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Research article

Bibliometric analysis of global research on air pollution and cardiovascular diseases: 2012–2022

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A R T I C L E I N F O

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A B S T R A C T

Background: The relationship between air pollution and cardiovascular diseases (CVDs) has garnered significant interest among researchers globally. This study employed bibliometric analysis to provide an overview of current research on the association between air pollution and CVDs, offering a comprehensive analysis of global research trends in this area.
Methods: An exhaustive scrutiny of literature pertaining to the nexus between air pollution and CVDs from 2012 to 2022 was conducted through rigorous screening of the Web of Science Core Collection (WoSCC). Publications were exclusively considered in English. Subsequently, sophisticated analytical tools including CiteSpace 6.2.4R, Vosviewer 1.6.19, HistCite 2.1, Python 3.7.5, Microsoft Charticulator, and Bibliometrix Online Analysis Platform were deployed to delineate research trends in this domain.
Results: The analysis of the dataset, comprising 1710 documents, unveiled a consistent escalation in scientific publications, peaking in 2022 with a total of 248 publications. Moreover, Environmental Science and Toxicology stood out as the predominant categories. Examination of keyword frequency highlighted the terms 'air pollution', 'cardiovascular disease', and 'particulate matter' as the most prevalent. Notably, the most prolific entities, in terms of authors, journals, organizations, and countries, were identified as Robert D. Brook, Environmental Health Perspectives, Harvard University, and the United States, respectively.
Conclusion: The findings presented a notable increase in high-quality publications on this topic over the past 11 years, suggesting a positive outlook for future research. The study concluded with an examination of three key themes in research trends related to air pollution and CVDs: the initial physiological response to pollutant exposure, the pathways through which pollutants are transmitted, and the subsequent effects on target organs. Additionally, various air pollutants, such as particulate matter, nitric dioxide, and ozone, could contribute to multiple CVDs, including

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coronary heart disease, hypertension, and heart failure. Although some hypotheses have been put forward, the mechanisms of air pollution-related CVDs still need to be explored in the future.

1. Introduction

Air pollution, comprising a complex amalgamation of particulate matter (PM) and gaseous contaminants, is implicated in approximately 8.8 million excess mortalities annually. Nearly half of these deaths are ascribed to outdoor pollution, while the remainder stem from household pollution, significantly exacerbating the global disease burden [1,2]. According to the World Health Organization (WHO) and the Global Burden of Disease study, air pollution ranked fourth in the hierarchy of global causes of morbidity and mortality, accounting for slightly fewer fatalities than high systolic blood pressure, tobacco, and dietary risks [3]. Although the detrimental effects of air pollution on respiratory disorders are widely recognized, it is noteworthy that CVDs account for fifty percent of air pollution-related fatalities [2]. Furthermore, compelling global evidence has conclusively demonstrated that approximately 20 % of CVDs fatalities are attributable to human exposure to air pollutants, such as $PM_{2.5}$, PM_{10}, ozone (O_3), and nitric dioxide (NO_2) [4,5]. While traditional risk factors do play a role in CVDs development, increasing attention has been paid to the role that environmental risk factors like ambient air pollution play [6].

Numerous large-scale epidemiological studies have shown that exposure to air pollution heightened cardiovascular risk factors like hyperlipidemia, hypertension, atherosclerotic vascular changes, and diabetes, as well as cardiovascular morbidity and mortality, including ischemic heart disease, heart failure, and stroke [7–9]. Several potential mechanisms, including activation of oxidative stress and inflammation, disruptions in autonomic balance and neuroendocrine regulation, increased vasoconstriction and coagulation, and the translocation of PM into the systemic circulation, have been proposed to explain the association between air pollution and CVDs [10,11]. Consequently, the interaction between air pollution and CVDs has emerged as a major environmental and public health concern, necessitating in-depth studies for proper identification and addressing.

Bibliometrics, a quantitative and statistical method used to assess the scholarly impact and characteristics of scientific output, is an essential part of the information discipline system and reveals patterns in literary information [12]. Specific information such as authors, keywords, journals, countries, institutions, and references can be extracted during the analysis process. By combining creative design and information visualization, bibliometric mapping graphically depicts bibliometric data, emphasizes the influences of a given study on a field, and may facilitate data comprehension [13]. Bibliometric analysis has been extensively utilized in numerous disciplines of medical research, such as cardiology, oncology, immunology, and public health, due to its potent prognostic function for research outlook. The behavior factors (e.g., sedentary behavior and physical exercise), as well as demographic factors (e.g., income) and CVDs bibliometric analysis, have been published [14–18]. However, a bibliometric analysis of air pollution and CVDs has not been

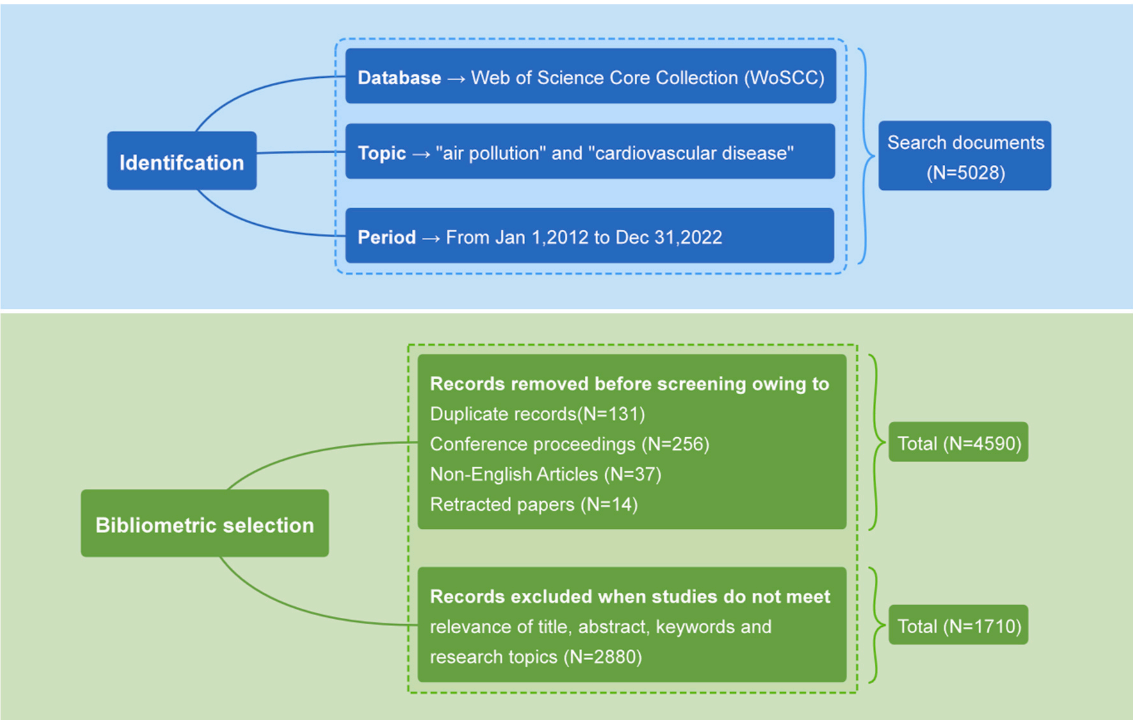

Fig. 1. The literature-screening process and research framework.

published, nor are the research trends and prospects between air pollution and CVDs evident to our knowledge. To fill the gap, we employed a bibliometric analysis of research related to air pollution and CVDs published from 2012 to 2022, utilizing the Web of Science Core Collection (WoSCC). This study examined information on keywords, authors, institutions, countries/regions, and journals, employing several tools to analyze the data. Ultimately, a greater comprehension of the complex association between air pollution and CVDs can provide direction for future research in this field, inform evidence-based strategies to promote heart health, and reduce the global burden of CVDs.

