

Analysis of Research Trends in Mine Safety/Mining Safety (MS) from the Perspective of a Comparative Vision

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ABSTRACT

Mine safety/Mining Safety (MS) is gaining significant attention in underground mine worldwide. Therefore, studies of MS have gained huge interest all over the world. However, little studies of MS reveal the map of the research field by big data from the perspective of a comparative vision over the past 23-year timespan. To this end, this study used big data and visualization tool (Vosviewer) to comparatively provide a comprehensive systematic mapping of MS studies in the WOSCC and Scopus. A total of 415 (WOSCC) and 691 (Scopus) articles were finally included. The number of articles shows a growth trend during 2000-2022, especially in the last five years. The most prolific authors are mainly from China which has published the highest number of articles. China is also the leading country in MS study, followed by USA. *Safety Science* is the top-publishing journal in the WOSCC (37, 8.92%) and Scopus (37, 5.35%), with the highest number of citations (1290 in the WOSCC and 1519 in the Scopus). Of Top10 most cited articles, 6 articles are published by Chinese authors in the WOSCC, and 4 articles from Chinese authors in the Scopus. China Univ Min and Technol had the most articles (60 in the WOSCC and 72 in the Scopus), but the average number of their citations per article (17.15) was somewhat low, though its total citations ranked first. In the WOSCC, Shandong Univ Sci and Technol has the highest number of citations per article (29.00), while in the Scopus, Univ Queensland ranks first in the average number of their citations (31.58). The main findings provide insights for MS researchers and policy-makers on the trends, progress, and future direction of the MS study.

Keywords: Mine safety/mining safety, Bibliometric analysis, Comparative study, VOSviewer, Big data.

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INTRODUCTION

Most of coal or metal in the world are underground. Therefore, mining is needed. However, mining is known to be one of the most hazardous occupations in the world.^[1-3] Because mining can pose a different set of hazards than other professions, such as fire, flood, explosion or collapse, etc. Thus, mine safety/Mining Safety (MS) is, of course, paramount in mining. Mine safety refers to the management of operations and events within the mining industry, for protecting miners by minimizing hazards, risks and accidents,^[4] and it is achieved through the identification and minimization of hazards that include environmental and equipment-based factors.^[5] Over the past 23 years, the study of MS has made remarkable progress all over the world to achieve the goal of MS by identifying and minimizing the hazards in the mines. However, no literature review in this field has been conducted on

a comprehensive systematic mapping of articles in the WOSCC and Scopus using bibliometric analysis from 2000 to 2022.

This study used the quantitative and qualitative methods to analyze the articles in the WOSCC and Scopus, because those methods reflect not only the level of individual research, but also the comprehensive national strength of a country.^[6] For a country, using the quantitative and qualitative methods to analyze the articles of one country can reflect its research level on a specific scientific field.^[7] As such, quantitative and qualitative methods were used to analyze the articles of MS in the two databases.

The comparative study of WOSCC and Scopus was conducted by identifying the similarities and differences between the two databases. Using two databases at the same time, more parameters of the research would have been identified, and more findings would be resulted in. Many studies compared two databases to identify more parameters and conclude more findings from different aspects.^[8-14] Accordingly, using the comparative study could conclude more findings.

In the light of the foregoing, this study used bibliometric analysis and visual tools to investigate the articles of WOSCC and Scopus by quantitative and qualitative methods, and provided a more



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accurate landscape of MS from the perspective of comparative vision within 23-year timespan. The rest sections of the paper are organized as follows: Section 2 presents the methodology, including bibliometric analysis, data source, research design and data collection, and tools used and data analysis; Section 3 reveals the results and discussion in detail; finally, this paper is concluded in Section 4.

METHODOLOGY

Bibliometric Analysis

Bibliometric analysis is used to achieve the objectives of this study because research studies with big data are considered to be more relevant than the subjective evaluation, and bibliometric methods help in obtaining scientific overviews.^[15] Besides, bibliometric analysis is to make statistics of numerous scientific publications in a certain research field, and reveal the history, current situation and trend of the research field through statistical tables and statistical images (Mapping the Literature on Sustainability Reporting: A Bibliometric Analysis Grounded in Scopus and Web of Science Core Collection). Therefore, Bibliometric analysis is performed to seek a better understanding the landscape of MS all over the world, and it looks at publications and their properties, and adds knowledge domain visualization to gain a sense of the development and evolution of a knowledge field. Therefore, this study performed a bibliometric analysis to seek a better understanding of the directions of scientific trends of MS.

Data source

The data in this study were retrieved from the two most widely used databases for bibliometric analysis in the world: the Clarivate Analytics' Web of Science Core Collection (WOSCC) and Elsevier's Scopus. The WoSCC is one of the vital sources of scientific information,^[16] and it have gone through strict quality selection and have advantages in reference data,^[17] including all cited references for all publications that are fully indexed and searchable. In addition, this database is not only an important search tool but also a significant basis for evaluating the scientific research findings. Therefore, many countries all over the world take it as an official or unofficial evaluating tool. Because of this, data acquired from WOSCC for analysis is authentic and representative. Scopus database hosted by Elsevier is also selected in study due to its broad coverage of scientific publications that have been reviewed by double or multiple-blind peers as well as its use as a platform that is easy for facilitating the bibliographic information export.^[18,19]

Furthermore, using WOSCC and Scopus databases can make the research results more comprehensive and also get a much larger sample compared to use only one database.^[11] Due to the reasons mentioned above, this study used the two world-leading research databases for bibliometric analysis.

Research Design and Data Collection

The study used a statistical bibliometric analysis method to map the global research outputs of MS study. The current study focused on articles in the WOSCC and Scopus. The WOSCC and Scopus are scholarly accessible platforms that host international publishing journals for researchers and scientists; hence no ethical approval was required for data extraction, analysis, and research presentation.^[10]

For the completeness of data, this bibliometric study analyzed a 23-year timespan of articles on MS research from 1 January 2000 to 31 December 2022, and the data was searched on April 3, 2023 and finished in one day. The document type was limited as Article and language focused on English. In order to improve the retrieval quality, this study used "Title" for the documents' screening. In addition, documents that are "Original Research Article" were included for data analysis. The retrieve strings were as follows:

WOSCC: mine safety (Title) OR mining safety (Title) and 2023 (Exclude-Publication Years) and Article (Document Types) and English (Languages).

Scopus: (TITLE (mine AND safety) OR TITLE (mining AND safety)) AND (EXCLUDE (PUBYEAR, 2023)) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")).

Totally, articles identified through WOSCC and Scopus are 527 and 1083, respectively. After screening, 415 and 691 articles are left in WOSCC and Scopus.

Tools Used and Data Analysis

For data visualization, there are many software tools supporting bibliometric analysis with an intend to present the result in an appropriate and most understandable way, such as HistCite,^[20] Bibliometrix, an R package,^[21] VOSviewer, BibExcel, CiteSpace, CoPalRed, Sci2, VantagePoint, and Gephi.^[22-24] The study chosen the VOSviewer software 1.6.18 (<https://www.vosviewer.com>), developed by the University of Leiden, because this software is user-friendly and intuitive, thus is used for data mining, mapping and visualization of the bibliometric networks.^[25] Besides, it is easy to interpret the graphical representation of bibliometric maps.

Microsoft Excel 2016 is also used for basic calculation and data analysis, including calculating the total articles, total citations, drawing the figure of global trends in the past 23 years in MS study, etc.

