RESEARCH ARTICLE

Research trends on the relationship between air pollution and cardiovascular diseases in 2013–2022 – A scientometric analysis

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Abstract

Exposure to air pollution is linked with an elevated risk of cardiovascular diseases (CVDs) and CVDs-related mortality. However, there is a shortage of scientometric analysis on this topic. Therefore, we propose a scientometric study to explore research hotspots and directions in this topical field over the past decade. We used the core collection of Web of Science (WoS) to obtain relevant publications and analyzed them using Excel, the Bibliometix R-package, CiteSpace, and VOSviewer. The study covered various aspects such as annual publications, highly cited papers, co-cited references, journals, authors, countries, organizations, and keywords. Research on air pollution and CVDs has remarkable increase over the past decade, with notable researchers including Kan H, Brook RD, Peters A, and Schwartz J. The 3144 articles were published by 4448 institutions in 131 countries/regions. The leading countries were the USA and China, and the most published journal was *Environmental Research*. Mortality, hospital admissions, oxidative stress, inflammation, long-term exposure, fine particulate matter, and $PM_{2.5}$ are the top areas that merit further investigation and hold significant potential for advancing our understanding of the complex relationship between air pollution and CVDs.

Introduction

Air pollution refers to the presence of harmful gases and particulate matter (PM) in the atmosphere that jeopardizes the health of humans and other living organisms. It is categorized into two main types: outdoor pollution, which is ambient air pollution, and indoor pollution, resulting from household fuel combustion. Certain chemicals are commonly targeted for measurement to assess and monitor air pollution. Among the gaseous pollutants, carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2) are the most commonly monitored. In addition to gaseous pollutants, PM plays a crucial role in air pollution. PM components consist of a wide range of substances, including ammonium salts, sulfates, nitrates, organic and elemental carbon particles, n-alkanes, polycyclic aromatic hydrocarbons, and other compounds. They include ultrafine particles or nanoparticles (diameter $< 0.1\mu m$, $PM_{0.1}$), fine particles of less than 2.5μm and 10μm in diameter ($PM_{2.5}$ and PM_{10}), and PM with diameter between 2.5 and 10μm (PM_{coarse}) (Yang et al. 2018; Aryal et al. 2021; Milici and Talavera 2021). These pollutants originate from multiple sources, including automobile exhaust, power plants, industrial processes, waste incinerators, natural sources like wildfires and dust storms, and more (Harrison 2020).

Without significant intervention, ambient air pollution was projected to cause a surge in fatalities exceeding 50% of the current figures by 2050. Air pollution substantially contributed to global mortality, accounting for up to 8.8 million deaths, or 11.6% of all deaths worldwide (Landrigan et al. 2018; Lelieveld et al. 2020). Extensive research has demonstrated that exposure to air pollution can heighten the likelihood of experiencing various health problems, including cancer, obesity, respiratory diseases, cardiovascular diseases (CVDs), and diabetes (Turner et al. 2020; Furlong and Klimentidis 2020;

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De Matteis et al. 2022; Bont et al. 2022; Yang et al. 2020). Of particular concern is the impact of air pollution on CVDs, which has been extensively studied and associated with various conditions such as myocardial infarction, heart failure, hypertension, stroke, atherosclerosis, and arrhythmias (Bont et al. 2022). This is due to air pollutants contributing to the development of atherosclerosis, characterized by the buildup of plaque in the arteries, leading to reduced blood flow to the heart and other parts of the body (Bevan et al. 2021). Additionally, pollutants can cause inflammation in the body and increase oxidative stress, both of which have been linked to a higher risk of heart disease (Joshi et al. 2022). Given the critical impact of air pollution on CVDs, research in this field has become a prominent subject. However, despite the extensive literature on the association between air pollution and CVDs, no scientometric analysis has been performed to explore current research trends and hotspots.

To provide an exhaustive understanding of the present research scenario in the field, we conducted a scientometric analysis. Our study aims to find out the publication trends, famous authors, prolific institutions and countries, influential journals, prevailing topics, and significant keywords from the past decade.

Methods

Data collection

On 14th January 2023, the data was obtained from the online database WoS. Search options are chosen: search in = "Web of Science Core Collection", and editions = "Science Citation Index Expanded (SCI-EXPANDED)–2003-present". The retrieval strategy and the number of obtained records are shown in Table 1. First, medical subject headings (Mesh) terms "air pollution" and "cardiovascular diseases" were found in PubMed. Then, relevant publications were retrieved using various subject keywords to enhance the reliability and comprehensiveness of the data. The search was conducted with the following content criteria: #1, TS = "air pollution*" or "air quality"; #2, TS = "cardiovascular disease*";

Table 1 The retrieval strategy and the number of obtained records regarding air pollution and CVDs

Search set	Retrieval strategy	Records
#1	TS = "air pollution*" or "air quality"	103,504
#2	TS = "cardiovascular disease*"	244,234
#3	#1 and #2	4175
#4	Period: 2013–2022	3271
#5	Article type: Articles or Reviews	3167
#6	Language: English	3146
#7	Exclude 2 retracted articles	3144

#3, "#1", and "#2". The next step was to set the timespan between 2013 to 2022, which resulted in 3271 records. After that, we selected English as the language and excluded all document types except articles and reviews. Documents excluded include sixty-six editorial materials, twenty-two meeting abstracts, twelve letters, two corrections, one news item, and one reprint. Using Zotero software, two articles that had been retracted were eliminated from consideration. As a result, our scientometric study included 3144 documents.

Analysis methods

The scientometric analysis is a quantitative research method that analyzes scientific literature to measure research productivity, impact, and collaboration. It provides insights into trends, influential researchers, and research gaps, aiding decision-making in science.

The "analyze results" feature of the WoS was used to obtain information on the 3144 documents, including the WoS categories, affiliations, countries or regions, research areas, and so on. The "citation report" was another function of the WoS that provided valuable information, such as the total number of publications, the number of citing articles, the number of times cited, and the h-index. The impact factor (IF) and Category Quartile for the top ten journals and co-cited journals were obtained from the 2022 Journal Citation Reports (JCR), also accessed from the WoS database.

Excel (Microsoft Office 2019) was utilized to effectively manage quantitative data and analyze publication trends with linear regression. Furthermore, the "bibliometrix" package in R (version 4.2.2) was applied to get the number of publications annually, analyze trend topics, and depict a collaboration world map and thematic map (Aria and Cuccurullo 2017).

CiteSpace was a visual software developed by Chaomei Chen (Chen 2006). In our study, version 6.1.R6 of CiteSpace was used to find the top 50 references with the strongest citation burst and conduct a dual-map overlay analysis.

VOSviewer (version 1.6.18), as a free JAVA-based software (van Eck and Waltman 2010), was used for analysis and visualization. In our study, we created maps of co-authorship among countries and organizations, co-occurrence of keywords, as well as maps of co-citation among cited authors, cited references, and cited sources. Furthermore, based on the total link strength, the software helped us identify which authors, institutions, and countries collaborated most closely.

Results

Publication trends

The literature search produced 3144 publications on air pollution and CVDs from 1st January 2013 to 31st December

2022. Figure 1 shows the annual production and the cumulative publications in this field of research, from which we can see an increasing trend from 199 papers (6.3%) published in 2013 to 480 articles (15.3%) published in 2022, with a slight drop between 2013 (199 papers) and 2014 (188 papers), as well as between 2016 (268 papers) and 2017 (258 papers). From 2017 to 2022, a rapid increase in publications was observed, indicating that this research field was in a rapid period of development. Moreover, articles published in the past four years accounted for over 50 percent of the total publications. As for yearly scientific production, the average annual growth rate was 10.7%, and the maximum annual growth rate was 22.9% in 2016. Finally, according to the growth trend prediction of the fitting straight line ($y = 34.218x + 126.2$; $R^2 = 0.9599$) in Fig. 1, more and more articles on air pollution and CVDs will be published in the future, demonstrating that this field of study continues to attract the interest of researchers in related fields.

Citation analysis

As a statistical approach, the citation analysis helps to identify the most influential authors, the most cited papers, famous research institutions, and important journals. The more times an article is cited, the higher its IF indicates that this article has a significant influence in a specific area (Baltussen and Kindler 2004a, b). In our study, each article received an average of 34.19 citations. In all the retrieved publications, there were 56,234 citing papers, including 53,667 papers without self-citations (accounting for 95.44%) and 2567 with self-citations (accounting for 4.56%). The total times cited for the paper was 107,509, including 90,711 without self-citations (accounting for 84.38%) and 16,798 with self-citations (accounting for 15.62%).