2. Methods

2.1. Data sources and searches

The WoSCC was selected as the repository for literature acquisition, encompassing the Science Citation Index (SCI-E), Social Science Citation Index (SSCI), Conference Citation Index (CPCI), Arts and Humanities Citation Index (AHCI), among others. Relative to alternative databases, WoSCC boasts comprehensive coverage and furnishes extensive bibliometric data [19]. In accordance with the minimum reporting requirements for bibliometric analysis as outlined by Montazeri et al. [20], this study provided a comprehensive account of the data sources, search strategies, and analytical tools employed. All stages of the analysis, from data extraction to processing and visualization, were explicitly detailed to ensure transparency and reproducibility of the findings. This approach followed the recommended practices for bibliometric studies in the biomedical field, aiming to foster a rigorous and replicable research framework.

As delineated in Fig. 1, the search methodology for this investigation was meticulously defined on June 20, 2023. A targeted search was executed within the WoSCC database for the period from January 1, 2012, to December 31, 2022. The search parameters were set as follows: Topic = ("air pollution" AND "cardiovascular disease"). Exclusively articles and reviews were considered, expressly excluding book chapters, letters, proceedings papers, editorial materials, meeting abstracts, and reprints. The focus was restricted to documents published in English. Additionally, a manual scrutiny of each document's content, including titles and abstracts, was undertaken to excise duplicative and non-pertinent entries, ensuring relevance to air pollution and CVDs. This rigorous selection process culminated in a dataset comprising 1710 records (1528 articles and 182 reviews). The compiled records were stored in plain text format under the designation 'download_txt'. This dataset encapsulated all pertinent bibliographic information—authors, titles, sources, abstracts, cited references, keywords, etc.—vital for subsequent analysis.

2.2. Statistical analysis

In this study, principal bibliometric techniques were deployed as follows: HistCite (version 2.1), a pivotal instrument for delineating the field's developmental history and for identifying seminal literature and leading authors, as well as for analyzing citation linkages among scholarly works, was utilized to aggregate data on publication counts, total global citation scores (TGCS), total local citation scores (TLCS). The bibliometric tools within the WoS database were harnessed to ascertain the annual publication output. Additionally, Python (version 3.7.5) and Matplotlib (version 3.1.1) were employed to fabricate dot-broken line graphs. VOSviewer (version 1.6.19) served to analyze factor scores and profile descriptions, while Microsoft Charticulator was pivotal in mapping the networks of country cooperation derived from VOSviewer outputs. This analytical phase involved scrutinizing publication volumes per country and pinpointing nations that wield considerable influence in the field. The Bibliometrix Online Analysis Platform was also engaged to probe the scientific collaborative networks among institutions. Furthermore, CiteSpace (version 6.2.4R) was utilized to delineate productive countries/regions, institutions, journals, authors, and keywords, as well as to map main co-cited references and their cluster diagrams. Crucially, this tool facilitated the examination of dual-map overlays of citations, timelines, citation bursts of references, and keywords to discern emerging trends. Time slicing was implemented from January 2012 to December 2022, with annual intervals. Selection criteria were established as follows: the top 25 % of institutions, the top 15 % of authors, the top 15 % of keywords, and the top 10 % of references from each annual segment. The Pathfinder method was employed for pruning, and the minimal duration for citation burst analysis was set at one year.

The focus of this research encompassed several core areas: (1) Quantitative analysis of publication data, utilizing WoSCC's visualization tools to illustrate annual changes in publication volume and geographic distribution. (2) Identification of key authors, institutions, and journals within the field. (3) Extraction and analysis of seminal literature. (4) Exploration of research frontiers and emerging trends. (5) Projections regarding the field's future trajectory.

3. Results

3.1. Analysis of the patterns in publication outputs, TGCS and TLCS

Between 2012 and 2022, an exhaustive search on the WoSCC identified a total of 1710 English-language papers pertinent to the topics of "air pollution" and "cardiovascular disease". The TGCS were employed as a bibliometric indicator to quantify the citations accrued by research papers listed in the WoS database. Concurrently, the TLCS were utilized to gauge the citations within a specific academic domain. Consequently, the amalgamation of TGCS and TLCS indices facilitated a more stringent evaluation of their respective scholarly impacts. According to Fig. 2, the left vertical axis represented the annual publication tally, exhibiting a consistent increase in the domain, escalating from 82 papers in 2012 to 248 papers in 2022. Conversely, the right vertical axis illustrated the quantity of TLCS, with deeper shades of blue denoting higher TLCS values. The dimensions of the circles were proportional to the TGCS. During the period from 2012 to 2016, the field underwent a gradual developmental phase, with articles consistently numbered between 80 and 150, indicating a burgeoning interest in this area. Significantly, the TLCS for the field showed a smooth ascent from 1141 to 1247. The TGCS values were approximately five times those of the TLCS and displayed a parallel upward trajectory. This trend partially reflected the burgeoning interest in this particular field, serving as an indicator of the utilization and prominence of scientific papers within the research process, as well as their role and stature in academic discourse. Notably, both TGCS and TLCS reached their zenith three times during the duration of our study (in 2014, 2015, and 2016), suggesting that these years may have featured the publication of seminal works.

However, the number of publications and citations experienced a slight decline in 2017, with 138 articles, marking the nadir of that year. Since 2018, a pronounced resurgence in growth was observed, with a significant escalation in both the number of published works and citations. The publication tally rose markedly from 175 in 2019 to 248 in 2022, a rise potentially attributed to the exploration of novel research themes or increased public recognition. Nonetheless, from 2017, TGCS and TLCS began to exhibit a sharply declining trend. The observed diminution in citations for recent articles did not necessarily signify that they were less frequently cited in comparison to earlier publications. Rather, the decrease can be attributed to the reduced timeframe for newer articles to gather citations and the influence of previous publications might wane as more contemporary research became available. The fluctuations in publications and citations underscored an escalating interest in air pollution related to CVDs as a salient topic of study. One can anticipate continual advancements in this field of research in the foreseeable future.

