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Review Article

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Trends and gaps in air quality and children's health: A biblio-metric analysis using scopus and VOSviewer

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ABSTRACT

Air pollution remains a critical global health issue that affects children. This bibliometric study analyses trends, research gaps, and key contributors to the literature on air pollution's impact on children's health, utilizing data from 1,590 publications indexed in the Scopus database between 1956 and 2024. Hazing's Publish or Perish and VOS viewer were used to analyse the data. Most studies on air quality focus on medicine (67.42%) and environmental science (41.32%). Key findings indicate that the United States leads in both publication volume and impact, contributing 467 papers and 27,252 total citations, with an h-index of 89. Researchers from institutions such as Harvard T.H. Chan School of Public Health and the University of Southern California are pivotal in advancing the discourse on how air pollution exacerbates conditions like asthma, bronchitis, and long-term cognitive impairments in children. Older foundational studies, particularly those published in the late 2000s, continue to be highly influential for their focus on neuroinflammation and cognitive deficits linked to air pollution. International collaboration is robust, with co-authorship networks between the United States, China, and several European countries. However, more interdisciplinary and longitudinal studies are needed to deepen our understanding of the mechanisms through which air pollution affects children's health. This study provides insights for future research efforts, strengthens scientific understanding, and supports the development of more effective public health interventions to reduce the burden of air pollution on children worldwide.

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Review

Over 90% of children worldwide breathe polluted air, leading to significant adverse effects on their health [1]. In 2021, air pollution was linked to death of 709,000 child deaths, making it the second leading cause of death among children under five, following malnutrition [2]. These alarming statistics have fuelled widespread research into the relationship between air quality and children's health. Studies have shown that exposure to fine Particulate Matter ($PM_{2.5}$), Nitrogen dioxide (NO_2) and Sulphur dioxide (SO_2) increases the risk of asthma, bronchitis, pneumonia, and decreased lung function in children [3- 7]. The primary sources of air pollution include household activities, waste incineration, traffic-related, industrial processes, agricultural practices, second-hand smoke, landscapes fires, volcanic eruptions, and dust and sandstorms [2, 8]. While household air pollution linked to poverty is on the decline, ambient air pollution resulting from industrialization and urbanisation is rising [9].

In 2016, respiratory tract infections caused by both ambient and household air pollution resulted in 543000 deaths among children under five years old [8]. Young children are particularly vulnerable because they breathe more rapidly and inhale more air per unit of body weight than adults. Their developing organs, proximity to pollution sources, and the potential for pollutants to impact them even before birth put them at higher risk [2]. Exposure to air pollution not only exacerbates illness in childhood but also has long-term consequences that can diminish quality of life in adulthood [1]. Children are vulnerable especially during fetal development and in their earliest years [8]. Notably, studies have linked prenatal and early-life exposure to NO_2 with an increased risk of autism spectrum disorders [10]. Other harmful exposures, such as formaldehyde, residential characteristics and the use of mosquito repellents have also been associated with respiratory allergic symptoms in children [11].

Additionally, early-life exposure to air pollution has been linked to an increased incidence of asthma in both early and middle childhood, with urban children being particularly susceptible [7]. Even short-term exposure to pollutants, at levels below recommended guidelines, has been shown to increase hospital visits and emergency room admissions [12].

Despite global efforts to address air pollution, its burden on children's health remains significant [7, 9]. The growing body of research reflects increasing concern about the short- and long-term effects of air pollution exposure [4, 13, 14]. However, Vilcins et.al (2024) suggests that more research is needed at the intersection of major health issue in children and air pollution [15]. Despite this progress, a comprehensive understanding of the current state of research, its trends, and potential gaps remain critical.
This study aims to examine the scientific literature published in the field of air pollution and the effects towards the children. It seeks to identify the primary focus and existing gaps in air pollution studies focusing on children's health. Conducting a bibliometric analysis is imperative for systematically evaluating the volume, impact, and research focus of academic publications related to the field proving insights into key contributors, research hotspots, and emerging areas of interest [16]. This study provides valuable insights that can guide future research directions, strengthen scientific understanding, and inform effective interventions to mitigate the health impacts of air pollution on children.

