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Global trends and hotspots in the study of the effects of PM2.5 on ischemic stroke

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Abstract

Aim The objective of this study was to visually analyse global research trends and hotspots regarding the role of PM2.5 in ischemic stroke.

Methods The Web of Science core collection database was used to search the literature on PM2.5 and ischemic stroke from 2006 to 2024. Visualization analysis was conducted using CiteSpace, VOSviewer, and an online bibliometric platform.

Results The analysis comprises 190 articles published between 2006 and 2024 by 1229 authors from 435 institutions in 39 countries, across 78 journals. Wellenius GA has the highest number of published and cited papers. China has the highest number of papers, while Canada has the highest citation frequency. Capital Medical University published the highest number of papers, and Harvard University had the highest citation frequency for a single paper. The study investigated the impact of PM2.5 on ischemic stroke in three phases. The first phase analysed hospitalisation rates for correlations. The second phase utilised large-scale multi-cohort data from around the world. The third phase involved studying global exposure risk through machine learning and model construction. Currently, there is limited research on the mechanisms involved, and further in-depth investigation is required.

Conclusion This paper presents a bibliometric analysis of the research framework and hotspots concerning the effect of PM2.5 on ischemic stroke. The analysis aims to provide a comprehensive understanding of this field for researchers. It is expected that research on the effect of PM2.5 on ischemic stroke will remain an important research topic in the future.

Keywords Bibliometric analysis, PM2.5, Ischemic stroke, Risk factors, Effects

Introduction

Ischemic stroke is the leading cause of death and disability worldwide, posing a great threat to human health [1]. Air pollution is an individual risk factor for ischemic stroke independent of smoking, poor diet, and physical inactivity in the United States. Air pollution accounts for more than a quarter of the stroke burden. [2]. Airborne fine particulate matter (PM2.5, aerodynamic diameter < 2.5 μm) is the main component of air pollution. At present, a large number of studies have shown that air pollution are highly associated with an increased risk of ischemic stroke, especially PM2.5 [3–5]. Gu et al. found

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that for every 10 μg/ m³ increase in the PM2.5 level in China, hospitalizations for acute cerebrovascular disease and Transient Ischemic Attacks increased by 0.20% and 0.33%, respectively [6]. Therefore, reducing air pollution and improving air quality are of great significance for reducing the incidence of ischemic stroke.

Bibliometric analysis is a widely used method for evaluating the quality and impact of academic research in various fields [7–10]. It presents the knowledge structure and research status of a field more intuitively through quantitative analysis of published literature, making it a faster and more accurate way to study trends and hotspots compared to systematic and wide-ranging reviews and other types of literature research. [11–13].

Research on the impact of global air pollution on human health has led to a gradual deepening of our understanding of the effect of air pollution on stroke. Specifically, research on the impact of PM2.5 on ischemic stroke has been ongoing for decades, resulting in significant developments and high-quality research results. To date, no bibliometric study has been conducted on the impact of PM2.5 on ischemic stroke to explore the distribution characteristics and trends in this research field. Therefore, this study aims to bibliometrically the relevant literature on the effect of PM2.5 on ischemic stroke, explore the current hotspots and possible future trends in this research field, identify potential research gaps, and provide an important reference for researchers and institutions in this field.

Materials and methods
Data sources and search strategy
The Web of Science (WOS) is an extensive, multidisciplinary database encompassing all high-impact scientific journals and distinguished indexes [14–16]. In comparison with Scopus or MEDLINE/PubMed, the literature measurement analysis facilitated by the WOS database can retrieve more comprehensive information [17]. A literature search using the Web Science Core (WoSCC) database on February 18, 2024. The articles were retrieved from January 1, 2000, to February 18, 2024.The search strategy employed was as follows:

Step1 (((((((((((((((((((((TS=(Ischemic Strokes)) OR TS=(Stroke, Ischemic)) OR TS=(Ischaemic Stroke)) OR TS=(Ischaemic Strokes)) OR TS=(Stroke, Ischaemic)) OR TS=(Cryptogenic Ischemic Stroke)) OR TS=(Cryptogenic Ischemic Strokes)) OR TS=(Ischemic Stroke, Cryptogenic)) OR TS=(Stroke, Cryptogenic Ischemic)) OR TS=(Cryptogenic Stroke)) OR TS=(Cryptogenic Strokes)) OR TS=(Stroke, Cryptogenic)) OR TS=(Cryptogenic Embolism Stroke)) OR TS=(Cryptogenic Embolism Strokes))OR TS=(Embolism Stroke, Cryptogenic)) OR TS=(Stroke, Cryptogenic Embolism)) OR TS=(Wake-up Stroke)) OR TS=(Stroke, Wake-up)) OR TS=(Wake up Stroke)) OR TS=(Wake-up Strokes)) OR TS=(Acute Ischemic Stroke)) OR TS=(Acute Ischemic Strokes)) OR TS=(Ischemic Stroke, Acute)) OR TS=(Stroke, Acute Ischemic)

Step2 TS=(PM2.5)

Step3 Step 1 AND Step 2, NOT TI = ("guideline" or "recommendation" or "consensus" or "case report" or "meta" or "review"), AND Language=English. A total of 308 relevant articles were searched.

After conducting an initial data search, two authors screened all manuscripts. Any discrepancies identified by the authors were then independently screened by a third author to ensure their relevance to the topic of this study. A total of 190 documents were retrieved and exported as 'full records and citation references' and 'tabs separate files' for further analysis.