Using the "citation report" function of the WoS, we have compiled Table 2, which provides us with the top 10 papers that have been cited the most times in the field of air pollution and CVDs. A quantitative and qualitative analysis of highly cited papers helped us determine which research fields were currently in the spotlight. Notably, all the articles in the table were published between 2013 and 2018. The article "Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015", which has been cited the most with 2453 citations (Forouzanfar et al. 2016). Published in 2018, the article written by Jeffrey D Stanaway et al. received 2283 citations (Stanaway et al. 2018). A review article written by Landrigan et al. (2018) came in third place (cited 1771 times) (Landrigan et al. 2018). The top ten cited works received 15,175 citations, accounting for 14.12 percent of the total times cited for these 3144 papers. Among the top ten cited articles, seven were published in the Lancet journal. Additionally, eight articles received over 1000 citations, making up 0.25% of all cited papers; 17 papers (accounting for 0.54%) were cited over 500 times, and 174 articles (accounting for 5.53%) were cited 100 times or more.

Figure 2, generated using VOSviewer, illustrates a co-cited relationship of the references in the analyzed articles. For inclusion in this analysis, references needed to meet a minimum requirement of 100 citations, resulting in 32 references meeting this criterion. Nodes in Fig. 2a grow as the number of references cited increases, whereas the degree of color denotes co-citation frequency (green: low, yellow: high) (Fig. 2b). The cited references were grouped into three clusters in Fig. 2a. Notably, the paper authored by Brook et al. (2010) was the most frequently cited in the field, with 1243 citations (Fig. 2), demonstrating the knowledge base in the field (Brook et al. 2010). The five most cited references,

Fig. 1 Annual publications on the relationship between air pollution and CVDs from 2013 to 2022
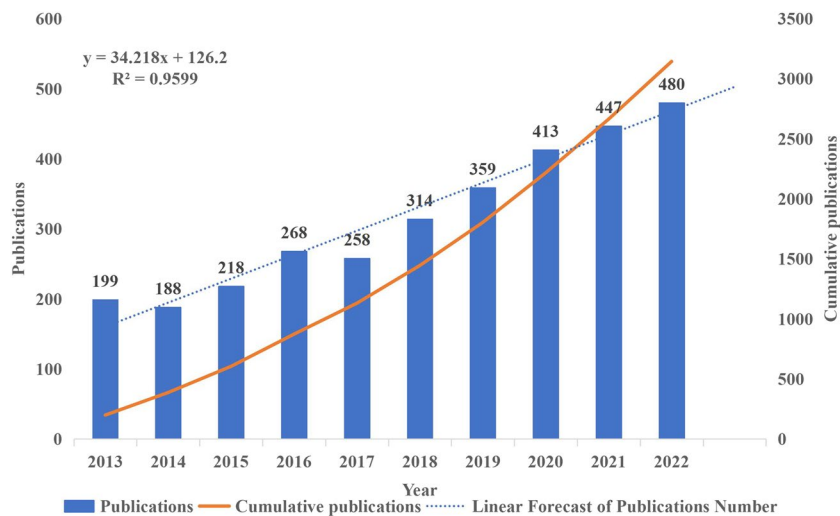
Table 2 Top 10-cited papers in the field of air pollution and cardiovascular diseases with publication year, titles, authors, journals, and total citations

Rank	Year	Title	Author	Journal	Citation
1	2016	Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015	Mohammad H Forouzanfar et al	Lancet	2453
2	2018	Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017	Jeffrey D Stanaway et al	Lancet	2283
3	2018	The Lancet Commission on pollution and health	Philip J Landrigan et al	Lancet	1771
4	2015	Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013	Mohammad H Forouzanfar et al	Lancet	1728
5	2015	A review on the human health impact of airborne particulate matter	Ki-Hyun Kim et al	Environment International	1472
6	2013	Rapid health transition in China, 1990–2010: findings from the Global Burden of Disease Study 2010	Gonghuan Yang et al	Lancet	1364
7	2013	Long-term air pollution exposure and cardio- respiratory mortality: a review	Gerard Hoek et al	Environmental Health	1167
8	2014	An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure	Richard T Burnett et al	Environmental Health Perspectives	1114
9	2014	Auditory and non-auditory effects of noise on health	Mathias Basner et al	Lancet	964
10	2014	Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multicentre ESCAPE project	Rob Beelen et al	Lancet	859

in descending order, are those authored by Brook et al. (2010) (1243 citations) (Brook et al. 2010), Brook et al. (2004) (364 citations) (Brook et al. 2004), Pope et al. (2004) (298 citations) (Pope et al. 2004), Miller et al. (2007) (282 citations) (Miller et al. 2007), and Cohen et al. (2017) (281 citations) (Cohen et al. 2017).

We utilized CiteSpace, with parameters set as "γ [0–1]: 1.0", "The Number of States: 2", "Minimum Duration: 2", and "Selection Criteria: Top 50" to identify 325 references with the strongest citation bursts pertaining to air pollution and CVDs. As shown in Fig. 3, we present the top 50 references. The top 3 references that exhibited the strongest citation bursts were as follows: "Particulate Matter Air Pollution and Cardiovascular Disease: An Update to the Scientific Statement From the American Heart Association (Brook et al. 2010)" (Strength: 143.67; Publication Year: 2010), "A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and

risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010 (Lim et al. 2012)" (Strength: 39.16; Publication Year: 2012) and "Air Pollution and Cardiovascular Disease (Rajagopalan et al. 2018)" (Strength: 36.15; Publication Year: 2018). Of these references, there were 16 began to experience citation bursts in 2013 and 26 from 2014 to 2018. Moreover, nine references (18%) continuously experienced citation bursts up to 2022, indicating that they were frequently cited within the past five years. These findings suggest that in the foreseeable future, the research field of air pollution and CVDs may continue to receive attention.

Authors analysis

This study involved a large cohort of 16,450 authors, of which 12,289 (75%) had contributed to only one paper. In Table 3, we present the top 10 authors who collectively

Fig. 2 The network map of co-citation between references with the lowest requirement of 100 citations in air pollution and CVDs research. **(a)** The network visualization map of co-cited references in air pollution and CVDs research. **(b)** The density visualization map of co-cited references in air pollution and CVDs research
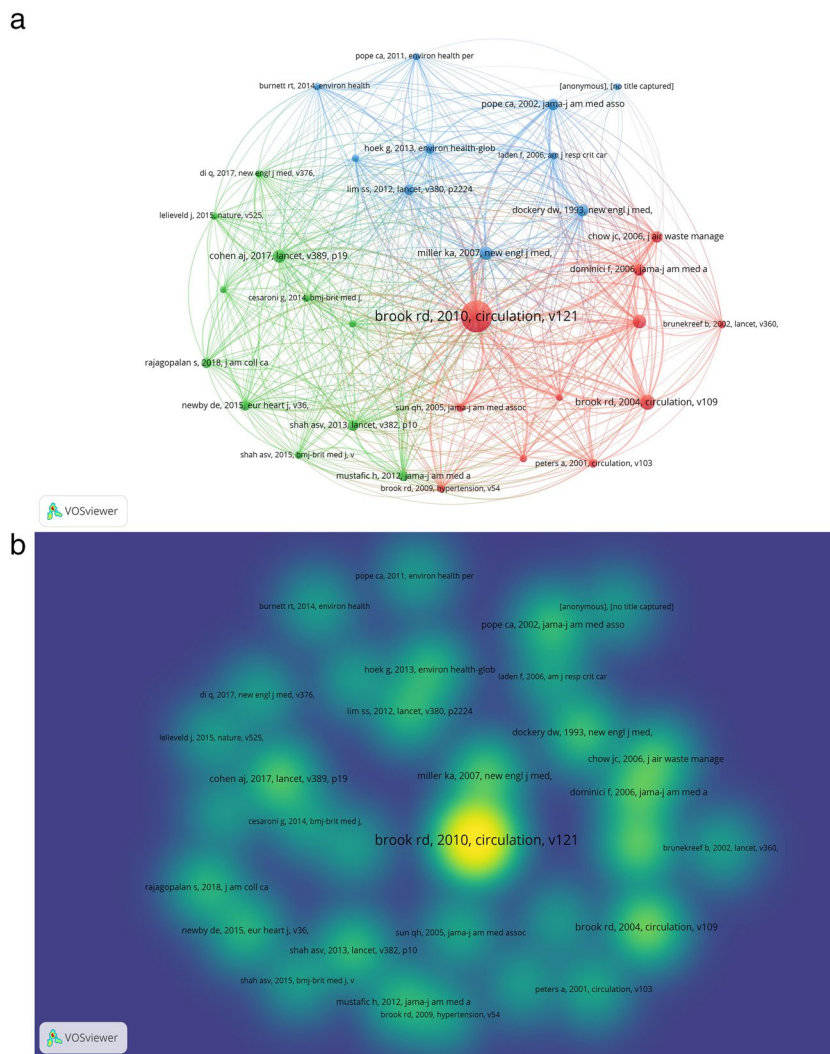
accounted for 13% of the total publications. Among these distinguished authors, Kan H was the most productive with 53 papers, followed by Schwartz J (52, 1.65%), Koutrakis P (42, 1.34%), Guo Y (41, 1.30%), Peters A (38, 1.21%), Brook RD (37, 1.18%), Chen R (37, 1.18%), Kaufman JD (37, 1.18%), Burnett RT (35, 1.11%), and Brauer M (32, 1.02%). It is worth noting that the greater productivity of an author may indicate their greater importance and representation in the field. Specifically, 11 authors had written more than 30 papers, while 49 had written a minimum of 20 documents.