3.2. Analysis of distribution of main research categories

Upon examination of the designated WoSCC research categories, it was ascertained that the 1710 articles initially identified were segregated into 20 research categories, as depicted in Fig. 3. The top 10 categories ranked by frequency, burst, and sigma were displayed in Table 1. The burst metric served as an indicator of the fluctuations in research activity within the domain, with elevated values signifying a more advanced stage of development. Conversely, the sigma metric, a composite indicator, incorporated both centrality and burst, derived from these dual factors. Nodes exhibiting higher centrality and burst displayed augmented sigma values, denoting their structural and citational prominence. The most frequently encountered categories included Environmental Science, Public Environmental & Occupational Health, Toxicology, Cardiac & Cardiovascular Systems, and Peripheral Vascular Disease. Toxicology has gained prominence as indicated by its high burst (9.05) and sigma values (13.52). The integration of Toxicology classifications indicated a pronounced focus on research concerning atmospheric contaminants, specifically $PM_{2.5}$, which was

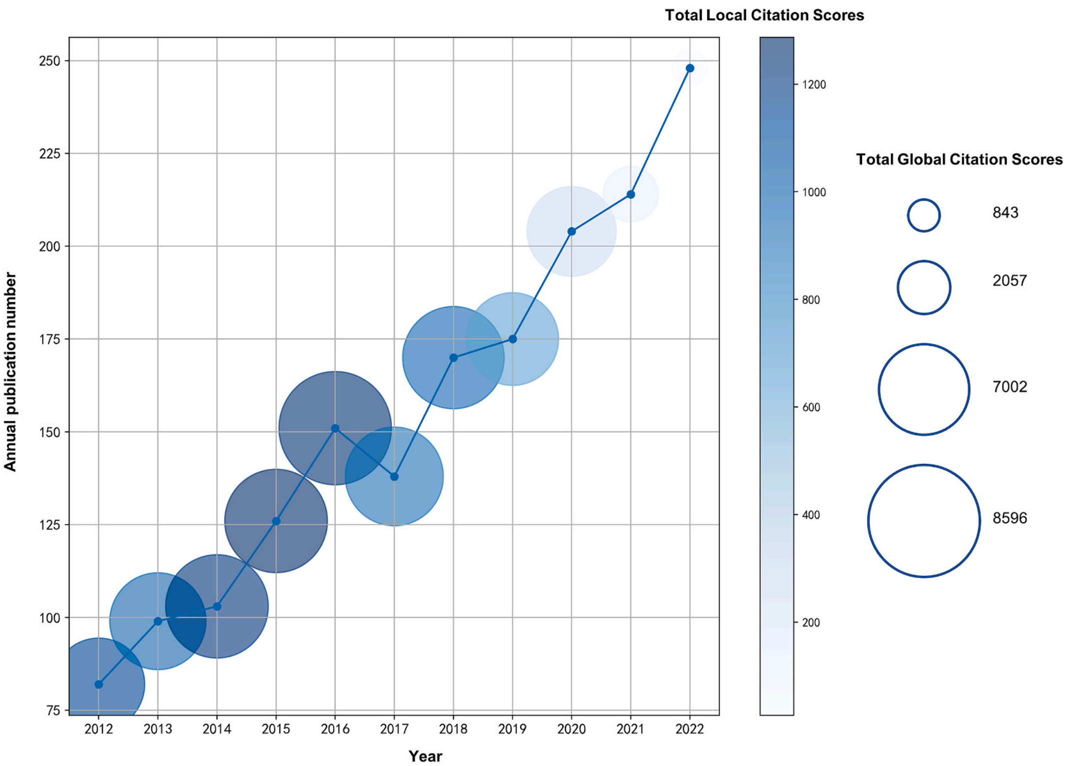

Fig. 2. Annual trend of publication output, frequency of the Total Local Citation Scores (TLCS) and the Total Global Citation Scores (TGCS) of the published papers per year from 2012 to 2022 in the field of air pollution and cardiovascular disease. The size of the circle represents TGCS, the depth of the color represents TLCS, and the folded portion represents the number of annual publications.

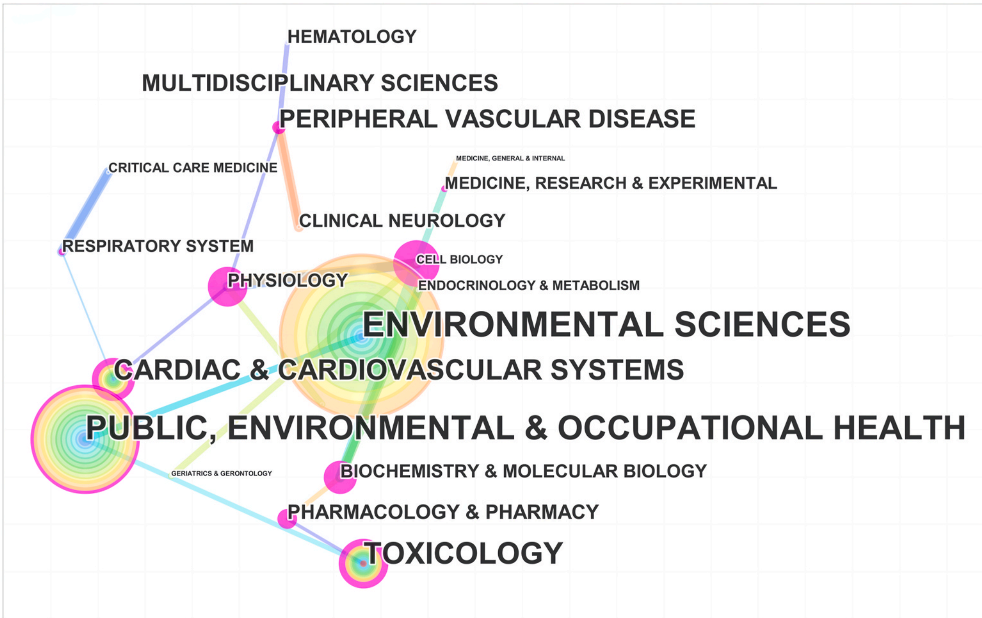

Fig. 3. Citespace category co-occurrence analysis network in air pollution and cardiovascular disease from 2012 to 2022. Each node represents one category and the size of the node reflects its frequency. The category labels are exhibited beside the node. Centrality is counted and shown as"purple circle" that connect several articles and play a pivot role in the network.

Table 1
Top 10 Categories by Frequency, Burst and Sigma in air pollution and cardiovascular disease from 2012 to 2022.

Frequency	Category	Burst	Category	Sigma	Category
913	Environmental Science	9.05	Toxicology	13.52	Toxicology
626	Public Environmental & Occupational Health	1.54	Physiology	1.58	Physiology
294	Toxicology	1.39	Peripheral Vascular Disease	1.41	Cell biology
233	Cardiac & Cardiovascular Systems	1.30	Medicine General & Internal	1.38	Peripheral Vascular Disease
120	Peripheral Vascular Disease	0.95	Hematology	1.17	Pharmacology & Pharmacy
80	Multidisciplinary Sciences	0.58	Neurosciences	1.17	Biochemistry & Molecular Biology
36	Pharmacology & Pharmacy	0.53	Pharmacology & Pharmacy	1.16	Respiratory system
26	Hematology	0.53	Medicine Research & Experimental	1.11	Medicine Research & Experimental
25	Physiology	0.36	Geriatrics & Gerontology	1.03	Geriatrics & Gerontology
25	Biochemistry & Molecular Biology	0.12	Clinical Neurology	1.00	Cardiac & Cardiovascular Systems

associated with the onset of cardiovascular and respiratory diseases in epidemiological and toxicological studies. The preeminence of Environmental Science as the foremost field can be attributed to the acknowledgment that complex diseases such as CVDs were influenced by the interplay between genetics and environmental factors. Additional categories suggested that researches into cardiovascular-related environmental risk factors were expected to continue increasing. Investigations within the realm of Environmental Sciences and the degradation of pollutants may contribute to reducing cardiovascular morbidity and mortality associated with ambient particulate matter.