EndNote 20 is chosen to screen the data. A total of 527 articles from the WOSCC and 1083 articles from the Scopus were imported into EndNote, of which 112 (WOSCC) and 392 (Scopus) articles were excluded based on a brief scan of titles and abstracts.

RESULTS AND DISCUSSION

Overview the Articles in the WOSCC and Scopus

Totally, 415 articles in the WOSCC and 691 articles in the Scopus were finally obtained in this study. Articles in the WOSCC were published in 179 journal sources, and Scopus 297 journal sources, which were contributed by 44 (WOSCC) and 64 (Scopus) countries, and 429 (WOSCC) and 1149 (Scopus) affiliations in MS study. Table 1 shows the basic information of two databases in MS research.

Table 1: Detail information in the WOSCC and Scopus.

Items	WOSCC	Scopus
Retrieval date	April 3, 2023	April 3, 2023
Document types	Article	Article
Language	English	English
Time span	2000-2022	2000-2022
Articles	415	691
Sources	179	297
Countries	44	64
Affiliations	429	1149
Total citations	5496	7881
Average citations per publication	13.24	11.41
Total authors	1270	1533
Single-authored articles	1167	1271
Multi-authored articles	103	262
Author keywords	1298	1864
Keywords plus	683	3828

Clearly, the global research outputs of the world in field of MS study cumulated to 415 (WOSCC) and 691 (Scopus) publications in the past 23-year timespan (Table 1). Some articles are crossover, that is to say, those articles are indexed by both databases. The number of articles in WOSCC ($n=415$) is less than that in Scopus ($n=691$). Totally, there are 1106 articles in the search results, of which 327 are crossover. Although there are overlapping articles, many articles are in only one database: WOSCC has 88 of those articles and Scopus has 264 articles. Therefore, using WOSCC and Scopus databases can make the research results to be more comprehensive. This is also certificated by Yang *et al.*^[26]

Global Trends of Articles in the WOSCC and Scopus

Figure 1 presents the trends in the number of articles of both databases in the analyzed period. Figure 1 also indicates the evolution of MS articles in 2000-2022. Generally, it is notable that a growth trend is observed since the year 2000 onwards, though there are some fluctuations. To be specific, the number of articles shows a rapid growth in the last five years, and the articles in both databases peaked in 2022.

As shown in Figure 1, the annual publication outputs increased from 4 in the year 2000 to 65 publications in the year 2022 in the WOSCC, with an annual growth rate of 69.32%, while for Scopus, it rose from 10 in the year 2000 to 84 in the year 2022, with an annual growth rate of 33.64%. The annual growth rate of the WOSCC is much faster than that of the Scopus. In fact, the number of total articles per year is relatively small during 2000-2009, but it quickly increased from 24 in 2010 to 49 in 2017. This means that this research field started to attract more and more researchers' attention from 2010 on. From 2018 to 2022, the number of articles increased from 43 to 84, with a sharply rise. Possible reason is that mine industries and researchers'

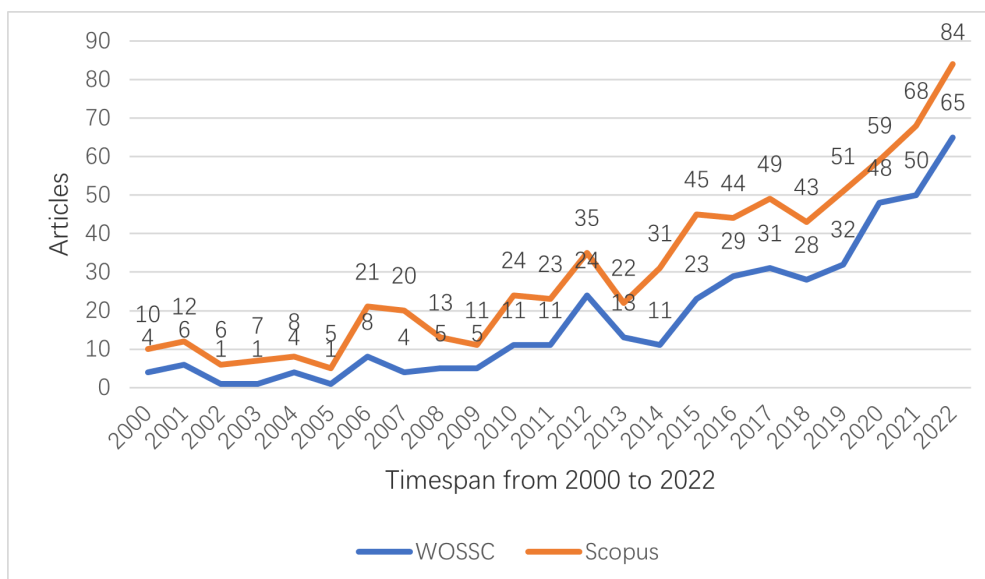


Figure 1: Global trend over the past 21 years.

increasingly interest results in an enormous growth in this field in the last few years.

Analysis of the global trends of articles in the two databases can see a rapid growth in the research output in MS fields from 2000-2022. This is to say, MS is being developed, and the development of MS will speed up in the near future. There are many reasons for this rapid growth, such as such as economic development, the continuous increase of GDP, growth in researchers, national funding incentives, etc.

Analysis of authors

Author is creator of an article. Therefore, the first level of this research refers to authors. As is noted in Table 1, 1270 authors participated in 415 articles' writing in the WOSCC, and 1533 authors took part in 691 articles' writing in the Scopus.

Firstly, the most co-cited authors were investigated int this study. Figures 2 and 3 present the images of most co-cited authors obtained from the analysis of WOSCC and Scopus databases.

As the size of nodes shown in Figure 2, the most co-cited authors in MS studies in the WOSCC database are Chen H, Gunningham N, Hison G, Jiskani IM, and Karacan CO, with respect to the ranking order of citations.

Based on the size of nodes shown in Figure 3, analysis shows that the most co-cited authors in the Scopus database were Li X, Chen H, Wang Y, Zhang Y, and Wang L. In fact, the analysis of the most co-cited authors in the two databases shows that those authors have done effective studies in MS field.

Table 2 shows the Top 11 most prolific authors with total articles (TA), total citations (TC), average citations per article (TC/TA) and country.

In the WOSCC, the most prolific authors are Chen H, with 7 articles, followed by Li X, Liu Q and Long R with 6 articles each. On the other hand, the author with the highest average citations per articles are Liu Q with 37.50 citations, followed by Li X. As for Scopus, the most productive authors are Li X with 16 articles, followed by Wang X with 11 articles. Li H and Zhang J ranked third with 9 articles, respectively. However, the authors that receive the most citations are Liu Q and Li X with 36.57 and 27, 69 citations, the same rank orders as in the WOSCC. Interestingly, only 5 of the top 10 authors have overlapped.

In addition, China is the country whose authors have published the highest number of articles in Top11, while in the Scopus, all Top11 authors are from China.

Analyzing the co-authorship is to seek to examine the links between authors and the authors' countries distribution.^[8] Figures 4 and 5 demonstrate the co-authorship in the WOSCC and Scopus, respectively. It was set the threshold of 2 authors as the minimum number of a document.

Figures 4 and 5 show the total strength of co-authorship links with other authors. As can be seen in Figures 4 and 5, the largest set of connected items consists of 9 authors in the WOSCC, while 27 authors in the Scopus.