Data analysis
The bibliometrics used in this study mainly include evaluation techniques and relational techniques [18]. Evaluation techniques are employed to assess the productivity and impact of scientific papers. These include the number of publications, which is used to assess productivity [19]; the number of citations, which is used to measure the impact of publications [20]; the h-index [21], which is used to measure the number of citations to "h" papers; the g-index, which is used to identify the largest number such that the top g articles receive at least g2 citations [22]; and the m-index, which takes into account the number of years since the article was published [23]. These techniques have been employed in the analysis of the PM2.5 effect on ischemic stroke, which has been conducted in collaboration with the most prolific authors and journals in this field. Concurrently, relational techniques are employed to investigate the co-occurrence of keywords and the co-citation of journals, with the generation of a visual graph. The term "co-citation" is used to describe the practice of multiple articles being cited jointly. The outcome of a keyword co-occurrence analysis is a network of topics and their interconnections. The content of a document is examined through the lens of a specific word, which can shed light on the relationship between concepts within a given field [24]. The higher the frequency of words, the stronger the conceptual connections [25].

The data in "tabs separate files" were imported into the bibliometric online analysis platform (http://bibliometric.com) to analyze the relationship between the collaborating countries/regions. CiteSpace [26] and VOSviewer [27], the two most commonly used visual tools analysis software in bibliometrics are mainly used to observe

research hotspots and trends in a certain field and visualize them in graphical form [27, 28]. We applied CiteSpace (version 6.2.R4) and VOSviewer (version 1.6.20) software to visualize bibliometric data. Imported in "full record and citation reference" format and collaborated on the filtered literature between countries/regions, co-authored and co-citation, co-occurrence, clustering and burst analysis. The PRISMA flowchart illustrates the methodology employed in this study, delineating the procedures undertaken for data acquisition, cleaning, and inclusion (Fig. 1) [23, 29].

Results
Summary
Following a rigorous process of literature cleaning, inclusion, and exclusion, a total of 308 literature sources were downloaded. These sources were then filtered to exclude early access literature, correction literature, editorial materials, conference abstracts, and conference proceedings. The final number of literature sources included for analysis was 190. The literature spanned the period from 2006 to 2024 and included 78 journals, 1229 authors, 435 institutions, and 39 countries. There were 5775 references cited.
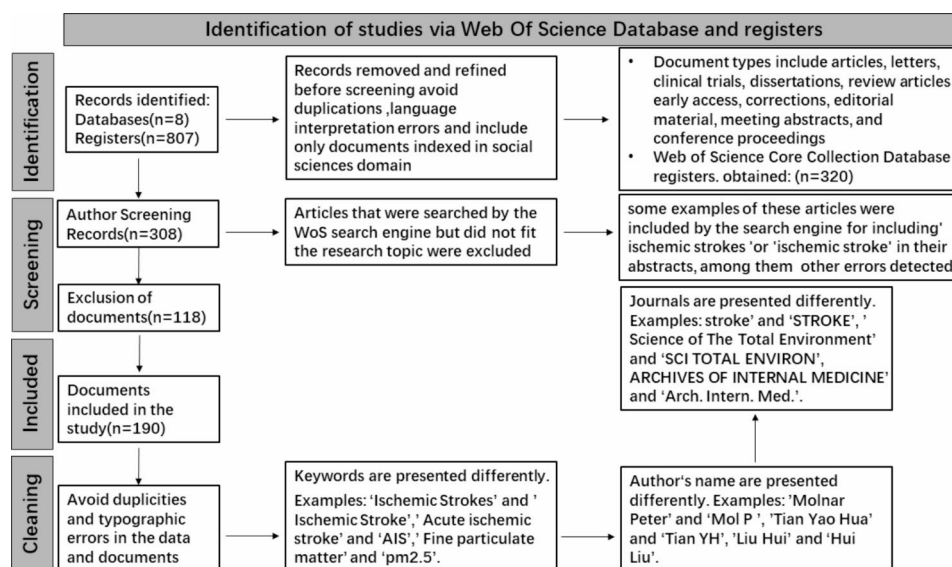
Publication review
Publication numbers
The top 5 by number of publications by author, country, institution and journal, as well as by citations, are summarised in Table 1. The top author by the number of publications and citations was Wellenius GA, with 8 publications and an average annual citation number of 88.875; this author focuses on the effect of duration of PM2.5 exposure on ischemic stroke and the relationship between air pollution exposure and ischemic stroke risk in women. The country with the most published studies was China with 106 publications and an average annual citation number of 37.831. Articles from the United States had the highest total number of citations and articles from Canada had the highest average number of citations at 106.077. Capital Medical University published the most articles, with a total of 16 articles, and the average citation of each article was 14.062. Harvard University had the highest average citations per article, which was 282.714. The Table 2 shows that the United States Department of Health and Human Services sponsored the highest number of articles in terms of funding sources. *SCIENCE OF THE TOTAL ENVIRONMENT* published the most articles, but the average single citation of *ENVIRONMENTAL POLLUTION* was the highest, which was 54.818.

Number of publications varies by year
By analyzing the number of papers published in a particular research field over the years and the countries in which they were published, we can determine the past development history of this field and the global attention to this field, and also predict the development prospects of this field.