Co-cited authors refer to those cited together by other scholars (Zhao 2006). The degree of co-citation is a measure of their influence in the field. In this regard, a notable finding emerged from the analysis. Brook RD was the most co-cited author among the top ten, with 2390 citations (2.22%), followed by Pope CA (1570, 1.46%), World Health Organization (1139, 1.06%), Zanobetti A (627, 0.58%), Schwartz J (552, 0.51%), Chen RJ (488, 0.45%),

Peters A (470, 0.44%), Bell ML (467, 0.43%), Munzel T (412, 0.38%), and Dominici F (411, 0.38%). Among the 59,995 co-cited authors, five were cited over 500 times, as shown in Table 3.

Figure 4, generated using VOSviewer, provides detailed information on co-citation among authors. A co-citation analysis was performed on 54 authors, with a minimum requirement of 200 citations. Among these authors, Brook RD had the highest link strength, with a total of 19,776 link strength. Pope CA came in second with a total link strength of 14,966. Zanobetti A ranked third with a total link strength of 6947, followed by Peters A (5470) and Schwartz J (5463).

Institutions analysis

A total of 4448 institutions worldwide published articles on air pollution and CVDs. Remarkably, 250 of these institutions have published ten or more articles, indicating

Fig. 3 Top 50 references with the strongest citations burst

Top 50 References with the Strongest Citation Bursts

References	Year	Strength	Begin	End	2013 - 2022
Brook RD, 2010, CIRCULATION, V121, P2331, DOI 10.1161/CIR.0b013e3181dbece1, DOI	2010	143.67	2013	2015	
Lim SS, 2012, LANCET, V380, P2224, DOI 10.1016/S0140-6736(12)61766-8, DOI	2012	39.16	2013	2017	
Mustafic H, 2012, JAMA-J AM MED ASSOC, V307, P713, DOI 10.1001/jama.2012.126, DOI	2012	27.98	2013	2017	
Pope CA, 2011, ENVIRON HEALTH PERSP, V119, P1616, DOI 10.1289/ehp.1103639, DOI	2011	16.83	2013	2016	
Ruckerl R, 2011, INHAL TOXICOL, V23, P555, DOI 10.3109/08958378.2011.593587, DOI	2011	16.83	2013	2016	
Wellenius GA, 2012, ARCH INTERN MED, V172, P229, DOI 10.1001/archinternmed.2011.732, DOI	2012	15.99	2013	2016	
Crouse DL, 2012, ENVIRON HEALTH PERSP, V120, P708, DOI 10.1289/ehp.1104049, DOI	2012	14.45	2013	2017	
Lipsett MJ, 2011, AM J RESP CRIT CARE, V184, P828, DOI 10.1164/rccm.201012-2082OC, DOI	2011	13.45	2013	2016	
Rich DQ, 2012, JAMA-J AM MED ASSOC, V307, P2068, DOI 10.1001/jama.2012.3488, DOI	2012	12.72	2013	2017	
Bauer M, 2010, J AM COLL CARDIOL, V56, P1803, DOI 10.1016/j.jacc.2010.04.065, DOI	2010	12.69	2013	2015	
Kunzli N, 2010, PLOS ONE, V5, P0, DOI 10.1371/journal.pone.0009096, DOI	2010	12.2	2013	2015	
Brook RD, 2009, HYPERTENSION, V54, P659, DOI 10.1161/HYPERTENSIONAHA.109.130237, DOI	2009	11.31	2013	2014	
Nawrot TS, 2011, LANCET, V377, P732, DOI 10.1016/S0140-6736(10)62296-9, DOI	2011	10.92	2013	2016	
Mills NL, 2009, NAT CLIN PRACT CARD, V6, P36, DOI 10.1038/ncpcardio1399, DOI	2009	10.75	2013	2014	
Zanobetti A, 2009, ENVIRON HEALTH PERSP, V117, P898, DOI 10.1289/ehp.0800108, DOI	2009	10.75	2013	2014	
Puett RC, 2009, ENVIRON HEALTH PERSP, V117, P1697, DOI 10.1289/ehp.0900572, DOI	2009	10.75	2013	2014	
Hoek G, 2013, ENVIRON HEALTH-GLOB, V12, P0, DOI 10.1186/1476-069X-12-43, DOI	2013	30.44	2014	2018	
Lepeule J, 2012, ENVIRON HEALTH PERSP, V120, P965, DOI 10.1289/ehp.1104660, DOI	2012	18.28	2014	2017	
Coogan PF, 2012, CIRCULATION, V125, P767, DOI 10.1161/CIRCULATIONAHA.111.052753, DOI	2012	14.61	2014	2017	
Cesaroni G, 2013, ENVIRON HEALTH PERSP, V121, P324, DOI 10.1289/ehp.1205862, DOI	2013	13.73	2014	2018	
Atkinson RW, 2013, EPIDEMIOLOGY, V24, P44, DOI 10.1097/EDE.0b013e318276ccb8, DOI	2013	13.11	2014	2018	
Chuang KJ, 2011, OCCUP ENVIRON MED, V68, P64, DOI 10.1136/oem.2009.052704, DOI	2011	11.09	2014	2016	
Bind MA, 2012, EPIDEMIOLOGY, V23, P332, DOI 10.1097/EDE.0b013e31824523f0, DOI	2012	10.95	2014	2017	
Adar SD, 2013, PLOS MED, V10, P0, DOI 10.1371/journal.pmed.1001430, DOI	2013	10.91	2014	2018	
Raaschou-Nielsen O, 2013, LANCET ONCOL, V14, P813, DOI 10.1016/S1470-2045(13)70279-1, DOI	2013	10.6	2014	2018	
Shah ASV, 2013, LANCET, V382, P1039, DOI 10.1016/S0140-6736(13)60898-3, DOI	2013	29.73	2015	2018	
Burnett RT, 2014, ENVIRON HEALTH PERSP, V122, P397, DOI 10.1289/ehp.1307049, DOI	2014	17.55	2015	2019	
Beelen R, 2014, LANCET, V383, P785, DOI 10.1016/S0140-6736(13)62158-3, DOI	2014	15.94	2015	2019	
Milojevic A, 2014, HEART, V100, P1093, DOI 10.1136/heartjnl-2013-304963, DOI	2014	13.54	2015	2019	
Stafoggia M, 2014, ENVIRON HEALTH PERSP, V122, P919, DOI 10.1289/ehp.1307301, DOI	2014	12.74	2015	2019	
Krishnan RM, 2012, J AM COLL CARDIOL, V60, P2158, DOI 10.1016/j.jacc.2012.08.973, DOI	2012	11.34	2015	2017	
Beelen R, 2014, EPIDEMIOLOGY, V25, P368, DOI 10.1097/EDE.0000000000000076, DOI	2014	10.87	2015	2019	
Shah ASV, 2015, BMJ-BRIT MED J, V350, P0, DOI 10.1136/bmj.h1295, DOI	2015	17.79	2016	2019	
Forouzanfar MH, 2015, LANCET, V386, P2287, DOI 10.1016/S0140-6736(15)00128-2, DOI	2015	12.79	2016	2018	
Atkinson RW, 2014, THORAX, V69, P660, DOI 10.1136/thoraxjnl-2013-204492, DOI	2014	12.66	2016	2019	
Newby DE, 2015, EUR HEART J, V36, P83, DOI 10.1093/eurheartj/ehu458, DOI	2015	23.06	2017	2020	
Lelieveld J, 2015, NATURE, V525, P367, DOI 10.1038/nature15371, DOI	2015	16.71	2017	2020	
Du YX, 2016, J THORAC DIS, V8, PE8, DOI 10.3978/j.issn.2072-1439.2015.11.37, DOI	2016	14.17	2018	2022	
Gakidou E, 2017, LANCET, V390, P1345, DOI 10.1016/S0140-6736(17)32366-8, DOI	2017	13.83	2018	2020	
Cosselman KE, 2015, NAT REV CARDIOL, V12, P627, DOI 10.1038/nrcardio.2015.152, DOI	2015	12.79	2018	2020	
Kim KH, 2015, ENVIRON INT, V74, P136, DOI 10.1016/j.envint.2014.10.005, DOI	2015	11.41	2018	2020	
Forouzanfar MH, 2016, LANCET, V388, P1659, DOI 10.1016/S0140-6736(16)31679-8, DOI	2016	10.67	2018	2020	
Cohen AJ, 2017, LANCET, V389, P1907, DOI 10.1016/S0140-6736(17)30505-6, DOI	2017	19.23	2019	2022	
Pope CA, 2016, CIRC RES, V119, P1204, DOI 10.1161/CIRCRESAHA.116.309279, DOI	2016	11.14	2019	2022	
Rajagopalan S, 2018, J AM COLL CARDIOL, V72, P2054, DOI 10.1016/j.jacc.2018.07.099, DOI	2018	36.15	2020	2022	
Liu C, 2019, NEW ENGL J MED, V381, P705, DOI 10.1056/NEJMoa1817364, DOI	2019	23.82	2020	2022	
Burnett R, 2018, P NATL ACAD SCI USA, V115, P9592, DOI 10.1073/pnas.1803222115, DOI	2018	14.14	2020	2022	
Stanaway JD, 2018, LANCET, V392, P1923, DOI 10.1016/S0140-6736(18)32225-6, DOI	2018	13.38	2020	2022	
Lelieveld J, 2019, EUR HEART J, V40, P1590, DOI 10.1093/eurheartj/ehz135, DOI	2019	11.98	2020	2022	
van Kempen E, 2018, INT J ENV RES PUB HE, V15, P0, DOI 10.3390/ijerph15020379, DOI	2018	10.59	2020	2022	