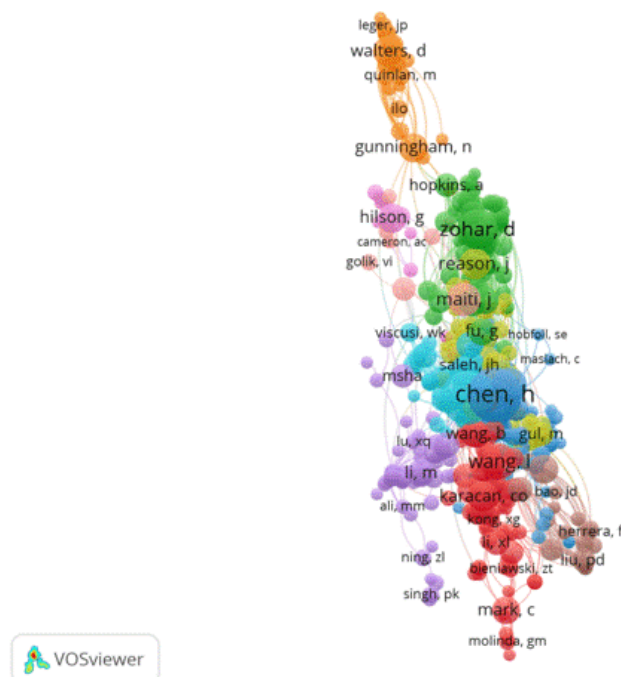


Figure 2: Most co-cited authors in MS Studies in the WOSCC database.

Analysis of Countries

As mentioned above, 44 countries in the WOSCC contributed to the scientific outputs in MS study. While in Scopus, the scientific outputs in this field are from 64 countries. Bibliographical coupling analysis of countries shows that research on MS study by 44 countries in WOSCC and 64 countries in the Scopus are interconnected, with 263 links and 8849 total link strengths in the WOSCC, and 368 links and 10652 total link strengths in the Scopus. It indicates that the MS study has become the focus worldwide.

For WOSCC, the data of United Kingdom is divided into England, Scotland, Wales, Northern Ireland, and this study combined them into the United Kingdom. For the Scopus, China includes Chinese mainland, Hong Kong, Macao, but excludes

Taiwan. Table 3 displays the Top10 countries in both databases. An analysis of the countries distribution showed that China is significantly leading in the number of articles about MS study in both databases with 211 (WOSCC) and 280 (Scopus) articles, followed by USA with 52 (WOSCC) and 90 (Scopus), respectively. Over the past 23 years, articles from China in WOSCC accounts for 50.84%, half of the total outputs in this field. However, the number of articles of China in the Scopus only occupies 40.52% in this study field. In terms of citations, China ranks first in both databases, with 2732 (WOSCC) and 3584 (Scopus) citations respectively, while USA is the second ranking, with 738 (WOSCC) and 1188 (Scopus) citations respectively. With respect to the number of cooperative countries (NCC) and total link strength (TLC), China both ranks in the first place, followed by USA. Despite the large articles number from China, the average

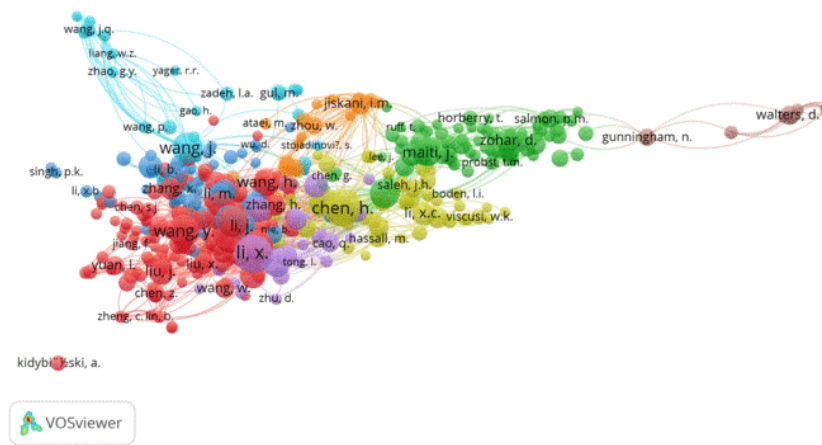


Figure 3: Most co-cited authors in MS studies in Scopus database.

Table 2: Top11 most prolific authors in the WOSCC and Scopus.

WOSCC					Scopus				
Authors	TA	TC	TC/TA	Country	Authors	TA	TC	TC/TA	Country
Chen H	7	107	15.29	China	Li X	16	443	27.69	China
Li X	6	218	36.33	China	Wang X	11	140	12.73	China
Liu Q	6	225	37.50	China	Li H	9	159	17.67	China
Long R	6	86	14.33	China	Zhang J	9	126	14.00	China
Jiskani I M	5	80	16.00	China	Chen H	8	120	15.00	China
Bao J	4	30	7.50	China	Li Y	8	35	4.38	China
Han S	4	66	16.50	China	Wang Y	8	101	12.63	China
Kecojevic V	4	43	10.75	USA	Chen J	7	100	14.29	China
Yang X	4	9	2.25	China	Jiskani I M	7	117	16.71	China
Zhang J	4	30	7.50	China	Liu Q	7	256	36.57	China
Zheng C	4	59	14.75	China	Wang C	7	51	7.29	China

citations per article were relatively low, only 12.95 (WOSCC) and 12.80 (Scopus). Undoubtedly, China is the leading country in MS study worldwide. One reason is the improvement in economic status, and the other reason may be the increase in research

and development funding for the progress of China's scientific output.^[27]

Among Top 10 countries in both databases, 9 countries overlap, though the rank orders of the two databases are somewhat

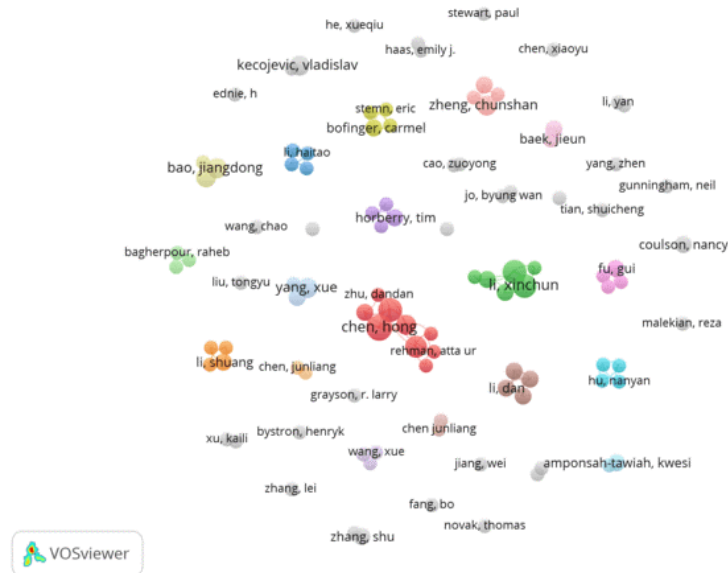


Figure 4: Co-authorship in the WOSCC.

Table 3: Top 10 countries with the most scientific articles.