The earliest study of PM2.5 on ischemic stroke was published by Paul J Villeneuve et al. in 2006 [30], and the number of publications has not increased significantly since then. A clear cut-off point was observed in 2014, and the number of published papers increased significantly thereafter (Fig. 2). The participation of countries and regions was an important factor affecting the number of papers published, and much of the contribution during this period was high-quality case-crossover analysis. In

Fig. 1 PRISMA flowchart

Table 1 Publications based on author, Country/Region, journal, and institution

Rank	Categories	Documents	Citations	Average citation/publication
	Author			
1	Wellenius Gregory A	8	711	88.875
2	Lin Hualiang	7	124	17.714
3	Guo Xiuhua	7	80	11.428
4	Wei Jing	7	68	9.714
5	Tian Yaohua	6	398	66.334
	Country/Region			
1	China	106	4010	37.830
2	USA	59	4300	72.881
3	Canada	13	2172	167.077
4	Australia	12	218	18.167
5	India	7	300	42.857
	Journal			
1	Science Of The Total Environment	16	459	28.687
2	Environmental Research	15	433	28.867
3	Environmental Pollution	11	603	54.818
4	Environmental Science And Pollution Research	9	46	5.112
5	Environment International	9	487	54.112
	Institution			
1	Capital Med Univ	16	225	14.062
2	Peking Univ	14	455	32.500
3	Sun Yat Sen Univ	12	152	12.667
4	Univ Maryland	10	113	11.300
5	Hlth Canada	9	1908	212.000

2014, scholars in Taiwan published the first study on the effect of regional PM2.5 levels on ischemic stroke. Since then, the number of regional cooperation and broader studies has increased significantly. Subsequently, the length of PM2.5 exposure period, source methods, and different production scenarios were studied from multiple perspectives. The number of publications peaked in 2022. Therefore, the increase of multi-regional, multi-angle, multi-level research ideas and cooperation and exchange has greatly promoted the development of this research field.

Inter-state cooperation

The United States had a large contribution to PM2.5 research. Four of the top five funding agencies were from the United States. Although the number of articles published in the United States was not the largest, the single cited number was the highest. Since 2013, China's contribution to this field has become increasingly prominent, with the largest number of articles published in this field, and the National Natural Science Foundation of China has also funded the largest number of research projects in this field (Table 2). As a country with a large population and deeply affected by PM2.5, China has an extremely high prevalence of ischemic stroke. It has invested huge in this field and made outstanding contributions. It is believed that China will make greater contributions in this field in the future. China and the United States also have the most cooperation and exchanges in this field (Figure 3). The latest research results published by Wellenius GA in 2024 are cooperated with Chinese scholars [31], and there are many more such cooperation and exchanges.

Distribution of citations between journals

The Dual-Map Overlay shows the distribution of citation relationships between journals (Fig. 4). The citing literature is on the left side of the graph, and the cited literature is on the right side of the graph. The colored path between the two represents the citation relationship. Two main citation pathways were found, indicating that studies published in veterinary, animal and natural sciences were mainly cited by studies published in environmental sciences, toxicology and nutrition. Studies published in neurology, kinesiology, and ophthalmology journals are primarily cited by studies published in health, nursing, and medical journals.

Table 2 Publications based on funding source

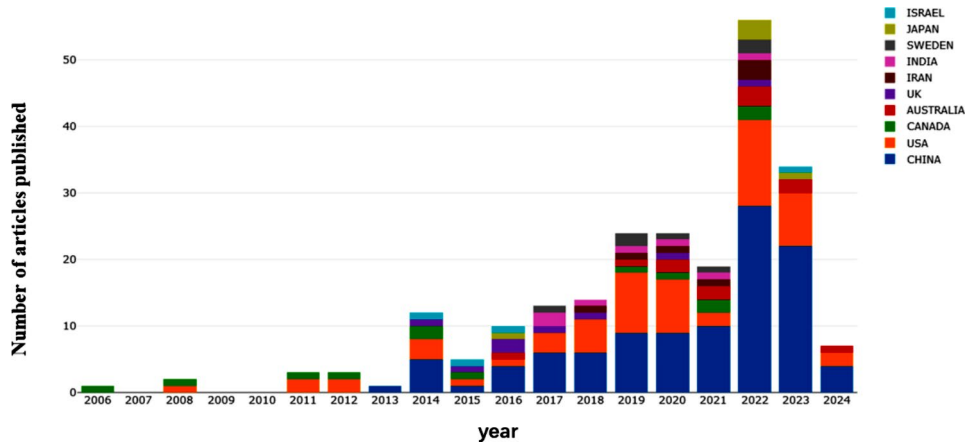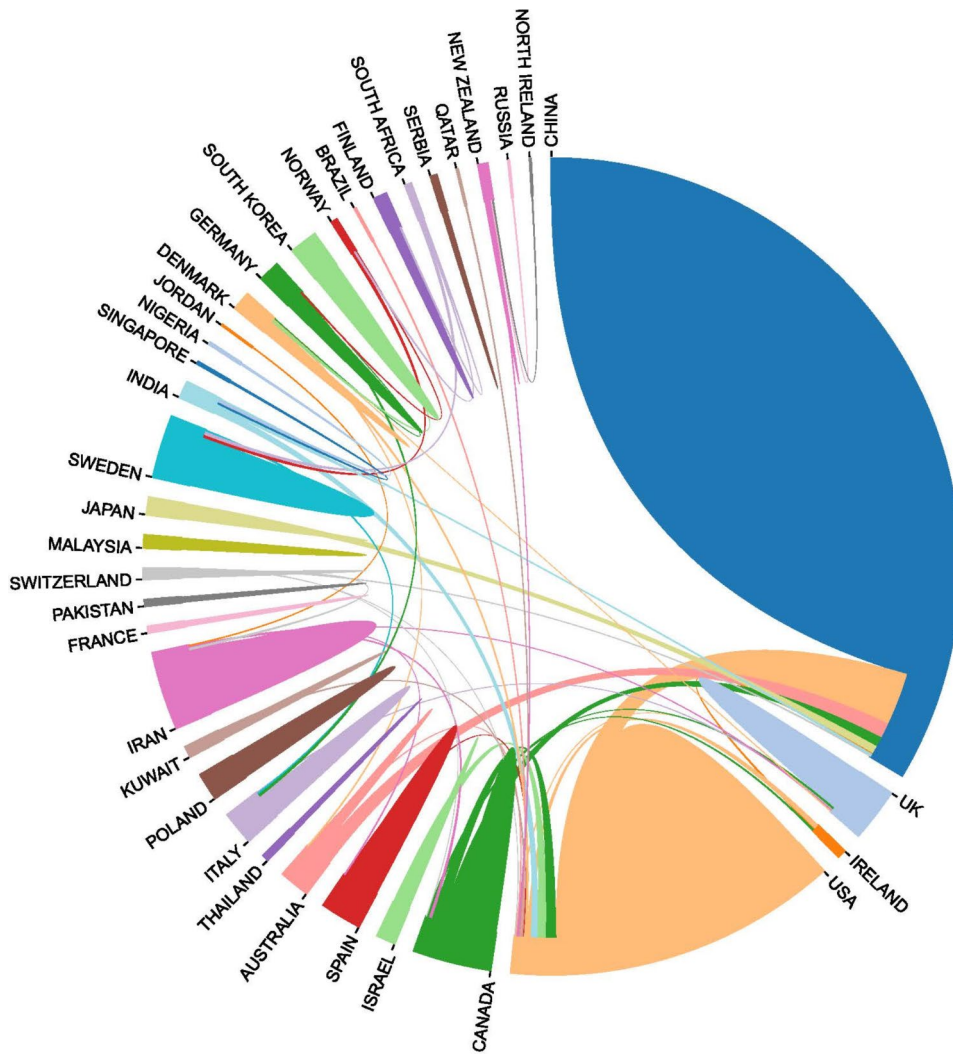| Fund	Count
Nationational Natural Science Foundation of China NSFC	72
United States Department of Health Human Services	41
National Institutes of Health NIH USA	40
NIH National Institute of Environmental Health Sciences Niehs	21
United States Environmental Protection Agency	11