3.3. Analysis of keyword Co-occurrence

Fig. 4A exhibited the Citespace network analysis of keyword co-occurrence, emphasizing air pollution, CVDs, PM, mortality, and exposure. In Fig. 4B, burst detection elucidated the top 25 keywords, encompassing heart rate variability, cardiovascular mortality, ultrafine particles, referent selection, and airborne particles, which were among the initial terms to garner attention. During this period, the field observed the introduction of two notable keywords, specifically the inhalation of diesel exhaust and its global repercussions, which could potentially herald pivotal developments in the domain. In recent years, considerable emphasis has been placed on terms such as ozone exposure, years of life lost, visits, and cardiac function. Keywords manifesting the longest duration of emergence included C-reactive protein and cardiac function. As depicted in Fig. 4C–a keyword clustering timeline graph spanning from January 2012 to December 2022, disclosed the shifts in prominence and the variations in word frequency rankings pertinent to air pollution and CVDs. Predicated on their co-occurrence relationships, the keywords were aggregated into 16 principal clusters. The right side delineated the labels for each cluster, with the horizontal axis denoting the primary occurrence times of the keywords. The

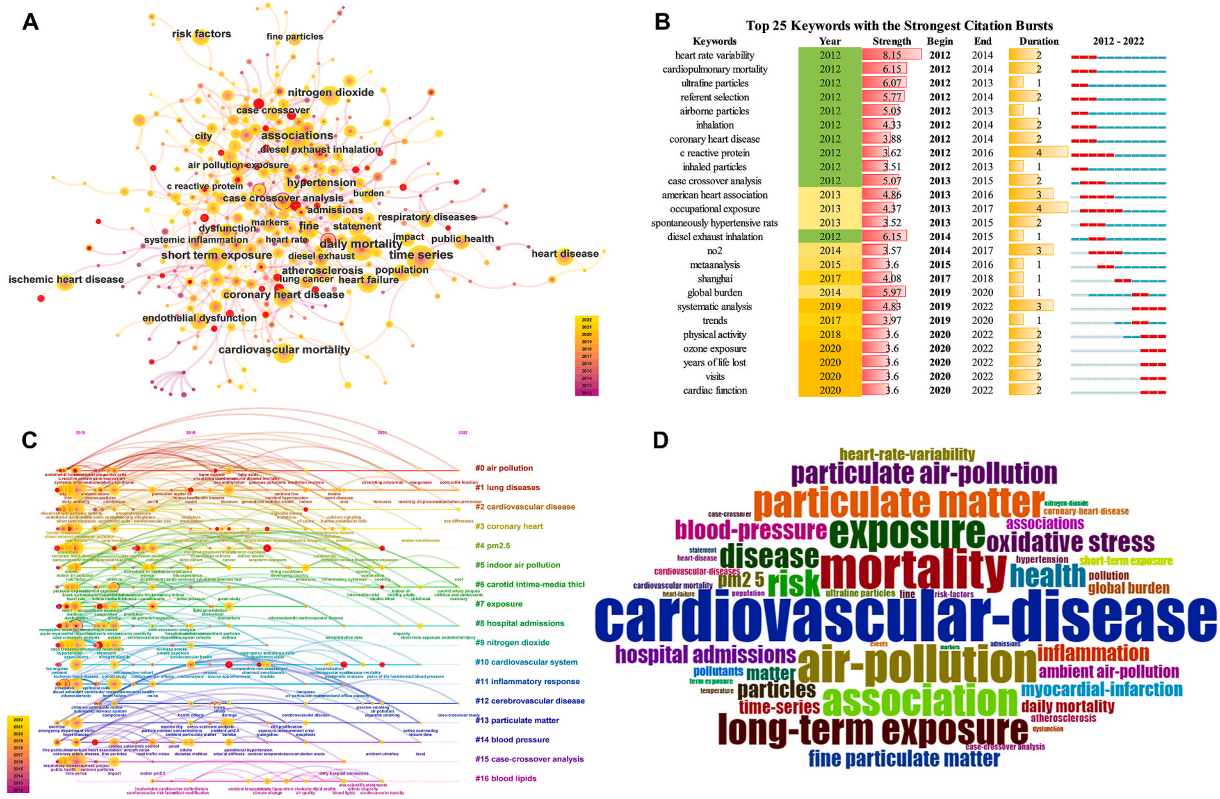

Fig. 4. **(A)** Citespace keyword co-occurrence analysis network in air pollution and cardiovascular disease from 2012 to 2022. Each node represents one keyword. The frequently used keywords are exhibited beside the node. **(B)** Citespace top 25 keywords burst detection, together with their strength and duration. The strength value reflected the frequency of citation. **(C)** Keyword clustering timeline graph. **(D)** Word-cloud plots.

cluster analysis pinpointed the following as the top ten terms: air pollution, lung diseases, CVDs, coronary heart disease, $PM_{2.5}$, indoor air pollution, carotid intima-media thickness, exposure, hospital admissions, and nitrogen dioxide. Furthermore, the interconnectedness among these keywords underscored their joint occurrence. Within this scope, Fig. 4D showcased the visual representation of the word cloud map, illustrating the distribution of density.

3.4. Analysis of the network of countries/regions cooperation

Research articles addressing the nexus between air pollution and CVDs were disseminated across 81 countries and regions globally. Fig. 5A delineated the global distribution of publications spanning various countries and regions. While a broad spectrum of countries and regions worldwide contributed to this corpus of research, Africa appeared to be less engaged in addressing the intersection of air pollution and CVDs. As demonstrated in Fig. 5B, the United States, China, and the United Kingdom were identified as the most prolific contributors. As illustrated in Fig. 5C–a meticulous examination of the collaborative partnerships and research statuses within the entities of the top 30 ranked publications was undertaken to ascertain research units possessing profound expertise in this specialized domain. The majority of collaboration between European and American countries occurred through the utilization of the online analysis platform Microsoft Charticulator in these collaborative networks. Similarly, China, paralleling the United States, exhibited more extensive collaboration than any other nation.