their sustained engagement in the field. The top 10 productive institutions, situated in three different nations, are presented in Table 4. Peking University in China had the highest number of publications ($n = 126$, 4.0%), followed by the University of Washington ($n = 111$, 3.5%), Harvard T.H. Chan School of Public Health ($n = 103$, 3.3%), Harvard University ($n = 96$, 3.1%), and Fudan University ($n = 89$, 2.8%). Evidently, institutions from the USA were highly ranked in terms of total publications and have had a significant impact on the research field of air pollution and CVDs.

To visually capture the collaborative network among institutions, a map (Fig. 5) was constructed, focusing on 60 institutions that met the criterion of having a minimum of 30 publications. Larger circles represent institutions with more publications, while more connecting lines indicate more

Table 3 Top 10 authors and co-cited authors on the research on air pollution and CVDs

Rank	Authors	Count	Co-Cited Authors	Citations
1	Kan H	53	Brook RD	2390
2	Schwartz J	52	Pope CA	1570
3	Koutrakis P	42	WHO	1139
4	Guo Y	41	Zanobetti A	627
5	Peters A	38	Schwartz J	552
6	Brook RD	37	Chen RJ	488
7	Chen R	37	Peters A	470
8	Kaufman JD	37	Bell ML	467
9	Burnett RT	35	Munzel T	412
10	Brauer M	32	Dominici F	411

WHO World Health Organization
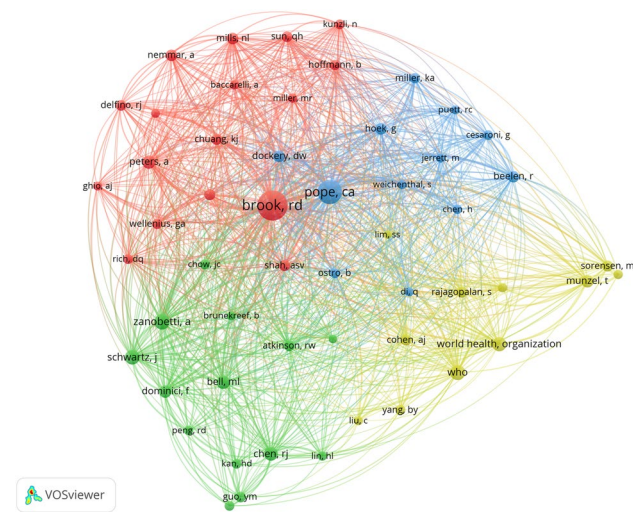
Fig. 4 The network visualization map of co-citations between authors with 200 or more than 200 citations

collaborations. According to total link strength, the University of Washington (312), Harvard University (250), the University of Basel (243), the University of Toronto (243), and Boston University (234) were the top five institutions.

Countries/Regions analysis

The study identified 131 countries/regions that contributed to research on air pollution and CVDs. The top ten countries/regions in terms of the number of articles published on this topic were geographically distributed across Asia, Europe, North America, and Oceania. The USA had the most publications (1196 of 3144 [38.0%]), followed by China (953 articles [30.3%]), England (257 articles [8.2%]), Canada (198 articles [6.3%]), and Germany (175 articles [5.6%]). Figure 6a, the collaboration world map, visually portrays the number of publications emanating from different countries/regions by using the color shades on the map. The thicker line corresponds to a greater quantity of papers produced. Additionally, the amount of cooperation between nations is demonstrated through the number of connecting lines featured within the graphic. The USA and China, with the USA occupying a central position, had intimate communication and collaboration in this field. Subsequently, the analysis focused on 37 countries/regions with 20 or more publications, and a collaborative network was established by taking into account the quantity and interconnectivity of publications within each country/region (Fig. 6b). The thickness of the lines connecting circles represents the relationship strength between various countries/regions, and the circle's size denotes the number of documents. It was found that there was an extensive collaboration between different countries/regions, such as China having tight collaboration with the USA, Australia, and Canada, and the USA having active collaboration with England, Canada, Germany, and Australia.

Research on air pollution and CVDs in low- and middle-income countries (LMICs) has shed light on the significant

Table 4 Most productive organizations contributing to this research field

Rank	Organization	Country	Total production	Total link strength
1	Peking University	China	126	152
2	University of Washington	USA	111	312
3	Harvard T.H. Chan School of Public Health	USA	103	215
4	Harvard University	USA	96	250
5	Fudan University	China	89	198
6	Sun Yat-sen University	China	78	194
7	University of Michigan	USA	72	111
8	U.S. Environmental Protection Agency	USA	71	103
9	Emory University	USA	67	228
10	Health Canada	Canada	67	223