Fig. 2 Number of national publications per year

Fig. 3 Cooperation between countries
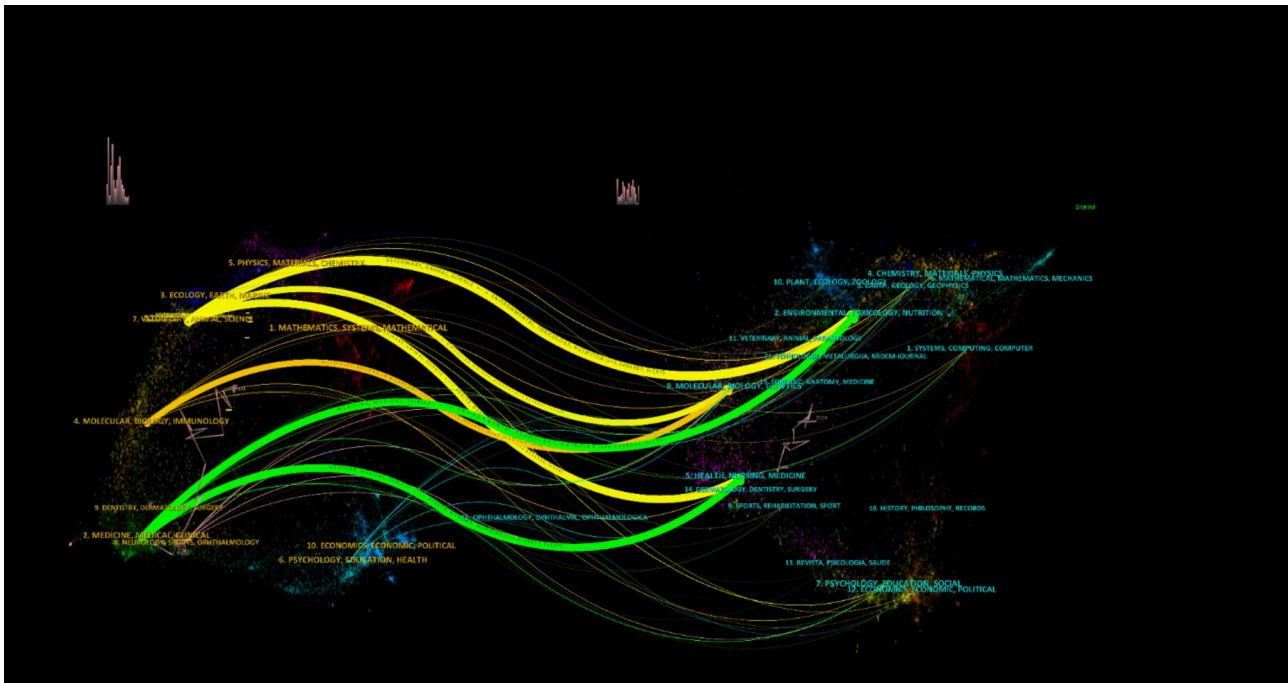
Fig. 4 Dual-Map Overlay