3.5. Analysis of distribution of participating institutions

In academic settings, it has been consistently observed that collaborative teams tend to generate research with a more substantial impact compared to individual researchers. Furthermore, an in-depth examination of the collaborative relationships among various countries/regions, institutions, and authors provides invaluable insights into the scholarly dynamics within a particular field. To facilitate this analysis, we utilized an online bibliometric analysis tool to investigate the prevalence of the top 10 institutions, as depicted in Fig. 6. Notably, Harvard University and the Harvard T.H. Chan School of Public Health were identified as the foremost institutions in terms of publications, with 302 and 189 publications, respectively. The University of Washington-Seattle followed closely, securing the third position with 167 publications. In the United States, seven researchers were associated with these leading institutions; in China, two researchers were linked to prominent institutions, and in Canada, one researcher was connected to a major

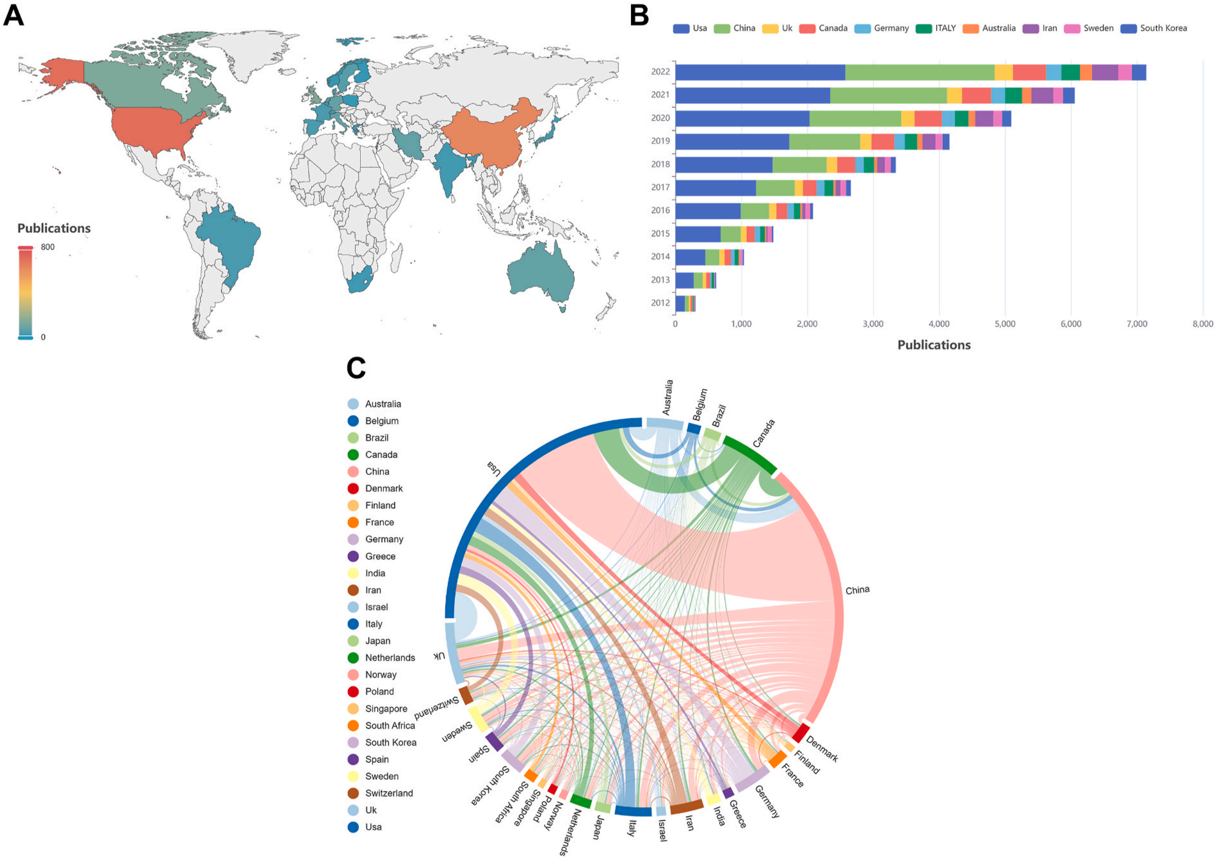

Fig. 5. (A–B) The changing trend of the annual publication quantity in the top 10 countries/regions from 2012 to 2022. **(C)** The international collaborations' visualization map of countries/region.

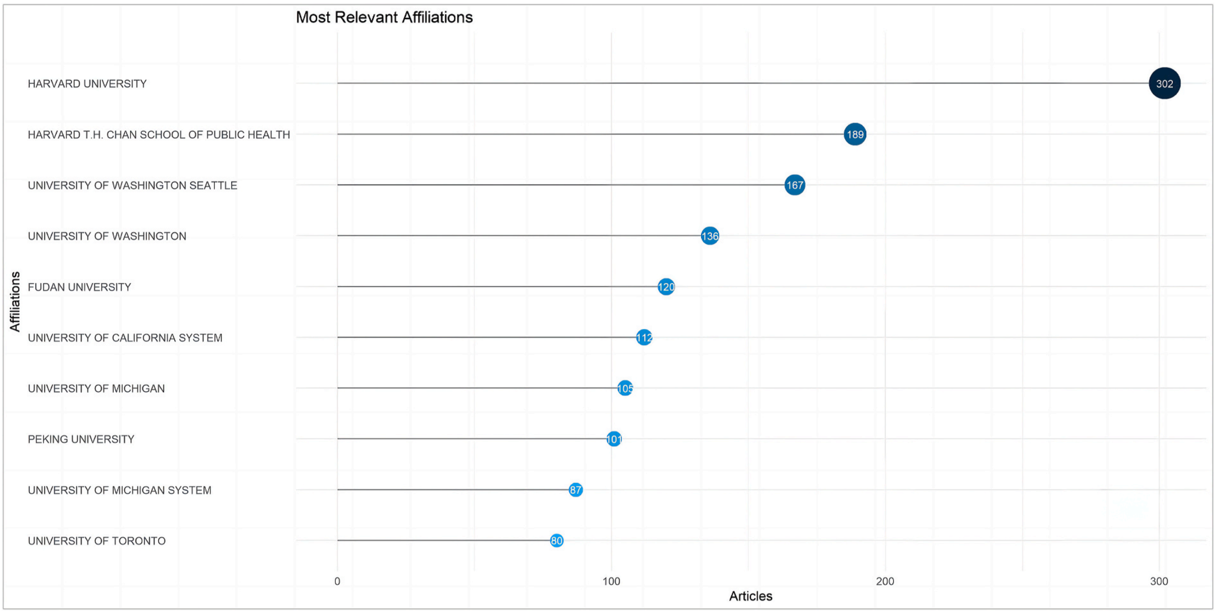

Fig. 6. In the visual analysis graph of air pollution and cardiovascular disease research institutions.

institution. The preponderance of publications from universities in the United States indicates a considerable influence and robust collaborations fostered in this specific domain, as illustrated by this distribution.

3.6. Analysis of productive authors and Co-cited authors

The analysis of author collaboration revealed a robust level of cooperation within the discipline. Table 2 displayed the top 10 authors who had achieved the highest co-citations and were the most frequently co-cited. Fig. 7A depicted the analysis of the productive author network, while Fig. 7B visualized the co-cited author network analysis. Over the past decade, a cadre of highly prolific authors, recognized as the top 10 in the field, cumulatively authored 320 papers focusing on the topics of air pollution and CVDs. The majority of these papers were cited more than 200 times, signifying the substantial reputation and impact of their research. Robert D. Brook emerged as the most cited author, amassing 1083 citations, and thereby establishing robust collaborative relationships. He was followed by Arden Pope with 696 citations, Antonella Zanobetti with 376 citations, and Joel Schwartz with 292 citations. Within the purview of CiteSpace analysis, researchers such as Renjie Chen and Haidong Kan et al. represented by nodes with a crimson inner circle, exhibited marked increases in their engagement levels. The aforementioned scholars have received recognition for their contributions to this field, and their endeavors have significantly advanced understanding of environmental mechanisms and the development of interventions for cardiovascular disorders.