Fig. 5 The network visu-
alization map of co-authorship
between institutions with 30 or
more than 30 publications
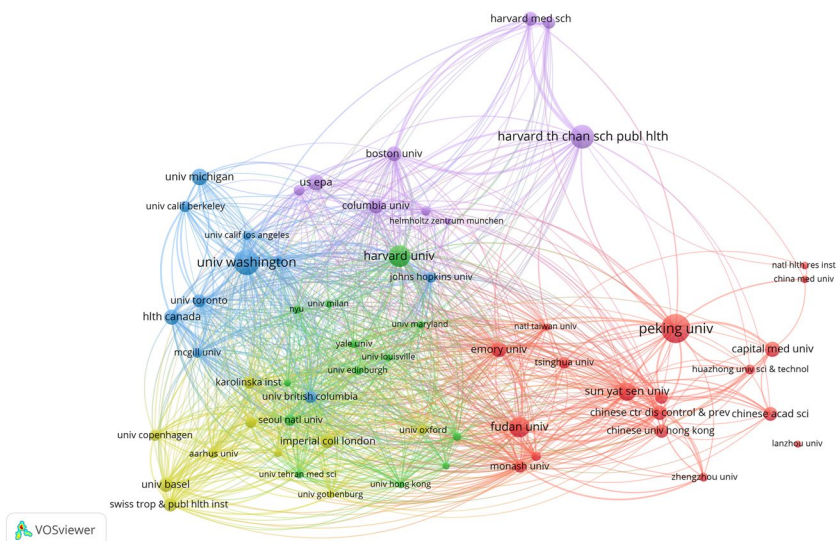
Fig. 6 The collaboration world
map and the overlay visu-
alization map of co-authorship
between countries with 20 or
more than 20 publications on
research of air pollution and
CVDs. **(a)** The collaboration
world map. **(b)** The overlay
visualization map of co-author-
ship between countries with 20
or more than 20 publications
on research of air pollution and
CVDs
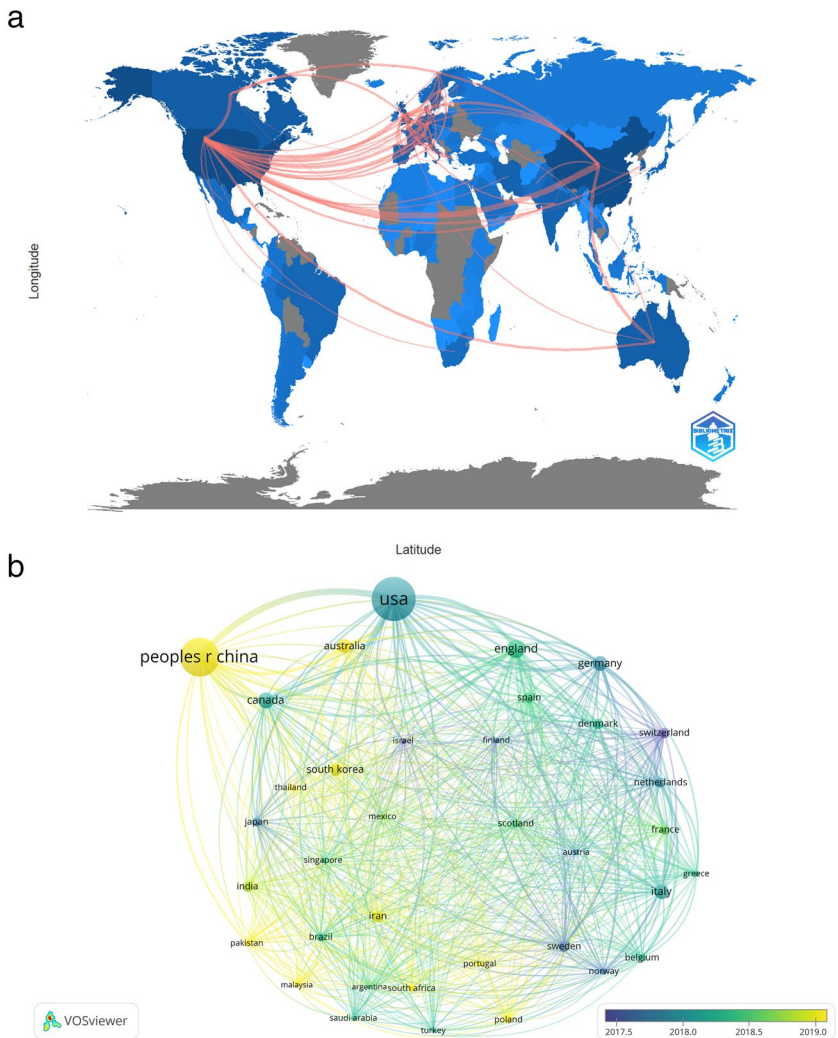
health burden posed by air pollution, as indicated by the World Health Organization's report that at least three-quarters of global deaths from CVDs occur in LMICs. Therefore, it is crucial to continue efforts in this field to develop targeted interventions and policies that can mitigate the adverse cardiovascular effects of air pollution. By doing so, we can improve public health outcomes in LMICs.

Journals analysis

Utilizing VOSviewer, this study sought to identify the most prolific and impactful journals in the area of air pollution and CVDs research. A total of 3144 articles were analyzed, spanning across 656 academic journals. The results revealed that 37.05% of all publications over the past decade were published in the top 10 most prolific journals. As shown in Table 5, *Environmental Research* demonstrated the highest number of publications (178, 5.7%), followed by the *International Journal of Environmental Research and Public Health* (165, 5.2%), *Science of the Total Environment* (155, 4.9%), *Environment International* (148, 4.7%), and *Environmental Science and Pollution Research* (133, 4.2%). Moreover, the journal with the highest IF among the top 10 was *Environment International* (IF = 13.352, Q1), followed by *Environmental Health Perspectives* (IF = 11.035, Q1). Notably, eight of the top 10 journals were situated within the Q1 JCR category, which represents the highest quartile of the JCR ranking. Additionally, eight of these journals boasted an IF score exceeding 5.

Within the top 10 co-cited journals identified in the study, eight journals received over 3000 citations. *Environmental Health Perspectives* had the most co-citations (co-citation = 12,109), followed by *Circulation* (co-citation = 6048), *Environmental Research* (co-citation = 4301), *Lancet* (co-citation = 4230), and *Science of the Total Environment* (co-citation = 4218). All of the top 10 co-cited journals were at the Q1 division of JCR, and six had an IF of over 10. Furthermore, the IF of the *Lancet* was the highest (IF = 202.731), followed by *Circulation* (IF = 39.918).

To gain further insights into the interdisciplinary nature of research on air pollution and CVDs, Chen and Leydesdorff's dual-map overlay of journals was utilized and shown via CiteSpace to visually depict the citing and cited journals (Chen and Leydesdorff 2014). The cited journals were positioned on the right-hand side, while the citing journals were on the left. The citation relationships were represented by colored paths (Chen 2017; Ke et al. 2020). Figure 7 revealed eight primary citation paths, including two yellow, three orange, and three green paths. The yellow paths demonstrated that studies published within the disciplines of Molecular/Biology/Genetics and Health/Nursing/Medicine were frequently cited in Veterinary/Animal/Science journals. The orange and green paths illustrated that the studies published in Environmental/Toxicology/Nutrition journals, Molecular/Biology/Genetics journals, and Health/Nursing/Medicine journals were often cited in Molecular/Biology/Immunology and Medicine/Medical/Clinical journals. This analysis suggests that the investigation of air pollution and CVDs demonstrates an interdisciplinary trend.

Disciplinary categories analysis

The study encompassed a comprehensive range of 121 distinct disciplinary categories. In Table 6, we present the top 5 categories, ranked based on the number of publications. Leading the pack with an impressive 1568 articles, "Environmental Sciences" secured the first position, followed by

Table 5 Top 10 journals and co-cited journals for research of air pollution and CVDs

Rank	Journal	Documents	IF 2022	Q	Co-cited Journal	Citations	IF 2022	Q
1	Environmental Research	178 (5.7%)	8.431	Q1	Environmental Health Perspectives	12,109	11.035	Q1
2	International Journal of Environmental Research and Public Health	165 (5.2%)	4.614	Q1,Q2	Circulation	6048	39.918	Q1
3	Science of the Total Environment	155 (4.9%)	10.753	Q1	Environmental Research	4301	8.431	Q1
4	Environment International	148 (4.7%)	13.352	Q1	Lancet	4230	202.731	Q1
5	Environmental Science and Pollution Research	133 (4.2%)	5.190	Q2	Science of the Total Environment	4218	10.753	Q1
6	Environmental Pollution	102 (3.2%)	9.988	Q1	Environment International	3778	13.352	Q1
7	Environmental Health Perspectives	94 (3.0%)	11.035	Q1	Epidemiology	3572	4.860	Q1,Q2
8	PLoS One	72 (2.3%)	3.752	Q2	Atmospheric Environment	3435	5.755	Q1,Q2
9	Environmental Health	71 (2.3%)	7.123	Q1	American Journal of Respiratory and Critical Care	2732	30.528	Q1
10	Ecotoxicology and Environmental Safety	47 (1.5%)	7.129	Q1	Environmental Pollution	2510	9.988	Q1

IF Impact Factor, *Q* Quartile in Category
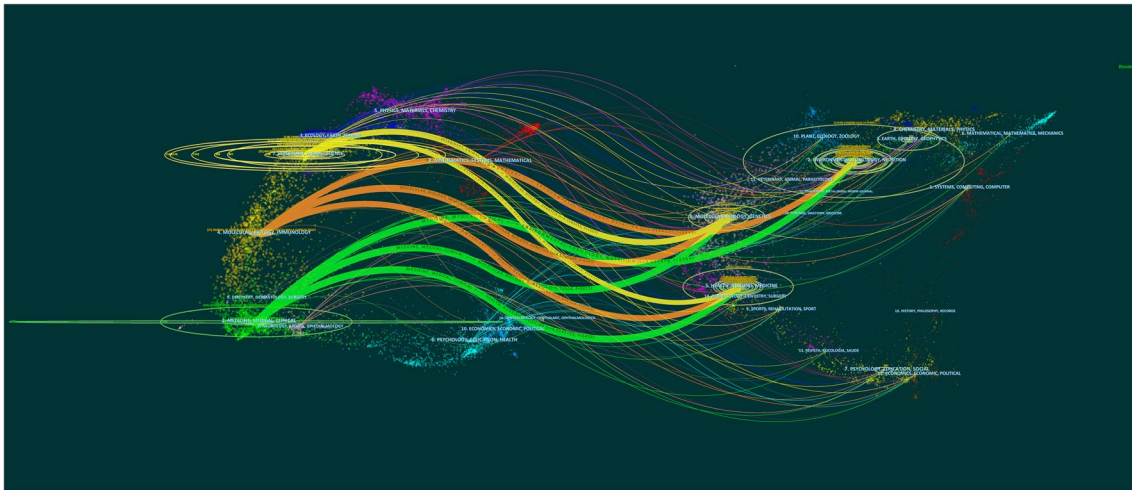
Fig. 7 The dual-map overlay of journals on research of air pollution and CVDs

"Public Environmental Occupational Health" (989 publications), "Toxicology" (407 publications), "Cardiac Cardiovascular Systems" (257 publications), and "Medicine General Internal" (131 publications).