Rank	Country	TA	TC	TC/TA	SA	NCC	TLS
1	China	211	2732	12.95	50.84%	18	2966
2	USA	52	738	14.19	12.53%	10	1494
3	Australia	34	656	19.29	8.19%	5	1375
4	South Africa	24	231	9.63	5.78%	4	325
5	India	22	428	19.45	5.30%	5	403
6	Poland	22	143	6.50	5.30%	7	345
7	Russia	14	58	4.14	3.37%	3	96
8	Canada	10	127	12.70	2.41%	3	326
8	United Kingdom	10	166	16.60	2.41%	5	553
10	Turkey	9	223	24.78	2.17%	3	284
Rank	Country	TA	TC	TC/TA	SA	NCC	TLS
1	China	280	3584	12.80	40.52%	20	3162
2	USA	90	1188	13.20	13.02%	13	1538
3	India	55	616	11.20	7.96%	6	455
4	Australia	51	909	17.82	7.38%	5	1478
5	Russia	36	352	9.78	5.21%	6	126
6	South Africa	36	305	8.47	5.21%	9	322
7	Poland	32	218	6.81	4.63%	9	382
8	Canada	18	199	11.06	2.60%	8	444
9	United Kingdom	16	188	11.75	2.32%	8	466
10	Iran	11	313	28.45	1.59%	7	834

different. It was observed that articles on MS published by Russia in the WOSCC and United Kingdom in the Scopus received the least citations (58) and 188, respectively.

Regarding the collaborative networks between 44 countries, WOSCC shows a network composed of 13 clusters, and clusters 1 and 2 are numerous clusters combined by 5 countries, while clusters 3, 4, 5, 6 and 7 are combined by 4 countries. For clusters 8, 9, 10 and 11, only 3 countries are included. Clusters 12 and 13

are composed of only one country. In contrast, in the Scopus, the collaboration network of 64 countries is comprised by 24 clusters. Clusters 1, 2 and 3 are made up of 8 countries, clusters 4 and 5 composed by 6 and 5 countries respectively, clusters 6 and 7 by 4 countries and clusters 8 and 9 by 3 countries. The remaining clusters have only one country included.

Figures 6 and 7 are collaborative networks of Top 10 most productive countries in the WOSCC and Scopus databases,

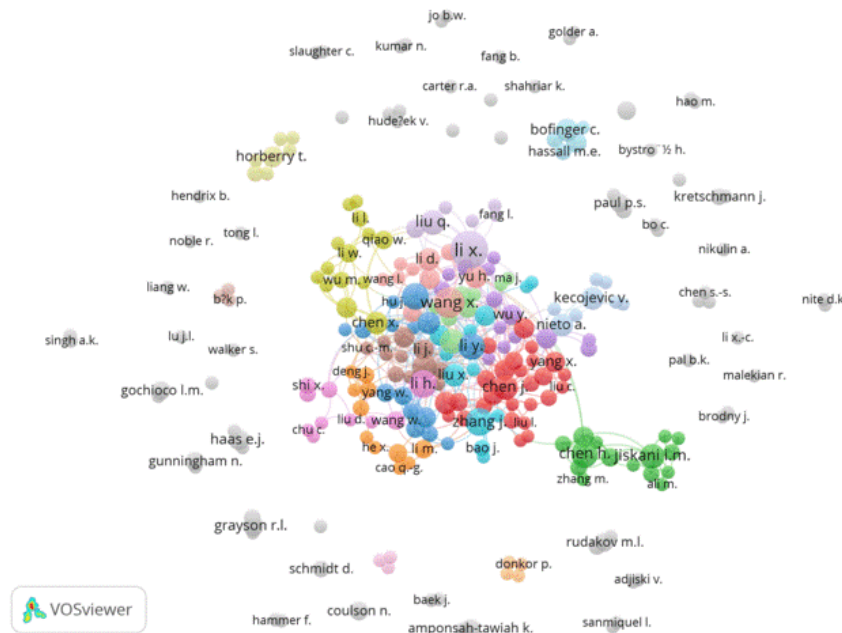


Figure 5: Co-authorship in the WOSCC.

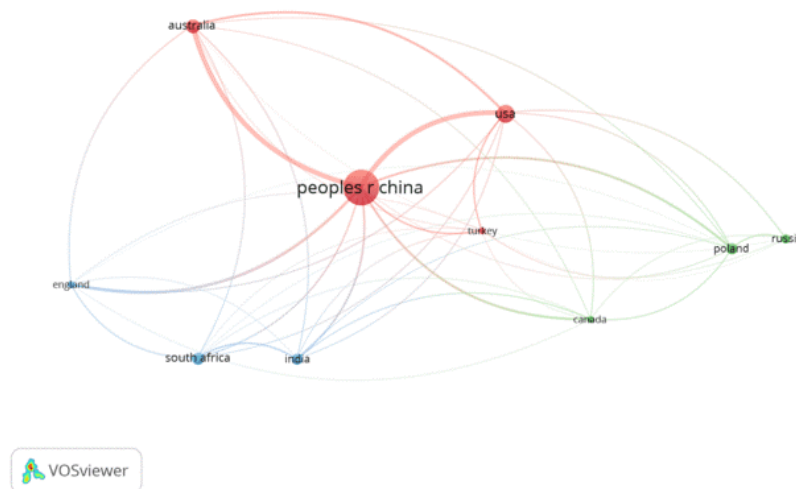


Figure 6: The collaborative networks of Top 10 most productive countries in WOSCC.

respectively. As noted in Figures 6 and 7, the larger the area of the node, the more the number of articles published in the country; solid circles indicate the countries, and the size proportion shows the number of scientific outputs; and the bigger the solid circle is denoting, the more scientific outputs the country published.^[28]

In Figure 6, it is notable that there are three clusters. Cluster 1 is combined of the China, USA, Australia and Turkey, which have

the largest number of articles due to international cooperation and most intensive collaboration, especially between the China and Australia. Clusters 2 and 3 are made up of 3 countries, with Canada, Poland and Russia (Cluster 2) as well as United Kingdom, India and South Africa (Cluster 3). As is shown in Figure 7, there are still three clusters, too. But, the countries in the three clusters are slightly different from that in the WOSCC. Clusters 1, 2 and 3 are combined by 4, 3 and 3 countries, respectively. Cluster 1 is

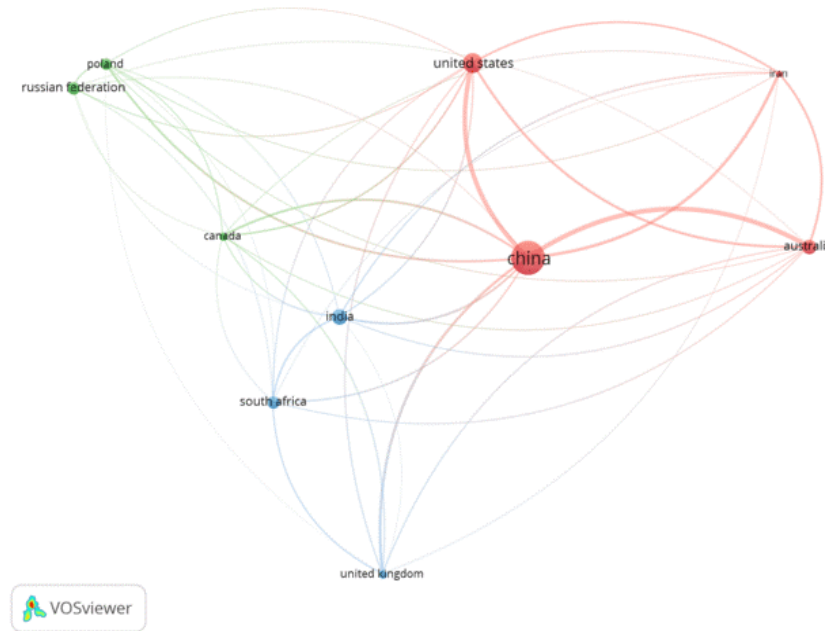


Figure 7: The collaborative networks of Top10 most productive countries in the Scopus.