Table 3 Top 5 cited articles

Rank	Articles	Cited
1	Burnett RT, Pope CA 3rd, Ezzati M, et al. An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. Environ Health Perspect. 2014 Apr;122(4):397–403.	1272
2	Shah AS, Lee KK, McAllister DA, et al. Short term exposure to air pollution and stroke: systematic review and meta-analysis. BMJ. 2015 Mar 24;350:h1295.	496
3	Song C, He J, Wu L, et al. Mao H. Health burden attributable to ambient $PM_{2.5}$ in China. Environ Pollut. 2017 Apr; 223:575–586.	401
4	Yin P, Brauer M, Cohen AJ, et al. The effect of air pollution on deaths, disease burden, and life expectancy across China and its provinces, 1990–2017: an analysis for the Global Burden of Disease Study 2017. Lancet Planet Health. 2020 Sep;4(9): e386-e398.	280
5	Lipsett MJ, Ostro BD, Reynolds P, et al. Long-term exposure to air pollution and cardiorespiratory disease in the California teachers study cohort. Am J Respir Crit Care Med. 2011 Oct 1;184(7):828 – 35.	258

Top 5 cited articles

The top 5 cited articles included 1 Meta-analysis articles and 4 clinical articles (Table 3). Publication dates ranged from 2011 to 2020. The article with the highest number of citations, entitled "An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure", was published by Burnett, Richard T et al. in 2014 in *ENVIRONMENTAL HEALTH PERSPECTIVES*, with a total of 1272 citations. Available relative risk information from studies of ambient air pollution (AAP), second-hand tobacco smoke, household solid cooking fuels and active smoking (AS) was integrated to fitted the integrated exposure response (IER) model, which estimated the combined risks of exposure to multi-source PM2.5 [32]. The second and fifth cited articles are the studies on the risk of PM2.5 exposure published by Shah AS et al. and Lipsett MJ et al. These studies elucidate the risk of PM2.5 exposure in two distinct aspects: short-term exposure and long-term

exposure, respectively [33, 34]. Air pollution in China remains a significant concern, with a considerable body of scholarship dedicated to understanding the impact of PM2.5 on public health. A review of the literature reveals that the third and fourth most-cited articles pertain to the disease burden associated with PM2.5 in China [35, 36].

Co-citation analysis

Author co-citation network analysis

Lotka's law was used to determine the minimum number of co-citations. [37]. Fifty-seven authors met the criteria, with Pope Ca, Wellenius GA, and Tian YH being the top three co-cited authors. The authors were divided into three clusters (Fig. 5).

Professor Pope Ca from Brigham Young University has conducted comprehensive research on the multifaceted, multi-regional, and multi-level impact of PM2.5 on disease. His team has made a substantial contribution to the
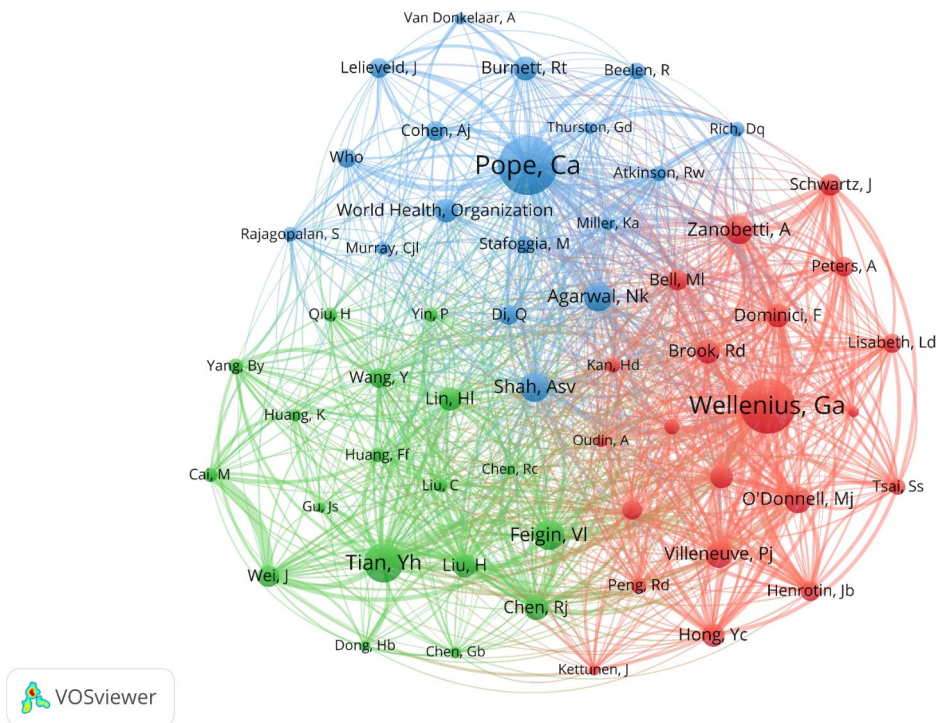
Fig. 5 Co-citation author analysis *Red*: cluster1; *Green*: cluster2; *Blue*: cluster3

assessment of the global burden of disease caused by fine particulate matter. Wellenius, a professor at Boston University, has been engaged in research in the field of environmental and health sciences for an extended period. His contributions to the field include a significant impact on the understanding of the influence of PM2.5 on cardiovascular and cerebrovascular disease. His research has been based on a thorough examination of the local area of PM2.5, the duration of exposure, and the factors influencing the PM2.5 exposure. Professor Tian YH of Beijing University has conducted extensive research on the impact of PM2.5 in China. His studies have covered a vast area, encompassing up to 184 cities, and have focused on the effects of PM2.5 on ischemic cerebral apoplexy. The findings have been used to inform national policy.

Journals co-citation network analysis

If at least one article from both journals is cited in the cited article, two journals are considered to be cited simultaneously [38]. Seventy journals met the criteria, with *ENVIRONMENTAL HEALTH PERSPECTIVES, STROKE,* and *ENVIRONMENT INTERNATIONAL* being the top three cited journals (Fig. 6). The total number of citations for ENVIRONMENTAL HEALTH PERSPECTIVES was high, and the average number of citations per article was as high as 211.14.