Methods

Search strategy

All data were extracted from the Scopus database on July 9, 2024. The search terms

included "air pollution," "children," "child," "infants," "pediatrics," and "youth." The search encompassed publications from all time periods from 1956 to July 2024, in all languages, and across all source and document types, including articles, reviews, conference papers, editorials, and book chapters. No documents were excluded, resulting in a total of 1,590 publications. Fig. 1 illustrates the flow diagram of the search and selection process.

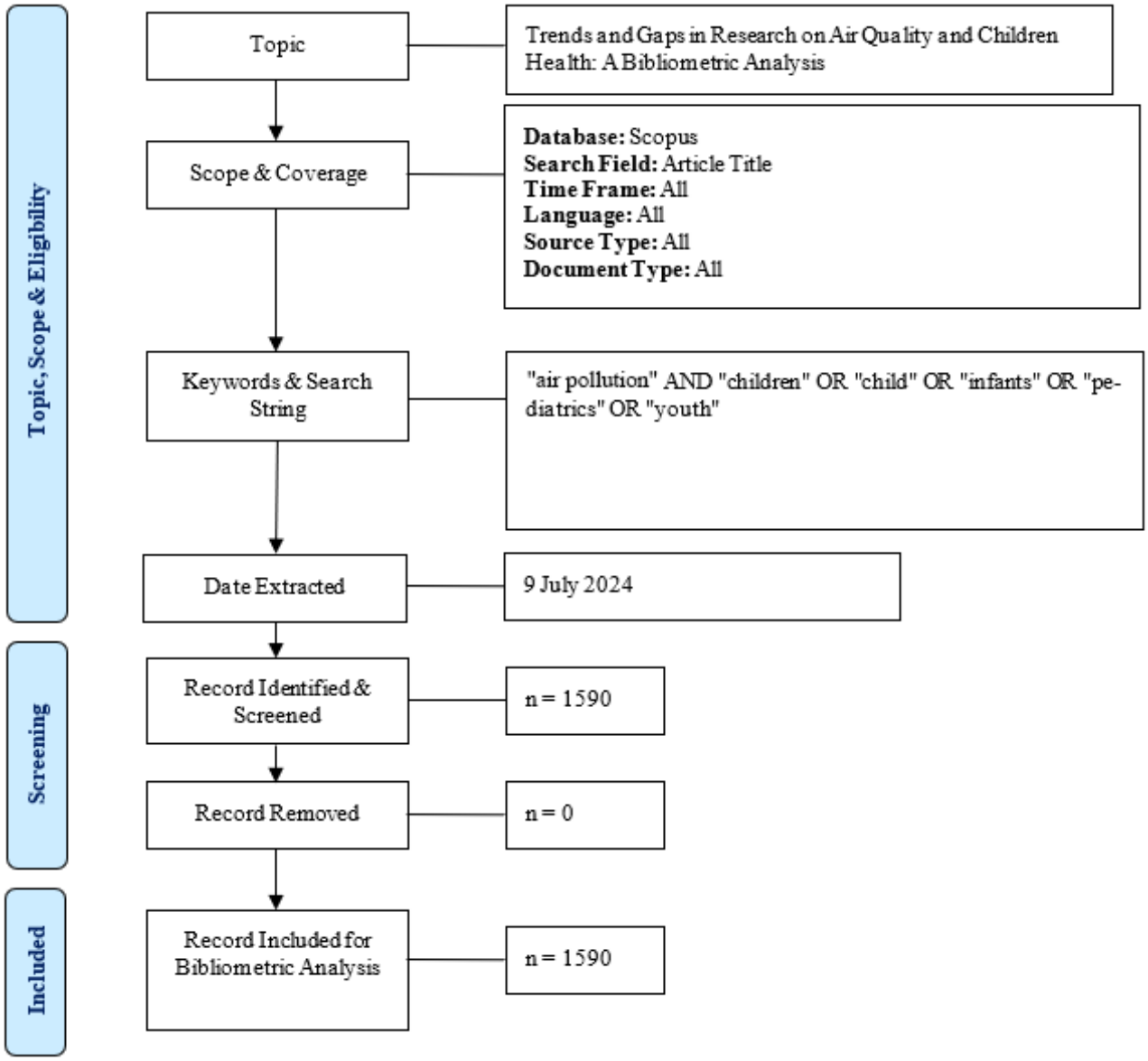

Fig. 1. Flow diagram of the search strategy

Data analysis

Data retrieved from the Scopus database were saved in .csv and .ris formats for further analysis. This dataset included information on document profiles such as document type, source type, languages, and subject areas. Descriptive statistics, including frequencies, percentages, and visualizations, were generated using Microsoft Excel. Citation metrics were calculated using Harzing's Publish or Perish software, while VOSViewer was utilized to visualize bibliometric networks.