Keywords analysis

In order to efficiently discover research hotspots and other relevant issues in a particular field, high-frequency keywords are often used as they give a full overview of the literature and facilitate a thorough analysis of the theme. Keyword co-occurrence analysis was performed using VOSviewer. From a total of 8,861 author keywords and keywords plus, 185 keywords that co-occurred at least 30 times were extracted. Except for the targeted keywords "air pollution" ($n=1915$) and "cardiovascular diseases" ($n=1297$) that we searched for, the top 10 most frequent keywords are "particulate matter" ($n=926$), "mortality" ($n=862$), "exposure" ($n=583$), "long-term exposure" ($n=575$), "association" ($n=492$), "risk" ($n=478$), "health" ($n=475$), "oxidative stress" ($n=473$), "$PM_{2.5}$" ($n=410$), and "inflammation" ($n=374$). Through the clustering function of VOSviewer, closely related keywords were grouped into the same cluster with the same color. These clusters reflected the main

Table 6 Top 5 disciplinary categories

Disciplinary Categories	Documents
Environmental Sciences	1568
Public Environmental Occupational Health	989
Toxicology	407
Cardiac Cardiovascular Systems	257
Medicine General Internal	131

research topics and fundamental research areas to which the keywords pertain (Li et al. 2015). As depicted in Fig. 8a, the keywords can be classified into five distinct categories., with each node representing a corresponding keyword and the node's size indicating the number of times the keyword appeared in corresponding publications.

Moreover, analyzing the temporal evolution of keywords can provide researchers with a more thorough picture of the research frontiers and trends in the field. In Fig. 8b, an overlay visualization map depicts the average year of publication for the keywords, with the closer the color to yellow, the later the keyword appeared. It can be observed that most of the keywords appeared after 2017, with earlier keywords including "particulate air pollution", "ultrafine particles", "coronary heart disease", "myocardial infarction", and "hospital admissions", et al. As research progressed, keywords such as "long-term exposure", "blood pressure", "exposure", "inflammation", and "oxidative stress" emerged. Noteworthily, in recent years, "$PM_{2.5}$", "short-term exposure", "fine particulate matter", "source apportionment", and "global burden" have become the focus and frontier topics of current research.

To investigate the current trends in research, we utilized the "bibliometrix" package within the R software to conduct trend topic and thematic map analyses.

The trending topics analysis identifies those with the most substantial growth rate over recent years. This analysis also provides a longitudinal evolution of these topics through an evolution plot showcasing the accumulative number of keywords and when the topic originated and progressed (Ruiz-Rosero et al. 2019). Figure 9 illustrates the buzz topics from 2013 to 2022, with the keywords identified from the keywords plus (Zhang et al. 2016). The topic exhibited a three-word frequency per year, and each word had at least

Fig. 8 Co-occurrence analysis of keywords. **(a)** Network visualization map of keywords of related studies (7 clusters). **(b)** Overlay visualization map of keywords according to average publication year (blue means earlier, yellow means later)
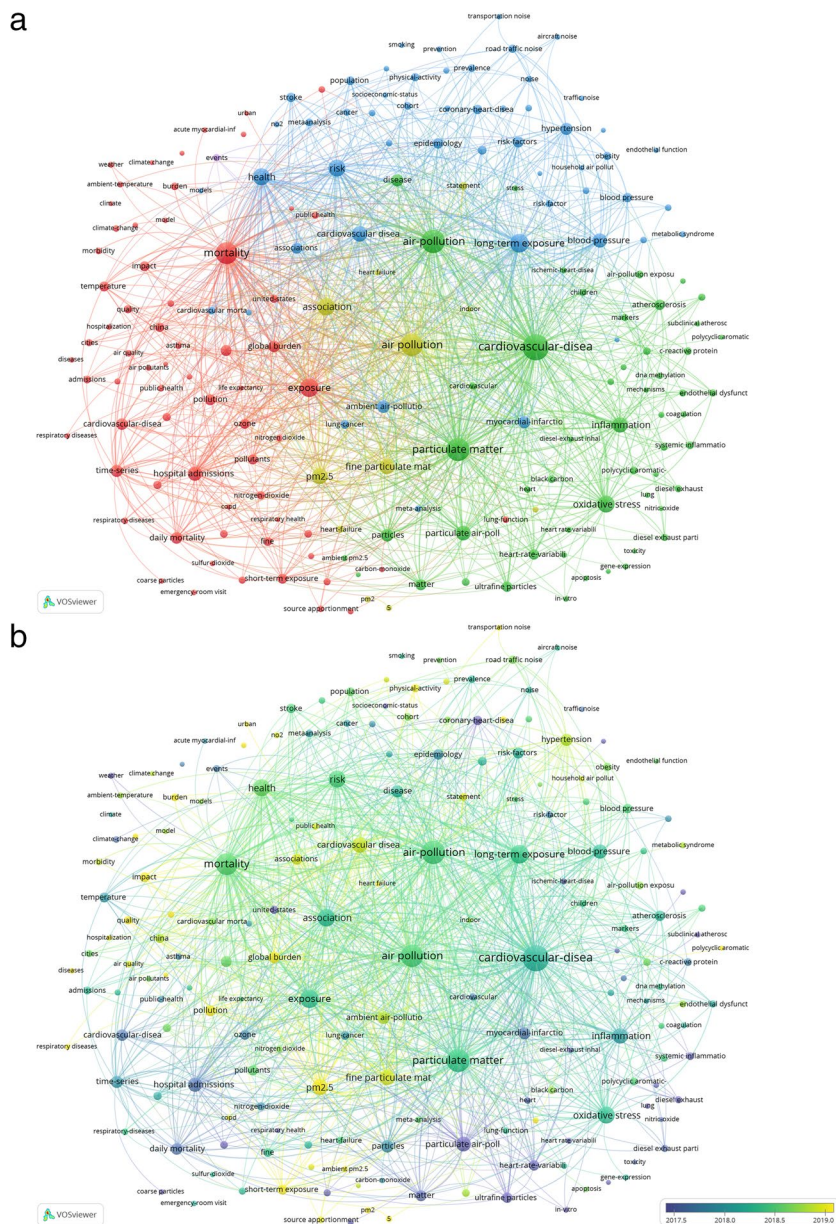

five frequencies. Except for the words "air pollution" and "cardiovascular diseases", keywords such as "blood pressure", "particulate air pollution", "ultrafine particles", "coronary heart disease", and "ambient air" demonstrated the most extended duration of six or five years. Of particular interest were "particulate air pollution" and "ultrafine particles", which occurred more frequently and lasted longer. Very recently, in 2021 and 2022, studies in the context of "global association", "middle-income", "incident hypertension", and "PM$_{2.5}$ exposure" have also been investigated.