Literature co-citation network analysis

Literature were cited analysis is a widely used to study the knowledge in certain areas framework method [39]. Figure 7 shows the literature co-citation network in the field of PM2.5 effect on ischemic stroke. In the figure, a node represents a document/article, while the connecting line between the two nodes represents the co-cited association between the two articles. The larger the node, the more citations an article has. The smaller the distance between two nodes, the higher the citation frequency of the literature.

There were 24 literatures that met the criteria (Fig. 7), and the top 3 cited references were Brook Robert D et al. 2010, Wellenius GA et al. 2012, and Wellenius GA et al. 2005. Brook Robert D et al. conducted a review of the effects of particulate air pollution on cardiovascular disease and concluded that the longer the exposure to PM2.5, the greater the risk of cardiovascular mortality and that lower levels of PM2.5 were associated with lower cardiovascular mortality [40]. Wellenius GA et al. found that exposure to PM2.5, a level considered generally safe by the US Environmental Protection Agency's, increased the risk of ischemic stroke within hours of exposure. This means that lower levels of PM2.5 are not safe [41]. Wellenius GA et al. in 2005 found that PM2.5 levels increased the risk of ischemic but not hemorrhagic stroke [42]. The above three articles reached the same conclusion from
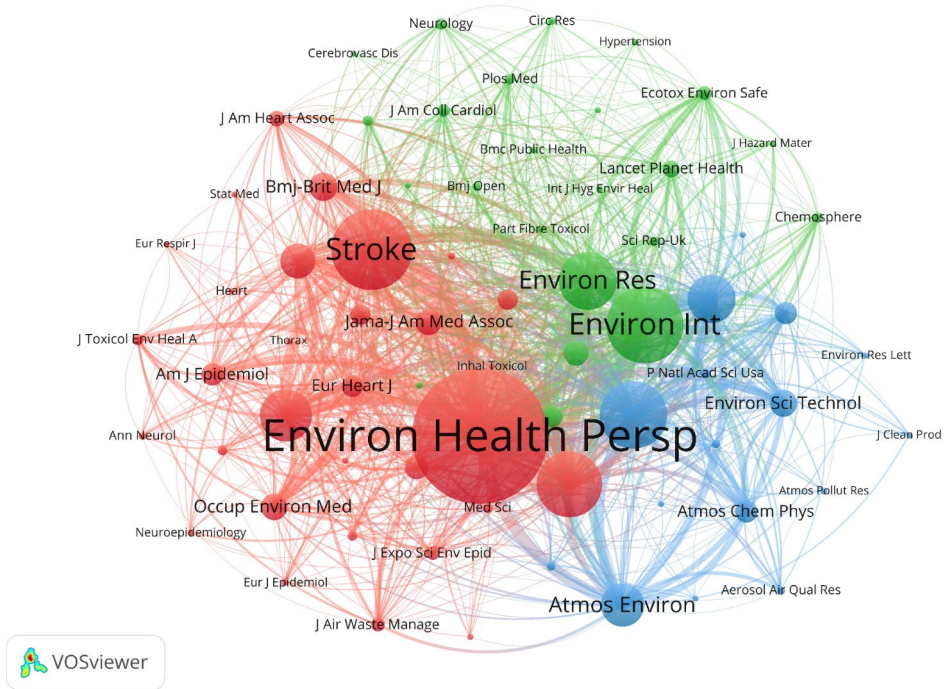
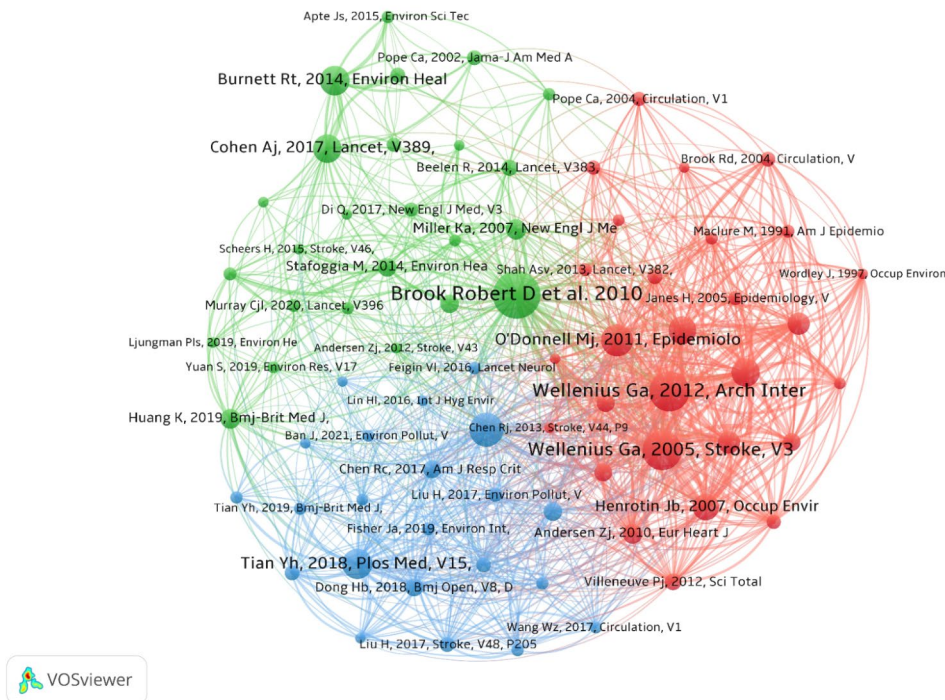**Fig. 6** Co-citation Jour analysis *Red*: cluster1; *Green*: cluster2; *Blue*: cluster3

Fig. 7 Co-citation reference analysis *Red*: cluster1; *Green*: cluster2; *Blue*: cluster3

different perspectives: exposure to PM2.5 may increase the risk of ischemic stroke. This provides a solid basis for further research.