The analysis of the data focused on several key aspects of research development and dissemination. This included investigating the distribution of document types and subject areas, as well as examining citation patterns and publication trends related to air quality and children's health. Additionally, the study delved into author and institutional productivity, identifying the most productive authors and institutions. The contribution of different countries to air pollution and children research was assessed, with a focus on the top 15 contributors and their share of global scientific output indexed by Scopus. The analysis also highlighted the leading journals in terms of publication numbers, along with key citation metrics and the 20 most highly cited articles. Furthermore, the study explored co-authorship patterns among authors, and countries, as well as co-occurrence relationships based on author keyword, titles and, abstracts. Finally, a comprehensive citation analysis was conducted, encompassing documents, sources, organisations, and countries.

The results are presented in terms of frequencies and percentages. Key metrics such as Total Citations (TCs), number of cited publications (NCPs), average Citations per Publication (C/P), and Citations per Cited Publication (C/CP) were calculated. Additionally, both the h-index and g-index were determined. Further analysis included the current cite score, publisher details, Source-Normalized Impact per Paper (SNIP), and SCImago Journal Rank (SJR) obtained from Scopus.

Results

Documents profiles

Five types of documents related to publications on air pollution and children's health were retrieved from the Scopus database, as detailed in Table 1. Articles accounted for the largest share, with 1,351 publications (84.9%), reflecting the dominant role of peer-reviewed journal articles in disseminating research. The remaining document types each comprised less than 10% of the total publications, likely due to the field's emphasis on peer-reviewed outputs: reviews with 125 publications (7.86%), conference papers with 76 (4.78%), editorials 22 (1.38%), and book chapters 16 (1.01%).

Table 1. Document type

Document Type	Total Publications (TP)	Percentage (%)
Article	1351	84.97%
Review	125	7.86%
Conference Paper	76	4.78%
Editorial	22	1.38%
Book Chapter	16	1.01%
Total	1590	100.00

Table 2. Source type

Source Type	Total Publications (TP)	Percentage (%)
Journal	1507	94.78%
Conference Proceeding	51	3.21%
Book	17	1.07%
Book Series	10	0.63%
Trade Journal	2	0.13%
Undefined	3	0.19%
Total	1590	100.00

Table 3. Languages

Language	Total Publications (TP)	Percentage (%)
English	1332	82.68%
Russian	77	4.78%
German	33	2.05%
Chinese	27	1.68%
French	23	1.43%
Polish	22	1.37%
Spanish	19	1.18%
Japanese	16	0.99%
Czech	13	0.81%
Portuguese	7	0.43%
Italian	6	0.37%
Moldavian	5	0.31%
Moldovan	5	0.31%
Romanian	5	0.31%
Slovak	5	0.31%
Serbian	3	0.19%
Bulgarian	2	0.12%
Croatian	2	0.12%
Dutch	2	0.12%
Bosnian	1	0.06%
Danish	1	0.06%
Hungarian	1	0.06%
Lithuanian	1	0.06%
Norwegian	1	0.06%
Ukrainian	1	0.06%
Undefined	1	0.06%
Total	1590	100.00

Table 2 shows the source type of the publication from 1956 until July 2024. Journal recorded the highest source type with a total percentage (94.78%), followed by conference proceeding (3.21%), book (1.07%), book series (0.63%), trade journal (0.13%) and undefined document (0.19%). These results suggest that there is a strong preference among researchers for traditional scientific journals, probably due to wider reach, higher impact, and inclusion in academic evaluations.

Table 3 indicates the languages on publication about the topic across the globe. The English language recorded the highest proportion of publications (82.68%), showing the principal language of scientific discourse. Russian (4.78%) and German (2.05%) constitute less than 5% while other languages less than 2%. These publications might contribute to localized insights and are limited internationally.