Table 4: Top 10 most productive sources in the WOSCC.

Rank	Source title	TA	TC	TC/NA	IF	5 years IF	BQ	Publisher
1	Safety Science	37	1290	34.86	6.392	6.432	Q1	Netherlands
2	Journal of the Southern African Institute of Mining and Metallurgy	16	125	7.81	0.64	0.928	Q4	South Africa
3	Resources Policy	14	178	12.71	8.222	7.658	Q1	United Kingdom
4	International Journal of Environmental Research and Public Health	9	68	7.56	4.614	4.799	Q ₂	Switzerland
5	Journal of Mining Science	9	43	4.78	0.85	0.812	Q4	USA
6	Process Safety and Environmental Protection	9	224	24.89	7.926	7.717	Q1	United Kingdom
7	Archives of Mining Sciences	8	38	4.75	1.435	1.169	Q3	Poland
8	Mining Metallurgy and Exploration	8	69	8.63	1.695	1.698	Q3	Germany
9	Sustainability	8	28	3.50	3.889	4.089	Q2	Switzerland
10	Complexity	7	73	10.43	2.121	2.213	Q2	USA

made up of the China, USA, Australia and India. Countries of clusters 2 and 3 in the Scopus are the same as that in the WOSCC. The China and USA have the most intensive collaboration, with 842 link strengths.

Analysis of Sources

415 articles were published in 179 different sources in the WOSCC, while 691 articles were published in 297 different sources in the Scopus. Tables 4 and 5 list Top 10 most productive sources in the WOSCC and Scopus, respectively. Table 4 and

Table 5 present the total articles (TA), total citation (TC), ratio of TC to NP, impact factors (IF) in 2021, 5-years impact factor (5 years IF), best quartile (BQ), and Publisher.

To carefully check Top 10 sources in the WOSCC and Scopus, it is observable that only 3 sources overlap. The total number of articles of Top10 sources are 125 (WOSCC) and 177 (Scopus). In the Top10 most productive sources, *Safety Science* is the top-publishing journal in the WOSCC (37) and Scopus (37), and it also has the highest number of citations, with 1290 in the

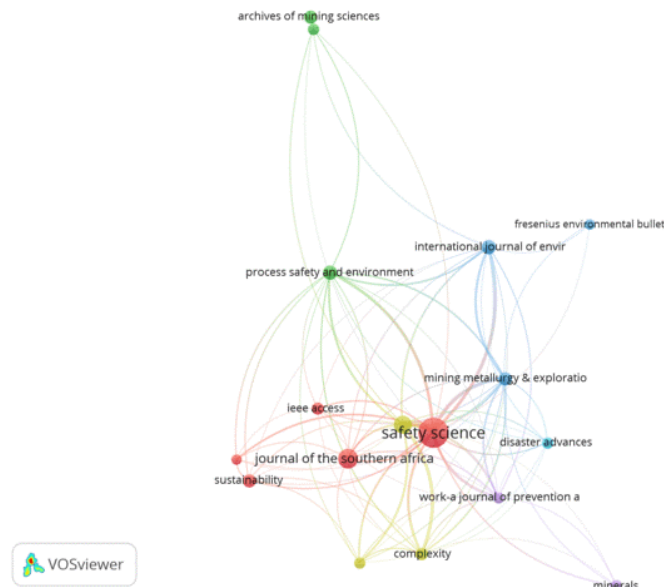


Figure 8: Network of Top20 sources in the WOSCC.

Table 5: Top 10 most productive sources in the Scopus.

Rank	Source title	TA	TC	TC/TA	IF	5 years IF	BQ	Publisher
1	Safety Science	37	1519	41.05	6.392	6.432	Q1	Netherlands
2	Journal of Mines, Metals and Fuels	22	17	0.77	No found	No found	Q4	India
3	Journal of the Southern African Institute of Mining and Metallurgy	21	173	8.24	0.64	0.928	Q4	South Africa
4	Journal of Coal Science and Engineering	20	23	1.15	-	-	-	China
5	Mining Engineering	18	37	2.06	-	-	Q4	USA
6	Resources Policy	15	217	14.47	8.222	7.658	Q1	United Kingdom
7	Coal Age	13	1	0.08	-	-	-	USA
8	Ausimm Bulletin	12	3	0.25	-	-	-	USA
9	Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu	10	91	9.10	-	-	-	Ukraine
10	International Journal of Mining Science and Technology	9	231	25.67	7.67	5.648	Q1	China



Figure 9: Network of Top 20 sources in the Scopus.



Figure 10: Map of articles citation in the WOSCC.



Figure 11: Map of articles citation in the Scopus.

WOSCC and 1519 in the Scopus. Besides, each article in *Safety Science* was cited about 35 times in the WOSCC and 41 times in the Scopus.

Regarding the quartile in the WOSCC, 5 out of 20 are best ranked in the first quartile, 5 sources are best ranked in the second quartile, while 6 sources are best ranked in the third quartile, and only 4 sources are best ranked in the fourth quartile. With respective

to the quartile in the Scopus, 4 sources are in the first quartile, 4 sources in the second quartile, 2 sources in the third quartile, and 5 in the fourth quartile. The quartiles for the remaining 5 sources are not found. Regarding the publisher of Top20 sources in the WOSCC database, USA (6) has the most sources, followed by Switzerland (4). Netherlands, United Kingdom and Germany have 2 sources. China, India, South Africa and Poland each have only 1 source. In the Scopus, the number of sources from USA is 7, in the first rank, followed by Switzerland with 4.

Although China is the country whose authors have published the highest number of articles in Top11, the number of journals supported by China is low, only 1 journal. Next step, Chinese government should improve the high-level journals in MS field and support more high-quality papers published in the journals sponsored by China.

Among Top20 sources in the WOSCC, eight sources are metallurgy and metallurgical engineering, including *Journal of the Southern African Institute of Mining and Metallurgy*, *Journal of Mining Science*, *Archives of Mining Sciences*, *Mining Metallurgy and Exploration*, *Minerals*, *Journal of the South African Institute of Mining and Metallurgy*, *International Journal of Mining Science and Technology*, and *Mining Engineering*; four sources are environmental sciences, covering *Resources Policy*, *International Journal of Environmental Research and Public Health*, *Sustainability*, and *Fresenius Environmental Bulletin*; three sources are engineering, and *Safety Science*, *Mathematical Problems in Engineering* and *Process Safety and Environmental Protection* are included; the rest of them belong to computer science, energy, etc., which reflects the interdisciplinarity of MS research field. In the Scopus, the categories of Top20 sources are much more diverse.

Figures 8 and 9 show the network of Top20 sources in the WOSCC and Scopus. Figure 8 displays 9 clusters, and cluster 1 includes 5 journals. Figure 9 contains 10 clusters, and cluster 1 involves four journals. As is present in Figures 8 and 9, *Safety Science* has the highest links and total link strengths.

Analysis of articles

For 415 articles in the WOSCC, 337 articles were extracted with minimum 1 citation per article, and network is shown in Figure 10. 512 articles were chosen from the Scopus, with minimum 1 citation per article, and the network is present in Figure 11. In Figures 10 and 11, using the circle symbols of different sizes and colors is to show the most cited article, and the highly cited articles highlighted in the map are consistent with the results shown in Table 6 and Table 7, respectively.