Finally, to explore potential avenues for future research, we draw the bibliometrix keywords thematic map, in which the horizontal axis represents the relevance degree of centrality (correlations among various topics), while the

vertical axis represents the development degree of density (cohesiveness among the nodes) (Ying et al. 2022). In the thematic map (Fig. 10), 190 keywords were examined, with a minimum cluster frequency of 5 per thousand documents and a label count of 3 for each cluster. The map is divided into four quadrants, each showcasing distinct typologies of themes. With their high density and centrality, motor themes, which are found in the upper right quadrant, likely represent well-developed and relevant concepts in the research field. The red-color keywords "hospital admissions", "daily mortality", and "time series" represented such motor themes and were essential in this field. Niche themes are located in the upper left quadrant of the thematic map and are topics that are well-developed but

Fig. 9 Trend topics around air pollution and CVDs research (2013–2022). The X-axis represents the year, while the Y-axis is the cumulate occurrences of the keywords
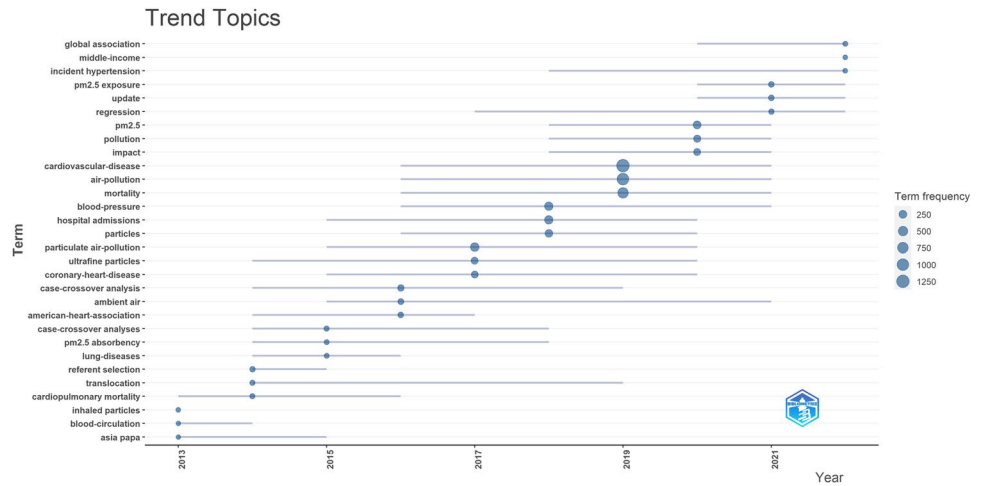
Fig. 10 The thematic map of keywords plus. (**a**) motor themes (first quadrant); (**b**) niche themes (second quadrant); (**c**) emerging or declining themes (third quadrant); (**d**) basic themes (fourth quadrant)
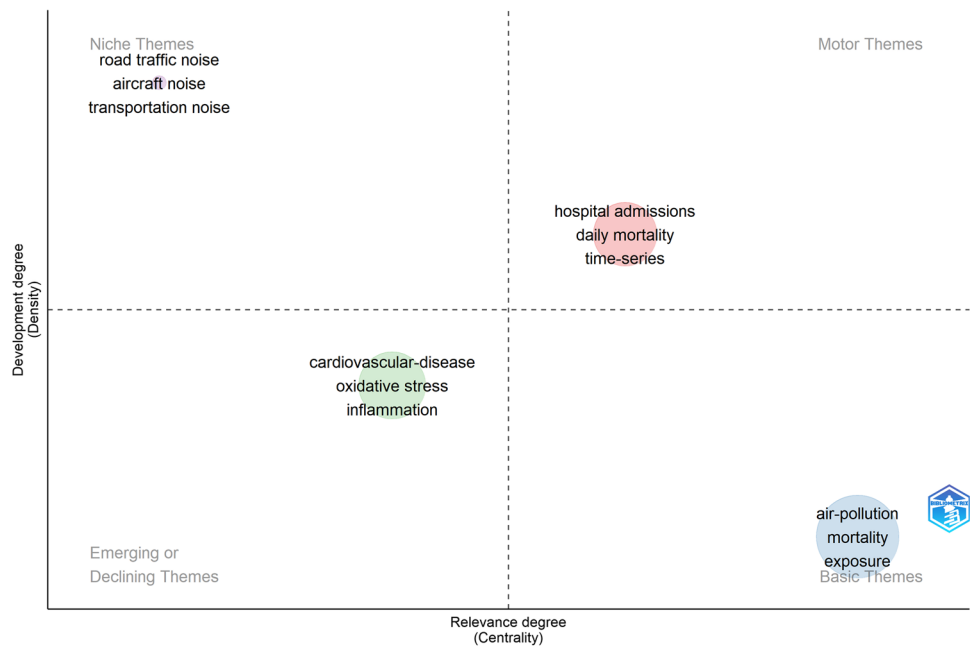
have become isolated. These themes can provide a basis for discussion with researchers from other fields (Agbo et al. 2021). Purple-colored keywords "road traffic noise", "aircraft noise", and "transportation noise" represented niche themes in this study. Emerging or decreasing themes, which have low density and centrality and may be marginal or vanishing, are displayed in the lower left quadrant of the map (Della Corte et al. 2019). Green-colored keywords "cardiovascular disease", "oxidative stress", and "inflammation" represented such themes in this study. The lower right quadrant features basic themes, which have low density (underdeveloped) but high centrality (important) and represent fundamental concepts and knowledge in the field of research. Blue-colored keywords "air pollution", "mortality", and "exposure" were located in this quadrant.

Discussion

A scientometric analysis was conducted using Bibliometrix, CiteSpace, and VOSviewer to investigate the publications related to air pollution and CVDs between 2013 and 2022. The study identified a total of 3,144 relevant documents published on this topic up to the end of 2022, with a steady increase in publication output observed over time, peaking in 2022. This indicates a growing interest and research focus on the correlation between air pollution and CVDs. The annual growth rate in publication output was 10.7%, with the highest growth rate recorded in 2016, suggesting a dramatic uptick in interest in this scientific field. With an average of 34.19 citations per paper, the documents received a total of 107,509 citations, implying a notable impact of

the research findings. The top 10 cited papers provided a comprehensive summary of the prevailing findings on the correlation between air pollution and CVDs. Among them, seven were published in the *Lancet* journal (Landrigan et al. 2018; Forouzanfar et al. 2016, 2015; Stanaway et al. 2018; Yang et al. 2013; Basner et al. 2014; Beelen et al. 2014), and three were authored by the GBD Risk Factor Collaborators (Forouzanfar et al. 2016, 2015; Stanaway et al. 2018). The GBD 2015 Risk Factor Collaborators published the most cited paper, receiving 2453 citations, in which they concluded that air pollution was the fifth major risk factor for both men and women, mainly contributing to DALYs (disability-adjusted life-years) related to cardiovascular and respiratory diseases, as well as common infectious diseases (Forouzanfar et al. 2016). The review article published on *Environment International* indicated that PM pollution is associated with an increased risk of hospitalization for myocardial infarction and worsening congestive heart failure in the elderly, and it increases cardiac risk by initiating and promoting atherosclerosis (Kim et al. 2015). Two articles published in 2013 and 2014 indicated that long-term exposure to fine particulate air pollution was associated with mortality, including cardiovascular mortality and natural-cause mortality (Hoek et al. 2013; Beelen et al. 2014). Moreover, investing in controlling air pollution not only reduces mortality but can also produce large economic gains. A study conducted in the USA found that every dollar invested in air pollution control has returned $30 to the economy, representing a 3000% return on investment (Landrigan et al. 2018). One particularly influential article authored by Brook RD, Rajagopalan S, et al. was the most cited reference and had the strongest citation bursts (Brook et al. 2010). The study concluded that exposure to $PM_{2.5}$ is linked with an elevated risk of cardiovascular morbidity and mortality. The research also emphasized that compared to short-term exposure (a few hours to weeks), longer-term exposure (a few years) is associated with a more significant increase in mortality risk. It can substantially reduce life expectancy, highlighting the critical role of chronic exposure to $PM_{2.5}$ in promoting adverse cardiovascular outcomes. Undoubtedly, this article represents a landmark in this area of research and provides essential reference values for future research.

In our study of 3144 papers authored by a total of 16,450 individuals, we identified the most productive authors in the field of air pollution and CVDs. Among them, Kan H, Schwartz J, Koutrakis P, Guo Y, and Peters A emerged as the most prolific authors based on their output. These authors stand out among their peers, indicating their significant contributions to the research area. Particularly noteworthy are Brook RD, Peters A, and Schwartz J, who have demonstrated particular success in this area of study based on their high productivity and co-citation rankings, as well as their inclusion among the top five in terms of total link strength. Brook

RD, in particular, had the highest citations and link strength among all authors. His research established that long-term exposure to fine particulate matter air pollution is associated with an increased risk of cardiovascular morbidity and mortality. Specifically, his study identified a significant association between $PM_{2.5}$ exposure and cardiovascular mortality, with a hazard ratio (HR) of 1.12 (95% confidence interval: 1.10–1.15) per 10 μg/m^3 increase in $PM_{2.5}$ (Pope et al. 2015). Then he noted that while air pollution is a complex mix of gases, the most compelling evidence for its harmful effects on human health pertains to fine particulate matter and ozone gas (Al-Kindi et al. 2020). His 2015 article on air pollution and CVDs is his most frequently cited publication on this topic, with 478 citations (Newby et al. 2015). Brook RD's extensive research has provided valuable insights into the complex mechanisms by which air pollution impacts the development of cardiovascular diseases. His work has played a crucial role in advancing scientific understanding of this critical public health issue.