Table 4. Subject area

Subject Area	Total Publications (TP)	Percentage (%)
Medicine	1072	67.42%
Environmental Science	657	41.32%
Biochemistry, Genetics and Molecular Biology	119	7.48%
Pharmacology, Toxicology and Pharmaceutics	72	4.53%
Social Sciences	69	4.34%
Engineering	67	4.21%
Earth and Planetary Sciences	51	3.21%
Immunology and Microbiology	41	2.58%
Multidisciplinary	31	1.95%
Neuroscience	29	1.82%
Computer Science	23	1.45%
Economics, Econometrics and Finance	21	1.32%
Psychology	19	1.19%
Agricultural and Biological Sciences	17	1.07%
Nursing	16	1.01%
Energy	12	0.75%
Chemical Engineering	10	0.63%
Arts and Humanities	9	0.57%
Chemistry	8	0.50%
Physics and Astronomy	7	0.44%
Mathematics	6	0.38%
Health Professions	4	0.25%
Materials Science	4	0.25%
Dentistry	2	0.13%
Business, Management and Accounting	1	0.06%
Decision Sciences	1	0.06%
Undefined	1	0.06%

Air quality and children's health research have been published extensively in subject area of Medicine (67.42%), followed by Environmental Science (41.32%). This underscores the interdisciplinary nature of this topic. Other subject areas had less than 10% publication, which reflect the complex, multifaceted impacts of air pollution on child health. Total publications according to the subject areas are shown in Table 4.

Publication trends

Table 5 presents the publication years alongside key metrics, including Total Publications (TP), Number of Cited Publications (NCP), Total Citations (TC), average citations per publication (C/P), Citations per Cited Publication (C/CP), h-index (h), and g-index (g). The highest number of publications was recorded in 2021 with 116 articles, followed by 110 in 2022, 87 in 2020, 84 in 2018, 77 in 2019, and 75 in 2023. Publication counts for years prior to 2017 were consistently below 70. However, total citations per year show a steady increase starting from 1997, with 2008 having the highest total citations, reaching 4,429. This result suggests that landmark studies in that period remain heavily referenced today.

Table 5. Year of Publication

Year	TP	NCP	TC	C/P	C/CP	h	g
2024	54	15	22	0.41	1.47	2	3
2023	75	52	238	3.17	4.58	8	11
2022	110	97	861	7.83	8.88	16	22
2021	116	108	2045	17.63	18.94	24	38
2020	87	77	1591	18.29	20.66	25	34
2019	77	75	2293	29.78	30.57	28	45
2018	84	78	2390	28.45	30.64	30	46
2017	68	64	3606	53.03	56.34	36	60
2016	43	42	1733	40.30	41.26	21	41
2015	59	57	3222	54.61	56.53	29	56
2014	51	48	2225	43.63	46.35	28	47
2013	42	38	2047	48.74	53.87	24	38
2012	35	28	1796	51.31	64.14	20	28
2011	44	36	1999	45.43	55.53	26	36
2010	33	33	1739	52.70	52.70	20	33
2009	30	23	1486	49.53	64.61	15	23
2008	42	41	4429	105.45	108.02	29	41
2007	34	31	1810	53.24	58.39	19	31
2006	27	26	1905	70.56	73.27	23	26
2005	20	19	1815	90.75	95.53	14	19
2004	28	27	2330	83.21	86.30	22	17
2003	18	17	1502	83.44	88.35	11	17

Table 5. Continued

Year	TP	NCP	TC	C/P	C/CP	h	g
2002	22	21	2076	94.36	98.86	14	21
2001	15	11	1068	71.20	97.09	9	11
2000	24	20	2257	94.04	112.85	13	20
1999	30	27	1692	56.40	62.67	19	27
1998	32	29	687	21.47	23.69	10	26
1997	20	15	1568	78.40	104.53	9	15
1996	14	12	575	41.07	47.92	9	12
1995	16	16	881	55.06	55.06	12	16
1994	13	11	590	45.38	53.64	8	11
1993	18	11	472	26.22	42.91	7	11
1992	11	8	546	49.64	68.25	5	8
1991	10	7	139	13.90	19.86	5	7
1990	15	10	236	15.73	23.60	5	10
1989	17	12	269	15.82	22.42	8	12
1988	9	4	46	5.11	11.50	2	4
1987	12	5	104	8.67	20.80	4	5
1986	13	8	222	17.08	27.75	5	8
1985	7	5	98	14.00	19.60	4	5
1984	4	2	6	1.50	3.00	2	2
1983	5	3	22	4.40	7.33	2	3
1982	12	4	184	15.33	46.00	2	4
1981	5	2	21	4.20	10.50	2	2
1980	11	5	15	1.36	3.00	2	3
1979	10	2	4	0.40	2.00	2	2
1978	4	1	1	0.25	1.00	1	1
1977	7	4	8	1.14	2.00	2	2
1976	9	7	79	8.78	11.29	3	7
1975	7	3	28	4.00	9.33	1	3
1974	10	3	37	3.70	12.33	2	3
1973	3	2	6	2.00	3.00	1	2
1972	6	3	18	3.00	6.00	1	3
1971	2	1	1	0.50	1.00	1	1
1970	6	4	45	7.50	11.25	3	4