Analysis of Top10 articles can support the understanding of MS research that gained massive attention from researchers. According to the number of citations, the basic information of Top10 articles is present in Tables 6 and 7. Tables 6 and 7 list the

Table 6: Top10 most cited articles in the WOSCC.

Rank	Title	Authors	Year	Journal name	DOI	TC	ATC Per Year	COA
1	Human health and safety risks management in underground coal mines using fuzzy TOPSIS.	Mahdevari S, Shahriar K, Esfahanipour A	2014	Science of the Total Environment	10.1016/j.scitotenv.2014.04.076	157	15.70	Iran
2	The role of behavioral factors on safety management in underground mines.	Paul PS, Maiti J	2007	Safety Science	10.1016/j.ssci.2006.07.006	129	7.59	India
3	Characteristics and trends of coal mine safety development.	Li XL; Cao ZY; Xu YL	2020	Energy Sources Part A-Recovery Utilization and Environmental Effects Q3	10.1080/15567036.2020.1852339	123	30.75	China
4	Research on the influencing factors in coal mine production safety based on the combination of DEMATEL and ISM.	Wang LL, Cao QG, Zhou LJ	2018	Safety Science	10.1016/j.ssci.2017.11.007	101	16.83	China
5	Status and future tasks of coal mining safety in China.	He XQ, Song L	2012	Safety Science	10.1016/j.ssci.2011.08.012	96	8.00	China
6	Effectiveness research on the multi-player evolutionary game of coal-mine safety regulation in China based on system dynamics.	Liu QL, Li XC, Meng XF	2019	Safety Science	10.1016/j.ssci.2018.07.014	94	18.80	China
7	Evolutionary game analysis and stability control scenarios of coal mine safety inspection system in China based on system dynamics.	Liu QL, Li XC, Hassall M	2015	Safety Science	10.1016/j.ssci.2015.07.005	89	9.89	China

Rank	Title	Authors	Year	Journal name	DOI	TC	ATC Per Year	COA
8	Mining-induced fault reactivation associated with the main conveyor belt roadway and safety of the Barapukuria Coal Mine in Bangladesh: Constraints from BEM simulations.	Islam MR, Shinjo R	2009	International Journal of Coal Geology	10.1016/j.coal.2009.06.007	88	5.87	Japan
9	Pythagorean fuzzy VIKOR-based approach for safety risk assessment in mine industry.	Gul M, AK MF, Guneri AF	2019	Journal of Safety Research	10.1016/j.jsr.2019.03.005	87	17.40	Turkey
10	A linguistic intuitionistic multi-criteria decision-making method based on the Frank Heronian mean operator and its application in evaluating coal mine safety.	Peng HG, Wang JQ, Cheng PF	2018	International Journal of Machine Learning and Cybernetics Q2	10.1007/s13042-016-0630-z	84	14.00	China

Note: ATC per year is the average of total citations per year.

rank order, the article title, author(s), articles year, journal name, DOI, Total Citations (TC), average of total citations per year (ATC per year) and Country of Affiliation (COA) in the WOSCC and Scopus, respectively.

When Tables 6 and 7 were examined, there is consistency in the WOSCC and Scopus on the top-cited articles in the first four articles. It is also observable that the article entitled “Human health and safety risks management in underground coal mines using fuzzy TOPSIS” published by Mahdevari *et al.* (2014) is the first most cited article, and has 157 citations in the WOSCC, while it has 185 citations in the Scopus. The article titled “The role of behavioral factors on safety management in underground mines” published by Paul and Maiti (2007) was the second most cited article in both databases. In the WOSCC and Scopus, the article under the title “Characteristics and trends of coal mine safety development” by Li *et al.* (2020) ranks in the third place, but its ATC per year is in the first rank, with 30.75 (WOSCC) and 33.75 (Scopus). The article with title “Research on the influencing factors in coal mine production safety based on the combination of DEMATEL and ISM” is in the fourth ranking. The four articles

were the Top 4 most cited in the two databases explored in MS study, which are effective studies on MS. Among the Top10 most cited articles in the WOSCC and Scopus, eight out of Top10 articles overlapped.

Although the number of citations relies on the timeline, it is not absolute. For example, article entitled “Characteristics and trends of coal mine safety development” was published in 2020, but it has been cited 123 times in the WOSCC and 135 times in the Scopus.

The journal with more cited articles is *Safety Science*. It includes 5 papers with a total of 509 citations in the WOSCC and 4 papers with a total of 481 citations in the Scopus. The journal *Safety Science* has published the most cited articles with five articles in the WOSCC and four articles in the Scopus and is ranked in the first quartile; thus, it is the most influential journal for MS topic.

In the WOSCC, 6 articles are published by Chinese authors, and the rest four articles are from Iran, India, Japan and Turkey. In the Scopus, 4 articles are from Chinese authors, the remaining six articles were published by Iran, India, Japan, Turkey, and Australia.

Table 7: Top 10 most cited articles in the Scopus.

Rank	Title	Authors	Year	Journal	DOI	TC	ATC per year	Country
1	Human health and safety risks management in underground coal mines using fuzzy TOPSIS.	Mahdevari S, Shahriar K, Esfahanipour A	2014	Science of the Total Environment	10.1016/j.scitotenv.2014.04.076	185	18.50	Iran
2	The role of behavioral factors on safety management in underground mines.	Paul PS, Maiti J	2007	Safety Science	10.1016/j.ssci.2006.07.006	162	9.82	India
3	Characteristics and trends of coal mine safety development.	Li XL; Cao ZY; Xu YL	2020	Energy Sources Part A-Recovery Utilization and Environmental Effects Q3	10.1080/15567036.2020.1852339	135	33.75	China
4	Research on the influencing factors in coal mine production safety based on the combination of DEMATEL and ISM.	Wang LL, Cao QG, Zhou LJ	2018	Safety Science	10.1016/j.ssci.2017.11.007	116	19.33	China
5	Safety rules and regulations on mine sites - The problem and a solution.	Laurence d.	2005	Journal of Safety Research	10.1016/J.JSR.2004.11.004	115	6.05	Australia
6	Mining-induced fault reactivation associated with the main conveyor belt roadway and safety of the Barapukuria Coal Mine in Bangladesh: Constraints from BEM simulations.	Islam MR, Shinjo R	2009	International Journal of Coal Geology	10.1016/j.coal.2009.06.007	104	6.93	Japan

Rank	Title	Authors	Year	Journal	DOI	TC	ATC per year	Country
7	Pythagorean fuzzy VIKOR-based approach for safety risk assessment in mine industry.	Gul M, AK MF, Guneri AF	2019	Journal of Safety Research	10.1016/j.jsr.2019.03.005	103	20.60	Turkey
7	Status and future tasks of coal mining safety in China.	He XQ, Song L	2012	Safety Science	10.1016/j.ssci.2011.08.012	103	8.58	China
7	Image-based safety assessment: Automated spatial safety risk identification of earthmoving and surface mining activities.	Chi s, Caldas CH	2012	Journal of Construction Engineering and Management	10.1061/(ASCE)CO.1943-7862.0000438	103	8.58	Australia
10	Effectiveness research on the multi-player evolutionary game of coal-mine safety regulation in China based on system dynamics.	Liu QL, Li XC, Meng XF	2019	Safety Science	10.1016/j.ssci.2018.07.014	100	20.00	China

Note: ATC per year is the average of total citations per year.