3.7. Analysis of networks and comprehensive Cluster View of the reference Co-citation

In the examination of air pollution and CVDs research, Table 3 encompasses the top 10 co-cited references, including three articles published between 2012 and 2022, each accruing over 150 citations. Notably, the journal Circulation emerged as the most frequently published source within this time frame. To delineate the research foci within this academic domain, a reference co-citation network analysis was utilized in Fig. 8A, which ascertained highly co-cited references that were frequently cited in tandem by subsequent articles. The clustering analysis of co-citation references and the elucidation of the common themes of pertinent documents were executed using the CiteSpace program. According to Fig. 8B–a total of 11 clusters were identified, each comprising multiple closely interconnected terms. The research prominently featured themes such as #0 air pollution, #1 prospective study, #2 particulate matter, #3 nitrogen dioxide, #4 cardiovascular diseases, #5 oxidative stress, #6 blood pressure, #7 coronary artery disease, #8 subclinical atherosclerosis, #9 p.m.$_{2.5}$, and #10 disease susceptibility.

3.8. Analysis of dual-map overlay of journals

Furthermore, the interrelation between referenced and co-referenced publications was elucidated through a dual-map overlay, as depicted in Fig. 9. Each marker on the map symbolized a journal, and the map was distinctly divided into two sections: a citation map on the left and another on the right. Ellipses in the left map were used to represent the number of publications linked to a specific journal as well as the ratio of authors to publications. The size of the ellipse indicated the quantity of writers, whereas the breadth of the ellipse symbolized the quantity of published works. To acquire a comprehensive understanding of the topic, it was recommended that readers focus primarily on articles emanating from journals that boasted a substantial body of work, as indicated by the elongated vertical axis of the ellipse. Additionally, it was imperative to prioritize articles authored by a larger cadre of researchers, which was signified by the elongated horizontal axis of the ellipse. The citation trajectories linking the left and right sections of the map served as conduits revealing the interdisciplinary connections within the domain. The map highlighted three principal citation trajectories, suggesting that publications in the domains of Molecular/Biology/Immunology and Medicine/Medical/Clinical frequently cited articles from the fields of Molecular/Biology/Genetics or Health/Nursing/Medicine. Refer to Table 4, a total of 840 journals have disseminated articles, with Environmental Health Perspectives and Circulation achieving the highest number of publications. The Lancet was closely subsequent, securing the highest Impact Factor (IF) of 168.9. It is pertinent to note that all top 10 journals have been categorized as Q1, half of the aforementioned prominent publications are affiliated with institutions based in the United States. To gain a comprehensive and profound understanding of the topic, it is advisable for readers to primarily consult articles published in these

Table 2
Top 10 most productive authors distributed by publications and citations who contributed to the publications on air pollution and cardiovascular disease research.

Rank	Count	Author	Rank	Count	Cited author
1	45	Brook, Robert D	1	1083	Brook, Robert D
2	43	Kan, Haidong	2	696	Pope, C Arden
3	37	Schwartz, Joel	3	376	Zanobetti, Antonella
4	34	Rajagopalan, Sanjay	4	292	Schwartz, Joel
5	31	Burnett, Richard T	5	285	Peters, Annette
6	28	Chen, Renjie	6	258	Dominici, Francesca
7	27	Kaufman, Joel D	7	256	Bell, Michelle L
8	26	Guo, Yuming	8	252	Mills, Nicholas L
9	26	Brauer, Michael	9	247	Hoek, Gerard
10	23	Diaz-sanchez, David	10	241	Shah, Anoop S V

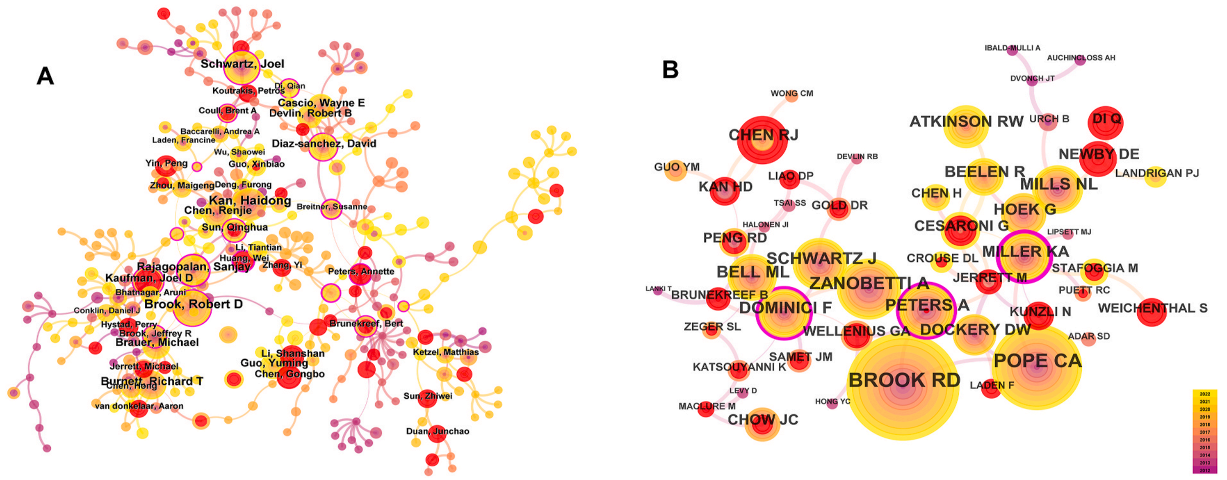

Fig. 7. Analysis of author and cited author. (A) Author co-authorship network analysis. (B) Author co-citation network analysis. For (A, B), each node represents an author/cited author, and the size of the ring denotes the number of publications of the author/cited author in a given year.

Table 3
The top 10 co-cited references in air pollution and cardiovascular disease research.

Author (Published Year)	Journal	Title	Citations
Brook, Robert D (2010)	Circulation	Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association	839
Brook, Robert D (2004)	Circulation	Air pollution and cardiovascular disease: a statement for healthcare professionals from the Expert Panel on Population and Prevention Science of the American Heart Association	252
Miller Kristin A (2007)	New England Journal of Medicine	Long-term exposure to air pollution and incidence of cardiovascular events in women	227
Pope C, Arden (2004)	Circulation	Cardiovascular Mortality and Long-Term Exposure to Particulate Air Pollution	226
Cohen Aaron J (2017)	Lancet	Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015	191
Dominici Francesca (2006)	JAMA	Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases	179
Shah Anoop S V (2013)	Lancet	Global association of air pollution and heart failure: a systematic review and meta-analysis	176
Mustafic Hazrije (2012)	JAMA	Main air pollutants and myocardial infarction: a systematic review and meta-analysis	162
Chow Judith C (2006)	Air & Waste Management Association	Health effects of fine particulate air pollution: lines that connect	153
Dockery D W (1993)	New England Journal of Medicine	An association between air pollution and mortality in six U.S. cities	150

distinguished journals.