Table 5. Continued

Year	TP	NCP	TC	C/P	C/CP	h	g
1969	2	1	7	3.50	7.00	1	1
1968	2	1	1	0.50	1.00	1	1
1967	2	2	47	23.50	23.50	2	2
1966	5	2	3	0.60	1.50	1	1
1965	1	0	0	0.00	0	0	0
1958	1	1	1	1.00	1.00	1	1
1956	1	1	1	1.00	1.00	1	1

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

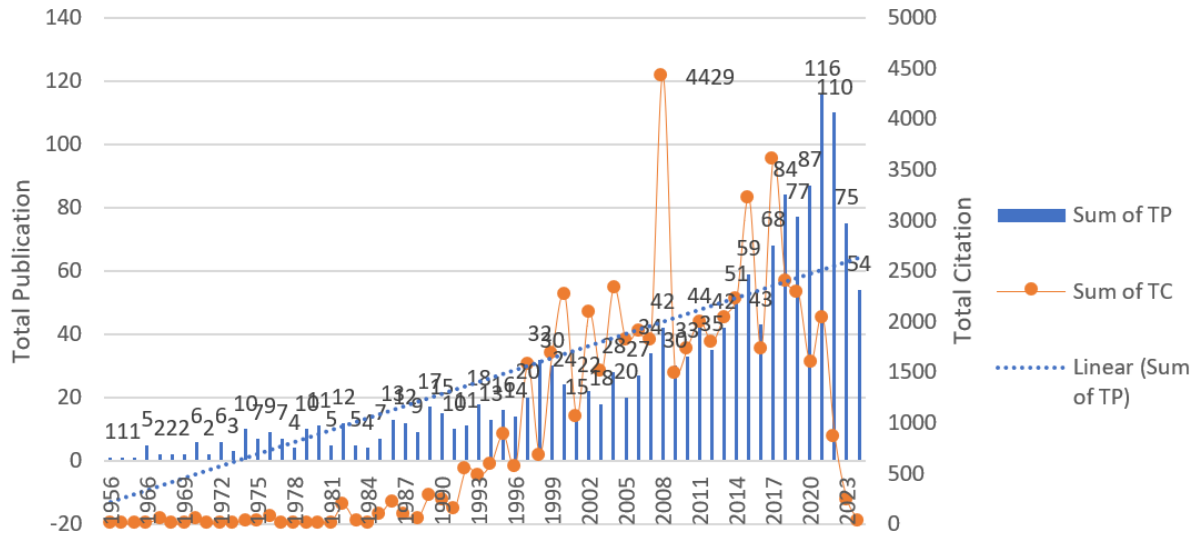

Fig. 2. Total Publications and citations by year

Publications and citations by year

Fig. 2 illustrates the trend of total publications and citations by year. The number of publications has steadily increased over time, peaking in 2021 with 116 publications. Citations, on the other hand, reached their highest point in 2008, with a total of 4,429 citations. The lower citation counts in 2023 and 2024 reflect the fact that these publications are more recent and have had less time to accumulate citations.

Publications by authors

The fifteen most productive authors in the field of air quality and children's health are presented in Table 6. Topping the list is Brunekreef, B. of the Institute for Risk Assessment Sciences, Netherlands, who authored 33 publications and garnered 3,261 total citations. From the same institution, Hoek, G., ranked second with 27 publications and 2,043 citations. Although third in publication count, Lurmann, F. of Sonoma Technology, Inc. (United States) authored 24 documents, received the second-highest number of citations (2,602), and achieved the highest average citations per publication (108.42). This highlights his substantial research influence and quality of work.