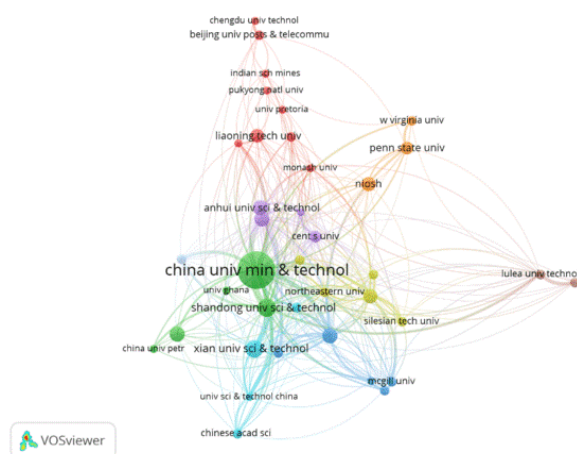


Figure 12: Network of affiliations in the WOSCC.

Analysis of affiliations

Totally, 415 articles were published by 429 affiliations in the WOSCC, while 691 articles were studied by 1149 affiliation. Thus,

the affiliations that published the articles on MS research were analyzed in this study. Figures 12 and 13 display the networks of affiliations in the WOSCC and Scopus.

As is shown in Figure 12, it is notable that the affiliation with the highest number of articles related to MS study was China University of Mining and Technology, followed by Shandong University Science and Technology and Xi'an Univ Sci and Technol. In the Scopus, China University of Mining and Technology still ranks in the first place on the basis of number of articles, and it is followed by China Univ Min and Technol Beijing and Shandong Univ Sci and Technol (Figure 13).

Table 8 present the Top11 most productive affiliations in the WOSCC and Scopus, including rank order, affiliations, the total articles, total citations, average citations per article (TC/TA), and country.

Table 8 shows the Top11 affiliations which are active in MS studies in both databases. In Table 8, it is seen that it is mostly different in the affiliations publishing studies on MS in the WOSCC and the

Scopus databases. When the affiliations in the WOSCC database were examined, it was found that China Univ Min and Technol had the most articles (60) related to MS studies, but the average number of their citations per article (17.15) was somewhat low

compared to that of other affiliations, though its total citations ranked first. It was also noted that the highest number of citations per article belonged to Shandong Univ Sci and Technol (29) although it had only 15 articles. Similarly, it was determined that although the number of their articles was low, the number of citations per article was higher for Univ Queensland (10, 28.30). When the active affiliations in terms of MS studies in the Scopus database were examined, it was also obtained that although Univ Queensland had only 19 articles, the average number of their citations (31.58) was the highest compared to that of other affiliations.

It is also observable that the top-ranking affiliations are dominated by China: among the Top11 affiliations in the WOSCC, 7 affiliations are from China, while USA, Australia, South Africa and Russia each has only one affiliation. In the Scopus, eight out of 11 affiliations are from China, and only one affiliation from USA, Australia and South Africa. 8 affiliations are overlapping, though the rank order is different.

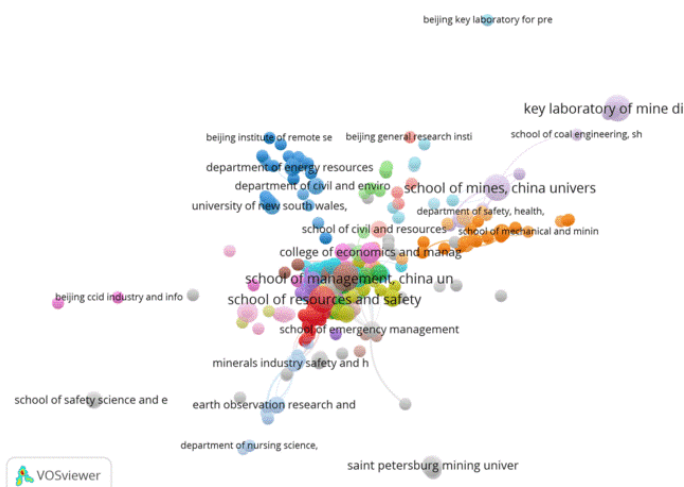


Figure 13: Network of affiliations in the Scopus.

Table 8: Top11 most productive affiliations in the WOSCC and Scopus.

Rank	Affiliations	TA	TC	TC/TA	Country	Rank	Affiliation	TA	TC	TC/TA	Country
1	China Univ Min and Technol.	60	1029	17.15	China	1	China Univ Min and Technol	72	1850	25.69	China
2	Shandong Univ Sci and Technol.	15	435	29.00	China	2	China Univ Min and Technol Beijing	30	474	15.80	China
3	Xian Univ Sci and Technol.	13	73	5.62	China	3	Shandong Univ Sci and Technol	29	522	18.00	China
4	Anhui Univ Sci and Technol	10	137	13.70	China	4	Anhui Univ Sci and Technol	20	196	9.80	China
4	China Univ Min and Technol Beijing	10	93	9.30	China	5	Univ Queensland	19	600	31.58	Australia
4	Univ Queensland	10	283	28.30	Australia	5	Cent South Univ	19	198	10.42	China
4	Univ Witwatersrand	10	98	9.80	South Africa	7	Pennsylvania State University	13	116	8.92	USA
8	Cent South Univ	9	42	4.67	China	8	Liaoning Tech Univ	11	23	2.09	China
8	NIOSH	9	154	17.11	USA	9	Univ Witwatersrand	10	115	11.50	South Africa
10	Liaoning Tech Univ	8	15	1.88	China	9	Henan Polytechnic University	10	122	12.20	China
10	Russian Acad Sci	8	35	4.38	Russia	9	University of Science and Technology Beijing	10	135	13.50	China



Figure 14: Co-occurrence of keywords in the WOSCC.



Figure 15: Co-occurrence of keywords in the Scopus.



Figure 16: Overlay visualization of keywords plus in the WOSCC.

Analysis of Keywords and Future Direction

Keywords

Keywords are words that capture the essence of a articles.^[29] Thus, keywords play a significant role in getting an article published, making an article searchable, and getting more citations.^[30] As such, it is vital to analyze the keywords in this study. The WOSCC database includes two types of keywords: author keywords

provided by original authors and keywords plus extracted from the titles of the cited references by Clarivate Analytics.^[31] Two types of keywords are also included in the Scopus database: author keywords chosen by the author to best reflect the content of the document and indexed keywords selected by Scopus and are standardized to vocabularies derived from thesauri that Elsevier owns or licenses.^[32] This means that author keywords are from the original authors for both databases, and keywords plus in the WOSCC are the same as indexed keywords in the Scopus.

Table 9: Top 11 author keyword and keywords plus in the WOSCC.

Author keywords	Occurrences	Total link strength	Keywords plus	Occurrences	Total link strength
Safety	37	170	Model	40	189
Mining	26	108	Management	37	222
Coal Mine Safety	16	44	Accidents	34	199
Coal Mine	14	42	Health	25	151
Mine Safety	13	44	System	20	110
Coal Mining	12	50	Performance	18	98
Mining Industry	12	44	China	16	99
Underground Mining	10	30	Climate	16	94
Accidents	9	54	Impact	15	89
Risk Assessment	9	31	Behavior	12	74
Safety Culture	9	19	Injuries	12	58

Table 10: Top 11 author keyword and keywords plus in the Scopus.