4. Discussion

It is generally acknowledged that the greatest environmental risk factor for the development of CVDs is air pollution. Our research indicated that the current focus of this subject was on toxicology and epidemiology, with a particular interest in examining the connection between $PM_{2.5}$ and the emergence of respiratory and cardiovascular diseases. This suggested that there would likely be further expansion in the field's ongoing research. The most recent highlighted keywords and the top 10 terms in the clustering analysis showed their co-occurrence. Therefore, our main focus was on investigating the pathophysiological and toxicological pathways linking air pollution to CVDs. The main contributors to the detrimental effects on health were ozone gas and fine particulate matter, which harmed several biological systems linked to oxidative stress, inflammation, endothelial function, and autonomic instability. The three primary aspects into which the processes behind air pollution-induced CVDs can be categorized were the first physiological response upon pollutant intake, the transmission pathway through which these pollutants spread, and the subsequent impact on the target organs [21].

Three primary processes that were initiated in the lung were oxidative stress generated by pollution, local inflammation, and activation of ion channels or receptors. After inhalation, air pollutants, particularly $PM_{2.5}$, were mostly collected in alveolar

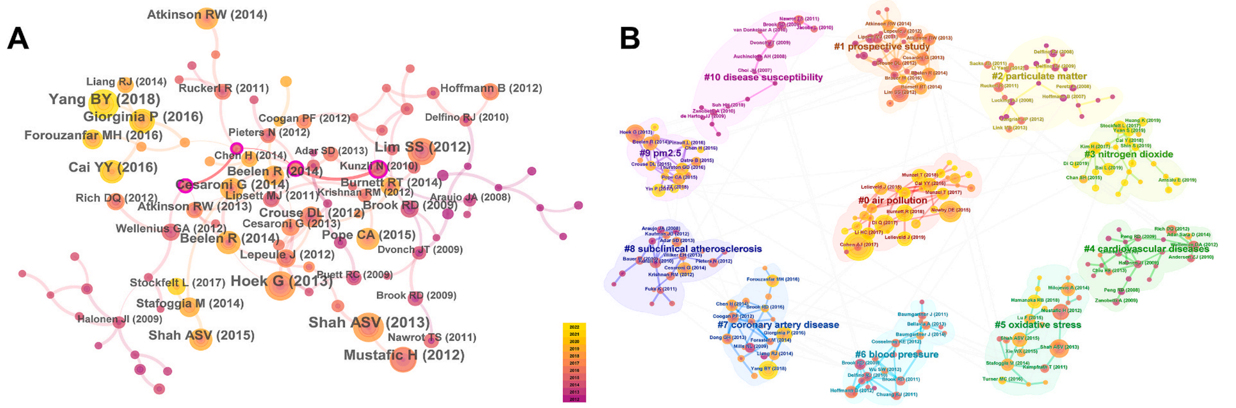

Fig. 8. (A) Document co-citation clusters network. Each node represents one reference. The color of the clusters shows when the co-citation links happened. The purple color means the citing year is relatively early, and the yellow color indicates that the citation time is relatively recent. **(B)** Reference co-citation analysis network (Cluster View). The labels of each cluster are exhibited beside the blocks.

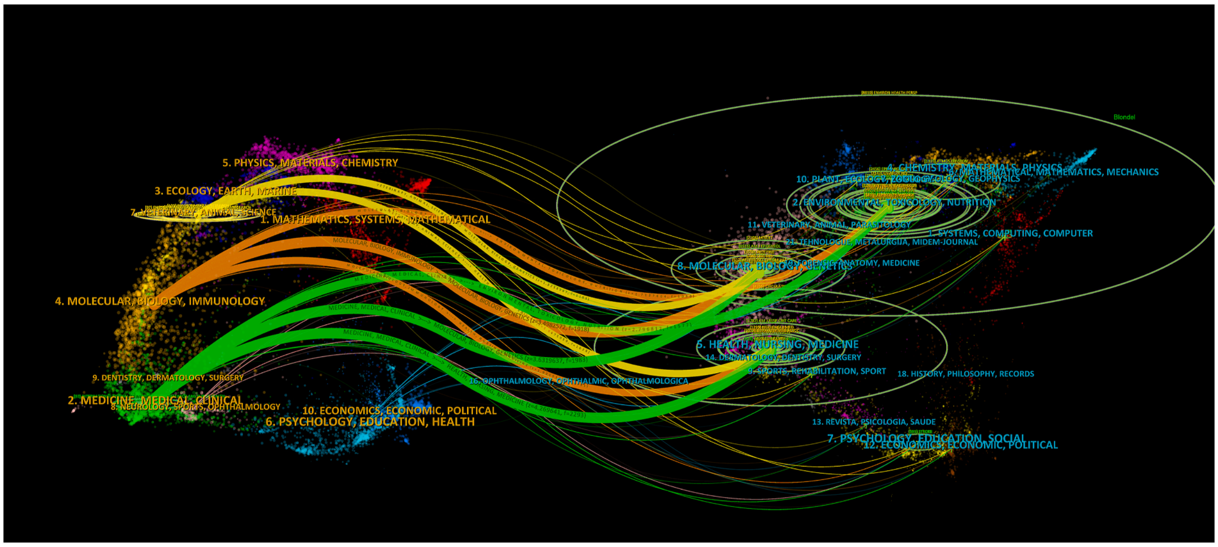

Fig. 9. The dual-map overlay of journals.

Table 4
The Top 10 journals that contributed to the publications on air pollution and cardiovascular disease research.

Rank	Journal title	Country	Count	H-index	IF 2022	Quartile in category (2022)
1	Environmental Health Perspectives	United States	1574	20	10.4	Q1
2	Circulation	United States	1386	35	37.8	Q1
3	Lancet	England	1066	29	168.9	Q1
4	Epidemiology	Netherlands	1054	18	13.6	Q1
5	Environmental Research	United States	1013	15	8.3	Q1
6	Respiratory and Critical Care Medicine	United States	891	14	24.7	Q1
7	Science of the Total Environment	Netherlands	883	14	9.8	Q1
8	Environment International	United States	838	15	11.8	Q1
9	Environmental Health	England	782	11	6.0	Q1
10	New England Journal of Medicine	England	780	15	158.5	Q1

macrophages through respiratory phagocytosis. Subsequently, this accumulation resulted in persistent and chronic inflammatory responses in other tissues. Initial particle detection and the propagation of inflammatory processes have been linked to NOD-like receptors, Toll-like receptors (TLRs), and secondary mediators, such as reactive oxygen species (ROS) [22–24]. Chronic high-$PM_{2.5}$ exposure has been shown to trigger the migration of inflammatory monocytes, or LY6C^{High} (CD11B^{+} GR1^{low}7/4^{high}) cells, from bone marrow to peripheral tissues. These cells then accumulated in organs through TLR4 signaling, resulting in systemic inflammatory responses [25–27]. Furthermore, the activation of various monocyte and T cell subsets via CC-chemokine receptor 2 (CCR2) and CXC-chemokine receptor 3 (CXCR3), respectively, also had an impact on the inflammatory response triggered by $PM_{2.5}$ [21].