Co-occurrence network and analysis of keywords

According to Lotka's law, 88 keywords were included in the co-occurrence network analysis (Fig. 8). The co-occurrence network was divided into 6 clusters. A total of 10 bursts were identified, with the highest intensity being 'hospital admissions' (strength, 4.27), followed by 'global burden' (strength, 4.14). The last burst was "PM2.5" (strength, 3.89; Fig. 9). In order to better analyse the annual research hotspots and the overall trend of change in the research area, citespace was used to perform a timezone analysis of the keywords (Fig. 10). The whole graph was divided into several vertical blocks from 2006 to 2024, with an interval of one year. Each block had several nodes, and each node represented a keyword. The nodes are composed of one or more colours, and each colour represents a year. The colour in the outer circle of the node represents the closest to the present, and the width of the colour represents the popularity of the year. If the node is all red, it represents the central hot word. The connection between the nodes represents the connection between two keywords. As you can see from the figure, the study of PM2.5 and ischemic stroke only started in 2006, less than 20 years ago. From 2006 to 2008, a large number of studies on air pollution, ischemic stroke, cardiovascular disease, hospital admissions and exposure were carried out in this area and continue to this day. In 2022, PM2.5 became a central buzzword in the field. From 2011 to 2014, this field focused on the global health burden of PM2.5, using a large number of case-crossover analysis methods, and a large number of Chinese scholars began to pay attention to this field. From 2016 to 2018, this field began to focus on national and regional research, and there were a large number of studies on the effect of PM2.5 on ischemic stroke in China. At the same time, since 2016, this area has received more and more attention, reaching a peak in 2023. From 2018, more in-depth research will be conducted on PM2.5 as a risk factor, and attention to this area will become more popular. By 28 February 2024, the number of research articles in 2024 will have reached the level of the whole year 2014. Research on the effect of PM2.5 on ischemic stroke is expected to show an increasing trend in the future.

Discussion

Bibliometrics can help people understand the research focus, framework and trend of a certain field intuitively and comprehensively. PM2.5 has been widely studied as

Fig. 8 Co-Occurrence of key words *Red*: cluster1; *Green*: cluster2; *Blue*: cluster3; *Yellow*: cluster4; Purple: cluster5; Light blue: cluster6

Top 10 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2006 - 2024
hospital admissions	2006	4.27	**2006**	2014	
cardiovascular diseases	2006	3.62	**2006**	2015	
time series	2006	3.15	**2006**	2014	
inflammation	2007	2.3	**2007**	2016	
coarse particles	2013	2.08	**2013**	2017	
global burden	2014	4.14	**2017**	2020	
myocardial infarction	2006	2.55	**2020**	2021	
model	2020	2.06	**2020**	2021	
pm2.5	2008	3.89	**2022**	2024	
risk factors	2022	3.33	**2022**	2024	

Fig. 9 Key words with the strongest citation bursts

Fig. 10 Timezone of key words

a risk factor for ischemic stroke, and reducing the level of PM2.5 can effectively reduce the occurrence of ischemic stroke. A summary of previous studies in this field has occasionally been reported, but there has been no bibliometric description of the literature in this field.

A bibliometric analysis of the study found that the most published author was Wellenius GA, who is affiliated with the Department of Environmental Health at the Boston University School of Public Health. The most cited article is a study by Burnett, Richard T et al., on risk estimation models for PM2.5 exposure. The research integrates the relative risk (RR) information of PM2.5 from different global scenarios and sources of different combustion types to construct and fit a sustainable and updated comprehensive exposure-response model, which can provide important reference for the regulation

of PM2.5[32]. Air pollution from PM2.5 is a global problem that has caused a global health burden. In the early stage, almost all the studies on PM2.5 came from developed countries such as Europe and the United States. However, the worst affected areas of PM2.5 pollution are mainly in developing countries. However, the research in this field from developing countries starts very late, and there is a lack of primary epidemiological investigation. From Fig. 2, we can find that the first study on China was reported in 2013, which was a study published by scholars in Taiwan on the relationship between PM2.5 level and hospitalization rate of ischemic stroke in Taipei City, Taiwan Province [43]. The initial study in this field was published in mainland China in 2014, although it was a Meta analysis [44]. This indicated that mainland China was also beginning to focus on the field. In India, another large developing country, the first study on PM2.5 within the country was not published until 2016 [45]. Furthermore, Burnett et al. not only included global PM2.5 data from various areas but also considered different sources of PM2.5 production, such as smoking, second-hand smoke, and household fuels. These sources are prevalent in daily life, which enhances the generalisation and wide application of the study's conclusions. This also better illustrates the global PM2.5 exposure risk worldwide. At that time, the study by Burnett, Richard T et al. made a significant contribution to the global PM2.5 exposure problem and was undoubtedly a major achievement. A global integrated exposure-response risk assessment has been applied similarly, providing a crucial reference for policymakers in the field of global climate policy [46–48].