The 3144 papers were contributed by 4448 institutions representing 131 countries/regions, with 2149 (68.35%) of the papers published by the USA and China, signifying their crucial role in driving the development of air pollution and CVDs research. Table 4 provides further insights, indicating that the USA was home to 60% of the top 10 institutions, highlighting its excellent traditional research institutions. Meanwhile, Peking University, one of the oldest academic institutions in China, emerged as the most productive research institution regarding air pollution and CVDs. The University of Washington ranked first in the institutions' co-authorship analysis, indicating its close collaboration with other agencies. The USA stood out as the leader in air pollution and CVDs research, with the highest number of publications among all countries. Additionally, China and the USA had the most partnerships among the countries that collaborated, reflecting the contemporary trend of scientific cooperation between large countries.

The study included 656 journals, and most of the top 10 most productive journals and co-cited journals belong to the field of Environmental Science. Notably, the journals *Environmental Research* and *Environmental Health Perspectives* emerged as significant contributors in terms of publication output and co-citations, respectively. However, it is noteworthy that although *Environmental Research* published the most documents, it was ranked third in terms of total co-citations. These five journals, namely, *Environmental Health Perspectives*, *Circulation*, *Environmental Research*, *Lancet*, and *Science of the Total Environment*, were found to dominate the number of citations, reflecting the considerable attention given to fundamental air pollution and CVDs research published in these journals.

The study utilized keywords co-occurrence, trend topic analysis, and thematic mapping to ascertain the prevailing research

areas of interest and emerging patterns in the domain of air pollution and CVDs. The analysis revealed a rapid increase in research attention on several key topics over the past decade. These topics include "mortality", "hospital admissions", "oxidative stress", "inflammation", and "long-term exposure". At present, keywords such as "fine particulate matter" and "$PM_{2.5}$" have also gained significant attention from researchers, indicating a potential emerging trend in the field.

In the study, a total of 185 keywords that occurred 30 or more times were used. Based on cluster analysis of co-occurrence keywords, 8861 keywords were analyzed and divided into five clusters, with the top three clusters consisting of over 50 keywords each. The largest cluster, Cluster 1, comprised 67 keywords and focused on the relationship between exposure to air pollution and cardiovascular mortality and hospital admissions. It has been suggested that air pollution exposure significantly contributes to cardiovascular mortality and hospital admissions, with a burden greater than previously recognized (Mannucci et al. 2019; Manisalidis et al. 2020). For example, Wellenius et al. conducted a study demonstrating a significant positive correlation between PM air pollution and hospital admissions for heart failure in seven cities in the USA. Specifically, the authors found that a 10 µg/m3 increase in PM_{10} was associated with a 0.7% rise in the daily rate of hospital admissions for heart failure (Wellenius et al. 2006). Similarly, in a population over 65 years old, a similar increase in the daily risk of hospital admissions due to heart failure was observed for each 10 µg/m3 rise in $PM_{2.5}$ concentration (Dominici et al. 2006). These results provide important insights into the deleterious effects of air pollution and highlight the need for measures to reduce exposure to PM in order to improve public health. Cluster 2 contains 53 keywords relating to the mechanisms of CVDs caused by air pollution, including oxidative stress and inflammation. Experimental and clinical research suggested that airborne particles are associated with an increased risk of CVDs by enhancing the propensity to coagulation, promoting endothelial dysfunction, increasing insulin resistance, triggering inflammation, increasing oxidative stress, and facilitating the development of atherosclerosis (Landrigan et al. 2018). Oxidative stress and inflammation remained key potential mechanisms by which particle inhalation may link to CVDs (Joshi et al. 2022; Miller and Newby 2020). Several genes that are implicated in the interactions between air pollution and risk factors and outcomes for CVDs have been identified. Notably, genes such as *GSTM1*, *TNF-α*, and *IL-6* have been found to be linked to inflammatory markers through gene-environment interactions (Ward-Caviness 2019). Cluster 3, also comprising 53 keywords, mainly focused on the potential of long-term exposure to

air pollution to increase the risk of CVDs, such as hypertension, MI, and stroke. A growing body of evidence supports the notion that extended exposure to air pollution, specifically fine particulate matter, and NO_2, was linked to the development of atherosclerosis, incident hypertension, stroke, MI, and heart failure (Bont et al. 2022; Konduracka and Rostoff 2022; Yang et al. 2018). These findings underscore the critical significance of decreasing the concerning levels of air pollution worldwide. Fine particulate matter ($PM_{2.5}$) has become a significant research trend due to its link with CVDs. Ambient air pollution was a prevalent issue in LMICs, where 98% of urban areas with populations exceeding 100,000 failed to meet the World Health Organization's global air quality guideline for $PM_{2.5}$ annually (Landrigan et al. 2018). However, research on high-concentration areas is scarce, necessitating further studies in LMICs due to substantial differences in population characteristics, access to healthcare, pollutant sources, composition, and spatial–temporal variability compared with high-income countries (Bont et al. 2022). A multi-faceted approach is required to reduce air pollution, including regulation, education, technological advancements, and individual actions. Personal exposure to $PM_{2.5}$ can be reduced through various measures, such as using facemasks, indoor air purifiers, and electric vehicles.

To our knowledge, no prior scientometric analysis of the relationship between air pollution and CVDs has been conducted. Unlike conventional literature reviews, this approach allows to identify research priorities, emerging trends, significant publications, authors, institutions, and countries. The findings contribute to the existing knowledge on this topic, aiding in knowledge mapping and identifying research gaps. Researchers can use these results to find potential collaborators and explore new research areas, promoting further advancements and practical applications in this field.

Nonetheless, this study also has certain limitations. Firstly, the study focused primarily on English-language journals, thus neglecting relevant literature published in other languages. Secondly, the utilization of scientometric software made it difficult to integrate results from other databases, resulting in potential research bias and omission of articles not present in the WoS database. Moreover, the software used to analyze the results had some limitations, as most of the findings were generated by machine algorithms, which were partially deficient in manual generalization. Furthermore, the conclusions drawn from some articles may be outdated, given that their publication date may be ages ago. The study did not consider articles published after January 2023. Despite these limitations, we believe that this study can provide valuable insights and serve as a source of research inspiration for future investigations.

Conclusion

In summary, the abundance of recent publications is indicative of the growing interest among scholars worldwide in investigating the correlation between air pollution and CVDs. Notably, Kan H emerged as the most productive author, while Brook RD, Peters A, and Schwartz J were identified as successful researchers in this field. The leading countries in terms of research output were the USA and China, with close cooperation between the two countries. Most of the top-ranked journals belonged to the "Environmental Science" category, with *Environmental Research* publishing the largest number of papers. The identification of potential research hotspots and trends was facilitated by keywords co-occurrence, trend topic analysis, and thematic map. Investigation into the mechanisms by which particle inhalation contributes to CVDs can provide valuable insights towards devising efficacious strategies for prevention and treatment, thereby reducing cardiovascular morbidity and mortality. Moreover, $PM_{2.5}$ is expected to become a key research focus. It is crucial to raise public awareness and provide education regarding the health consequences of exposure to air pollutants. Governments and communities can also work collaboratively to implement policies and programs that aim to reduce air pollution, such as investing in renewable energy, promoting public transportation, and implementing green spaces in urban areas. This scientometric analysis provides a visual representation of the field of air pollution and CVDs, aiding in tracking the intellectual structures of research frontiers and specific knowledge domains related to air pollution and CVDs.

Author contributions Daitian Zheng conceived and designed the study, conducted the visual analysis of the data, and wrote a large part of the manuscript. Qiuping Yang and Jinyao Wu retrieved the dataset from the Web of Science, while Huiting Tian and Zeqi Ji provided software guidance and revised the manuscript. Lingzhi Chen, Jiehui Cai, Zhiyang Li, and Yexi Chen were responsible for interpreting the findings of the study. All authors read and approved the final version of the manuscript.

Data availability All data generated or analyzed for this study are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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