It was shown that exposure to air pollution resulted in systemic effects that triggered inflammatory responses. These reactions were facilitated by the synthesis of reactive biological intermediates such oxidized phospholipids and 7-ketocholesterol. In the presence of oxidized phospholipids, the TLR4, NADPH oxidase 2 (NOX2), and Neutrophil Cytosolic Factor 1 (NCF1) pathways were implicated in vascular and systemic inflammation [26]. The oxidized product 7-ketocholesterol facilitated thrombosis, atherosclerosis, and endothelial dysfunction via CD36-dependent pathways [28]. Furthermore, breathing in $PM_{2.5}$ particles for an extended period of time increased the generation of reactive oxygen species (ROS) and inflammatory cell infiltration into the vasculature, which led to the negative consequences previously mentioned. This event resulted in diastolic dysfunction, an increase in cardiac afterload, and alterations in the reserve of coronary blood flow. In the end, these changes could result in left ventricular hypertrophy, fibrosis, and poor function.

In an in vivo environment, $PM_{2.5}$ influenced the levels of plasminogen activator in plasma tissue, which in turn triggered thrombus development. Nonetheless, the difference in air pollution components and concentrations seen in the results of the current study could be the reason for the mismatch. Furthermore, there were some effects of $PM_{2.5}$ on the central nervous system. The olfactory nerve may trigger autonomic dysfunction or activate the adrenal axis in response to cerebral stimulation [29–31]. Additionally, O_3 tended to activate the adrenal axis [32]. Insulin resistance or high blood pressure may be related to elevated glucocorticoid levels. Regarding its effects on DNA methylation, $PM_{2.5}$ can also trigger a thrombo-inflammatory response, however its consequences on the total methylation state and chromatin structure of the genome are still unknown [33,34].

Prolonged contact to the environment might cause chronic alterations in the end organs, which can make the host more vulnerable. Along with the exacerbation of cardiometabolic illnesses such as diabetes mellitus, hypertension, vascular hypertrophy, left ventricular remodeling or hypertrophy, proteinuria, and renal disease, these modifications included the advancement of atherosclerosis [35]. Research indicated that even prolonged low-level exposure to $PM_{2.5}$ can increase the risk of cardiovascular death [36–38], with an increase in the daily exposure concentration of $PM_{2.5}$ being linked to an increased relative risk of cardiovascular mortality [39]. Prolonged exposure to O_3 showed a lesser correlation with CVDs mortality than did $PM_{2.5}$ [40]. The evidence regarding the association between ambient O_3 and the chance of being hospitalized for different CVDs is currently sparse and inconsistent [5]. Moreover, there is a correlation between prolonged exposure to PM2.5 and increased carotid intima-media thickness [41], atherosclerosis development [42], and higher blood pressure [43–45]. However, there is still disagreement regarding the relationship between blood pressure, inflammatory marker levels, and $PM_{2.5}$ concentration [21]. It has been demonstrated that children and teenagers who are exposed to air pollution have elevated blood pressure. This association has been further supported by a recent meta-analysis that included 14 studies and showed that elevated blood pressure in this population is positively correlated with both short- and long-term exposure to $PM_{2.5}$ [46]. Furthermore, it has been shown that exposure to $PM_{2.5}$ raises the risk of ventricular tachycardia or ventricular fibrillation, with those who have already experienced a myocardial infarction being particularly susceptible [47]. Moreover, $PM_{2.5}$ has been connected to the emergence of diabetes and insulin resistance [27,48].

Preventing CVDs necessitates controlling air pollution. Interventions can be implemented on various fronts. The government and relevant agencies should set air quality standards, formulate plans, and establish a comprehensive environmental pollution supervision, management, punishment, and accountability mechanism. Upgrading industrial technology, promoting the use of low-carbon solar energy, regular monitoring, of transportation fuels or vehicles and assessment of air pollution risks are crucial. Researchers are encouraged to develop, test, and evaluate interventions to reduce air pollution's impact on CVDs outcomes in clinical and population settings. Communities should educate residents on air pollutant hazards, manage high-risk groups, and individuals can use air filters and masks, avoid pollutant products, and consume antioxidant-rich foods to combat oxidative stress. Encouraging the intake of fresh vegetables, fruits, and antioxidants like vitamins C and E can contribute to a healthy lifestyle. In the future, trends to improve the accuracy of pollution exposure risk assessment may involve data synchronization of multiple atmospheric environment elements and interdisciplinary research across fields such as atmospheric science, environmental science, epidemiology, and toxicology. The clinicians can advise high-risk groups, such as those with CVDs, to regular consumption of fresh fruits, vegetables, and antioxidants like vitamins C and E is recommended.

Subsequently, the bulk of the countries and regions that have published analyses of air pollution are closely affiliated with American and European countries, according to our research. Future research on the relationship between air pollution and cardiovascular health is expected to be more comprehensive due to the increased cooperation and communication between several countries and regions.

5. Advantage and limitations

Bibliometrics predicts the future trend in discipline development and illustrates the complete process of discipline formation and development. Next, provide a line of reference for selecting a scientific research topic and building technological protocols. There were certain limitations, but this study employed this methodology to extensively analyze the impact of air pollution on CVDs and conduct a systematic evaluation of the research horizons. First, because we only took into consideration works in English, a large percentage of non-English literature was overlooked. Second, the limits of the scientometric software now in use made it difficult to merge two or more databases for analysis. As a result, this study only used the WoSCC database to screen the literature, which increased the risk that relevant literature was overlooked. Citing literature may be delayed due to its time-sensitive nature. Also, search engines provided inconsistent and unsatisfactory search features, have limited relative coverage and produce inconsistent and hard-to-trust search results. Finally, certain human errors were unavoidable because we purposefully took out some irrelevant literature on purpose. In conclusion, the current bibliometric analysis of air pollution can create a more intuitive understanding of the field in terms of space, time, and author relationships, which not only offered hope for novel treatment targets for CVDs but also shed light on the study of inflammation and many other serious organ diseases.

6. Conclusion

In conclusion, we have concluded that there has been an increase in research output in this area, showing that both scientists and the general public are becoming more interested in this topic after reviewing the literature on air pollution and CVDs for the past 11 years. Important contributions from authors, organizations, and nations offered priceless insights for upcoming research and practice to lower the incidence of CVDs and advance public health. Additionally, we summarized three themes regarding current research trends. Second, various air pollutants, not only $PM_{2.5}$, O_3, and NO_2, could contribute to multiple CVDs, including coronary heart disease, hypertension, and heart failure. We expect the research field in this area to continue to develop and expand, with a focus on other air pollutants such as PM_{10}, sulfur dioxide, heavy metal, and carbon monoxide. Third, although some hypotheses were put forward, the mechanisms of air pollution related CVDs still need to be explored in the future.

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Availability of data and materials

The original data associated with this study has not been deposited into any publicly available repository, as the data used to support the results of this study are provided by the Web of Science Core Collection with permission. Additional data will be made available on request to the corresponding authors.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Conflict of interest disclosures

The authors declare that they have no competing interests.

CRediT authorship contribution statement

Song Wen: Writing – original draft, Formal analysis, Data curation, Conceptualization. **Qing Tan:** Writing – original draft, Software, Formal analysis, Data curation. **Rewaan Baheti:** Writing – review & editing, Writing – original draft. **Jing Wan:** Writing – review & editing, Supervision, Project administration. **Shuilian Yu:** Writing – review & editing, Supervision, Project administration. **Bin Zhang:** Writing – review & editing, Supervision, Project administration, Conceptualization. **Yuqing Huang:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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