Co-citation analysis offers valuable insights into the structural characteristics of a research area. The authors were divided into three clusters based on their citations. Cluster 1 authors focused on studying the impact of PM2.5 levels on the risk of ischemic stroke in various regions of the world. Cluster 2 authors conducted a study on the relationship between PM2.5 levels and ischemic stroke risk in various regions of China. These researches included multiple perspectives on different exposure periods, surrounding environments, and different subtypes of ischemic stroke. Chen Gongbo et al. [49], Liang, Ruiming et al. [50] and Zhang, Yi et al. [51] conducted studies on the effects of long-term and short-term exposure to PM2.5 on the risk of ischemic stroke. They concluded that PM2.5 is associated with a high risk of ischemic stroke, regardless of the duration of exposure. Furthermore, studies have been conducted on the various components of PM2.5. Zhang et al. [51] discovered that exposure to NH_4^+ was linked to the highest risk of ischemic stroke, while polycyclic aromatic hydrocarbons (PHS) were primarily associated with ischemic stroke. NH_4^+ originated mainly from residential and agricultural emissions, while PHS mainly came from automobiles and

other related fuel combustion [52, 53]. Many of these studies are based on large, multi-city samples, Tian Y et al. conducted a study based on data from the National Urban Workers' Basic Medical Insurance database, which recorded 8,834,533 patients hospitalized for cardiovascular reasons in 184 cities in China from 1 January 2014 to 31 December 2017. The study found that short-term exposure to PM2.5 was associated with increased hospital admissions for all major cardiovascular diseases except hemorrhagic stroke in China. This association was observed even when exposure levels did not exceed current regulatory limit [54], Cai M et al. found that exposure to PM2.5 was highly associated with a high risk of ischemic stroke recurrence in China, based on data from more than 1 million stroke patients [55]. The authors of Cluster 3 focus on risk assessment and model construction related to PM2.5. This provides a reference for preventing and treating PM2.5 exposure in the future.

The top 3 cited references were Brook Robert D et al. 2010 [40], Wellenius GA et al. 2012 [41], and Wellenius GA et al. 2005 [42]. The papers represent early and pioneering research in the field, providing a solid theoretical foundation for subsequent studies. The journals in which they were published are of high quality and widely accepted by researchers. The authors are also leading scientists in the field, and their research results are significantly forward-looking and instructive. The co-cited articles were divided into three categories. Cluster 1 was constructed around Wellenius GA et al. 2012 and Wellenius GA et al. 2005. These studies mainly demonstrated that PM2.5 contributes to the risk of ischemic stroke. Cluster 2 was constructed around Brook Robert D et al. In 2010, multiple cohorts and large sample data further confirmed that PM2.5 increases the risk of ischemic stroke. Cluster 3, as analysed by Tian Yh et al. in 2018, provides insight into the development trend and pattern of ischemic stroke caused by PM2.5 from a time series perspective.

To gain a better understanding of the dynamic developmental changes and patterns in the field, this study utilized Citespace for burst word analysis and Timezone analysis. The findings indicate that between 2006–2016, the field primarily focused on the relationship between air pollution and hospital admissions. The study found that air pollution significantly affected cardiovascular disease admissions, and when ischemic stroke was included in the study of cardiovascular disease. Between 2013 and 2017, researchers increasingly focused on the significant role of particulate matter in air pollution, including the effect of PM2.5 levels on ischemic stroke. The buzzwords during this period were 'hospital admissions' and 'cardiovascular disease'. Between 2017 and 2020, scholars in the field shifted their focus towards the worldwide impact of air pollution. This period also saw a significant increase

in the number of articles published in the field, with many developing countries joining the research efforts. The term 'global burden' was coined to describe this phenomenon. Since then, researchers have subdivided air pollution into different types, with PM2.5 receiving significant attention as a risk factor. This focus began with the explosion in 2022, which saw a peak in publications on the topic. In recent years, advancements in research methods have enabled researchers to conduct large-scale exposure risk assessments around the world regarding PM2.5 as a risk factor. This has provided valuable insights for the development of global climate policies. Therefore, the key terms for 2020–2024 are "PM2.5", "risk factor", and "modelling".

This bibliometric study examines the impact of PM2.5 on ischemic stroke and serves as a valuable reference for those interested in this field. However, there are some limitations to consider. Firstly, the study only includes research articles, excluding conferences, letters, and articles in non-English languages, which limits the scope of the articles included. Secondly, the search was restricted to the WoSCC database. The WoSCC database covers most research articles, but it is challenging to guarantee the inclusion of all articles in the field. Despite these limitations, they do not affect the broad applicability of the findings of this study. The analyses are based on real-world data, and the results are reliable. They reflect the structural characteristics and dynamics of the field and are valuable for a comprehensive understanding of the field. Additionally, they are highly informative for the study of future trends in the field. There is a significant amount of high-quality evidence from clinical studies, epidemiological investigations, and large-sample model construction regarding the effect of PM2.5 on ischemic stroke. However, the mechanism behind this effect remains unclear and requires further research in the future.

Conclusion

The study of the effects of PM2.5 on ischemic stroke is a relevant and attractive field. Environmentalists, neurologists, and other professionals will continue to advance this field. In recent years, the addition of computationalists and meteorologists has led to the development of models and the use of meteorological satellite remote sensing. Bibliometrics analyses the research framework and hotspots of PM2.5's impact on ischemic stroke, which is a significant driver of ischemic stroke. The model construction, based on large samples and multiple cohorts, effectively assessed the global exposure risk of PM2.5. This provides an important reference for the development of global climate change response strategies and helps researchers to have a more comprehensive understanding of the field, providing ideas for future research.

Author contributions
Qian Liu: conception, methodology, software, data collection, writing - original manuscript. Shijie Yang: methodology, software, data collection. Chen He Cheng: writing - revision, editing and financial support.

Data availability
No datasets were generated or analysed during the current study.

Declarations

Competing interests
The authors declare no competing interests.

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