J, Liu J (2016) Controlling factors of symbiotic disaster between coal gas and spontaneous combustion in longwall mining gobs. Fuel 182:886–896. https://doi.org/10.1016/j.fuel.2016.05.090

Xiang J, Bi P, Pisaniello D, Hansen A (2014) Health impacts of workplace heat exposure: an epidemiological review. Ind Health 52:91–101. https://doi.org/10.2486/indhealth.2012-0145

Xie H (2021a) Research framework and anticipated results of deep rock mechanics and mining theory. Adv Eng Sci 49:1–16. https://doi.org/10.15961/j.jsuese.201700025

Xie H (2021b) Research review of the state key research development program of China: deep rock mechanics and mining theory. J China Coal Soc 44:1283–1305. https://doi.org/10.13225/j.cnki.jccs.2019.6038

Xie H, Li C, Gao M, Zhang R, Gao F, Zhu J (2021) Conceptualization and preliminary research on deep in situ rock mechanics. Chin J Rock Mech Eng 40:217–232. https://doi.org/10.13722/j.cnki.jrme.2020.0317

Xu Y, Li Z, Wang J, Chen Y, Li R, Wang Q, Jia M (2022) Ventilation and heat exchange characteristics in high geotemperature tunnels considering buoyancy-driven flow and groundwater flow. Int J Therm Sci 173:107400. https://doi.org/10.1016/j.ijthermalsci.2021.107400

Yang X, Han Q, Pang J, Shi X, Hou D, Liu C (2011) Progress of heat-hazard treatment in deep mines. Min Sci Technol 21:295–299. https://doi.org/10.1016/j.mstc.2011.02.015

Yang W, Han S, Li W (2020) Geological factors controlling deep geothermal anomalies in the Qianjiaying Mine. Int J Min Sci Technol 30:839–847. https://doi.org/10.1016/j.ijmst.2020.08.003

Yu D, Xu Z, Martínez L (2020) Visualizing the intellectual structure of the fuzzy linguistic knowledge domain: a bibliometric analysis. Int J Fuzzy Syst 22:2397–2413. https://doi.org/10.1007/s40815-020-00959-x

Yuan Y, Gao X, Wu H, Zhang Z, Cao X, Sun L, Yu N (2017) Coupled cooling method and application of latent heat thermal energy storage combined with pre-cooling of envelope: Method and model development. Energy (Oxford) 119:817–833. https://doi.org/10.1016/j.energy.2016.11.058

Zhai X, Xu Y, Yu Z (2019) Design and performance simulation of a novel liquid CO2 cycle refrigeration system for heat hazard control in coal mines. J Therm Sci 28:585–595. https://doi.org/10.1007/s11630-019-1111-y

Zhang L, Zhong Y, Geng Y (2019) A bibliometric and visual study on urban mining. J Clean Prod 239:118067. https://doi.org/10.1016/j.jclepro.2019.118067

Zhang Y, Huang P (2020) Influence of mine shallow roadway on airflow temperature. Arab J Geosci:13. https://doi.org/10.1007/s12517-019-4934-7

Zhang Y, Wan Z, Gu B, Zhou C, Cheng J (2017) Unsteady temperature field of surrounding rock mass in high geothermal roadway during mechanical ventilation. J Cent South Univ 24:374–381. https://doi.org/10.1007/s11771-017-3439-3

Zhu S, Wu S, Cheng J, Li S, Li M (2015) An underground air-route temperature prediction model for ultra-deep coal mines. Minerals-Basel 5:527–545. https://doi.org/10.3390/min5030508

Zou X, Yue WL, Vu HL (2018) Visualization and analysis of mapping knowledge domain of road safety studies. Accid Anal Prev 118:131–145. https://doi.org/10.1016/j.aap.2018.06.010