Author keywords	Occurrences	Total link strength	Keywords plus	Occurrences	Total link strength
Safety	46	170	Coal Mines	198	2416
Mining	33	127	Coal	139	1932
Coal Mine	30	86	Mining	134	1651
Coal Mine Safety	26	43	Safety	123	1655
Mining Industry	23	67	Accident Prevention	115	1305
Mine Safety	22	41	Article	80	1582
Coal Mining	17	49	Human	79	1364
Risk Assessment	15	52	Coal Mining	77	1351
Safety Culture	13	23	Coal Industry	72	936
Mining Safety	12	13	Risk Assessment	71	1125
Underground Mining	12	28	Accidents	62	830

To be comprehensive, this study analyzed the author keywords and keywords plus together.

Author Keywords include a list of terms that authors believe them to best represent the content of their articles,^[33] and were selected prudently.^[31] Keywords Plus, generated by an automatic computer algorithm, is words or phrases that appear frequently in the titles of an article's references and not necessarily in the title of the article or as Author Keywords.^[34] And they are able to capture an article's content with greater depth and variety.^[34] To this end, Author keywords and keywords plus are both selected for keywords analysis.

Related to the analysis of keywords in the research, the keywords used in studies on MS were analyzed. The analysis results obtained in this context is given in Figures 14 and 15.

Tables 9 and 10 list the Top11 most-occurring author keywords and keywords plus in the WOSCC and Scopus, covering the occurrences and total link strength.

As is shown keywords Table 9, the author keywords and keywords plus of Top11 are greatly different, only 1 keyword (accidents) appears in Top11 author keywords and Top11 keywords plus. In the Scopus, there are some differences in the Top11 author keywords and Top11 keywords plus, and 4 keywords appear in both Top11 author keywords and Top11 keywords plus. However, 9 of Top11 keywords appear in both databases, while only one keyword plus overlaps for the two databases. When Tables 9 and 10 were examined, it was determined that "safety" and "mining" were the most used author keywords in both databases, and the two author keywords connect strongly with the rest of the keywords. Besides, they also represent terms or synonyms from which the term MS is composed.

occupational health into consideration, and will rise to the level of an occupational culture. Besides, the hot topic of MS study is moving from management to prevention. Based on the analysis above, the most used keywords plus are the highest frequency in articles published in the last three years, and they will also be the main research directions in the near future.

To sum up, the current MS research analysis gives us a comprehensive mapping of the research trends for articles indexed by the WOSCC and Scopus databases from the perspective of a comparative vision. Although it provides insights into MS research characteristics, there are still some limitations to be considered. Firstly, this study only analyzed the articles in English, and articles in other languages (such as Chinese, Turkish, Spanish, etc. in the WOSCC and Scopus) were excluded in this study, which will exclude some high-quality articles in MS field. As is known to all, some very famous scholars published some high-quality papers, because of language barrier. Of course, the main reason that retrieved the articles in English is that the vast majority of articles are written in English in both databases. Secondly, this study only focused on articles in order to exclude the republication of an articles. General speaking, one paper will be published in conference proceedings and then published in a journal. In this case, part of the high-quality review or conference proceedings will be excluded. Thirdly, bibliometric analysis deeply relies on the most cited articles. Just as Lopes and de Carvalho stated “the most cited references tend to be the oldest ones, thereby generating a temporal bias”.^[41] Hopefully, future study will try to avoid those limitations, or try to mitigate them. Comparing the findings in the future study with that in this paper will be useful for future study.

CONCLUSION AND FUTURE RESEARCH

On the whole, this study used the bibliometric analysis and visualization tool to comparatively analyze the articles indexed in WOSCC database and Scopus database to provide a comprehensive mapping of MS study over the past 23-year timespan. And it also used the quantitative and qualitative methods to give a comparative vision from different points of view on the MS studies. In this study, significant insights were made into various aspects, including the total articles in the WOSCC and Scopus, the global trends of MS study over the past 23 years, the most prolific authors, countries' contribution, the productive sources, most cited articles, affiliations and keywords analysis. Specifically, the main conclusions can be drawn from the study as follows:

- (1) A growth trend is observed since the year 2000 onwards in both databases, though there are some fluctuations. Specifically, the number of articles shows a rapid growth in the last five year.
- (2) 1270 authors participated in 415 articles' writing in the WOSCC, and 1533 authors contributed to 691 articles' writing

in the Scopus. Analysis of the top5 most co-cited authors in both databases showed that only one most co-cited author overlaps. 5 out of the top 10 prolific authors have overlapped. Besides, China is the country whose authors have published the highest number of articles in Top11 prolific authors (WOSCC) and all Top11 authors from China (Scopus). For co-authorship, the largest set of connected items consists of 9 authors in the WOSCC, while 27 authors in the Scopus.

(3) 44 countries in the WOSCC contributed to the scientific outputs in MS study, while 64 countries in the Scopus. In the two databases, China is the leading country in MS study worldwide, followed by USA. 9 countries of Top10 overlapped, though the rank orders are somewhat different. For the collaborative networks of Top10 most productive countries in both databases, the cooperation of China, USA and Australia was increasingly close, especially China and USA have the most intensive collaboration, with 842 link strengths.

(4) 415 articles were published in 179 different sources in the WOSCC, while 691 articles in 297 different sources in the Scopus. Of the Top 20 sources in the WOSCC and Scopus, 11 sources overlap. *Safety Science* is the top-publishing journal of MS study in the WOSCC (37, 8.92%) and Scopus (37, 5.35%), also it also has the highest number of citations, with 1290 in the WOSCC and 1519 in the Scopus. The network of Top 20 shows that *Safety Science* has the highest links and total link strengths. Regarding the publisher of Top20 sources, USA has the most sources, with 6 (WOSCCA) and 7 (Scopus) sources, then followed by Switzerland with 4 sources in each database.

(5) There is consistency in the WOSCC and Scopus on the top-cited articles on this research in the first four articles. Of the top 10 articles in the two databases, eight out of Top10 articles overlap. The journal with more cited articles is *Safety Science*. It includes 5 papers with a total of 509 citations in the WOSCC and 4 papers with a total of 481 citations in Scopus. 6 articles are published by Chinese authors in the WOSCC, and 4 articles from Chinese authors in the Scopus.

(6) Totally, 415 articles were published by 429 affiliations in the WOSCC, while 691 articles by 1149 affiliation in the Scopus. In the WOSCC, China Univ Min and Technol had the most articles (60) related to MS studies, but the average number of their citations per article (17.15) was somewhat low, though its total citations ranked first. In the Scopus, China Univ Min and Technol still ranks first in the most articles. In the WOSCC, Shandong Univ Sci and Technol has the highest number of citations per article (29.00), while in the Scopus, Univ Queensland ranks first in the average number of their citations (31.58).

(7) In both databases, the author keywords and keywords plus of Top11 have similarities and differences. In WOSCC, they show more differences, while in Scopus, there are more similarities.

9 of Top11 keywords appear in both databases, while only one keyword plus overlaps for the two databases. “safety” and “mining” were the most used author keywords “coal mine safety”, “coal mine”, “coal mining”, “coal”, etc. are still most-occurring keywords, which denotes the focus of MS study on the safety of coal mine/mining, not other mines. Future direction will most likely focus on people who work in the mines, analyze the problems MS from the perspective of occupation, and more occupational. Hot topic of MS study is moving from management to prevention.

Now, MS study is increasingly growing, and will be one of the most important research fields all over the world. The MS study will expand dramatically in the near future. It is better that the future study will focus on risk assessment, human safety, occupational health, etc., taking more attention to miners who work in the underground mines.

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DATA AVAILABILITY

The data used to support the findings of this study are included within the article.

CONFLICT OF INTEREST

The author declares that there is no competing interest for this work.

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