Table 6. Most productive authors

Author Name	Affiliation	Country	TP (%)	NCP	TC	C/P	C/CP	h	g
Brunekreef, B.	Institute for Risk Assessment Sciences	Netherlands	33 (2.08)	33	3261	98.82	98.82	23	33
Hoek, G.	Institute for Risk Assessment Sciences	Netherlands	27 (1.70)	26	2043	75.67	78.58	20	27
Lurmann, F.	Sonoma Technology, Inc.	United States	24 (1.51)	24	2602	108.42	108.42	20	24
Dong, G.H.	Sun Yat-Sen University	China	21 (1.32)	21	817	38.90	38.90	16	21
Sunyer, J.	Instituto de Salud Global de Barcelona	Barcelona	21 (1.32)	21	1790	85.24	85.24	19	21
Torres-Jardón, R.	Universidad Nacional Autónoma de México	Mexico	20 (1.26)	16	3160	158.00	197.50	16	20
Calderón-Garcidueñas, L.	University of Montana	United States	19 (1.19)	16	2726	143.47	170.38	15	19
Berhane, K.	Mailman School of Public Health	United States	18 (1.13)	18	2177	120.94	120.94	16	18

Table 6. Continued

Author Name	Affiliation	Country	TP (%)	NCP	TC	C/P	C/CP	h	g
Gilliland, F.D.	Keck School of Medicine of USC	United States	16 (1.01)	16	1017	63.56	63.56	14	16
Heinrich, J.	Ludwig-Maximilians-Universität München	Germany	16 (1.01)	16	2179	136.19	136.19	13	16
Jalaludin, J.	Universiti Putra Malaysia	Malaysia	15 (0.94)	14	172	11.47	12.29	8	13
Schwartz, J.	Harvard T.H. Chan School of Public Health	United States	15 (0.94)	15	2110	140.67	140.67	14	15
McConnell, R.	Keck School of Medicine of USC	United States	14 (0.88)	14	2027	144.79	144.79	13	14
Lu, C.	Central South University	China	13 (0.82)	9	491	37.77	54.56	8	13
Nawrot, T.S.	KU Leuven	Belgium	13 (0.82)	13	428	32.92	32.92	10	13
Shima, M.	Hyogo Medical University	Japan	13 (0.82)	12	368	28.31	30.67	10	13

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

Publication by number of author

Table 7 indicates that research in this field is typically collaborative. The highest proportion of publications was authored by three authors, accounting for 12.96%, followed by those with five authors (11.13%), and four authors (11.01%). The maximum number of authors for a single publication was 72 authors (0.06%), emphasizing large, multidisciplinary research teams in the study.

Table 7. Number of author(s) per document

Row Labels	TP	Percentage
1	136	8.55%
2	155	9.75%
3	206	12.96%
4	175	11.01%
5	177	11.13%
6	156	9.81%
7	121	7.61%
8	86	5.41%
9	80	5.03%
10	74	4.65%
11	50	3.14%
12	39	2.45%
13	32	2.01%
14	24	1.51%
15	16	1.01%
16	8	0.50%
17	5	0.31%
18	7	0.44%
19	2	0.13%
20	4	0.25%
21	1	0.06%
22	2	0.13%
23	5	0.31%
24	2	0.13%
25	1	0.06%
27	3	0.19%
28	1	0.06%
34	1	0.06%
35	1	0.06%
36	1	0.06%
43	1	0.06%
47	2	0.13%
49	1	0.06%
72	1	0.06%
0*	14	0.88%
Grand Total	1590	100.00%

Publications by institutions

Table 8 highlights the fifteen most productive institutions in this field, each with a minimum of five publications. Leading the list is the Harvard T.H. Chan School of Public Health from the United States, with 53 publications. This institution also ranks highest in several key metrics, including the number of cited publications (49), total citations (3,674), h-index (31), and g-index (53). Other high-performing institutions are University of Southern California (47 publications), Keck School of Medicine of USC (44 publications), and Icahn School of Medicine at Mount Sinai (34 publications). These data confirm that the United States institutions leading in air quality and children's health research.

Table 8. Most productive institutions with minimum of five publications

Institution	TP	Country	NCP	TC	C/P	C/CP	h	g
Harvard T.H. Chan School of Public Health	53	United States	49	3674	69.32	74.98	31	53
University of Southern California	47	United States	46	3104	66.04	67.48	31	47
Keck School of Medicine of USC	44	United States	43	3281	74.57	76.30	28	44
Icahn School of Medicine at Mount Sinai	34	United States	30	1880	55.29	62.67	19	34
University of California, Berkeley	33	United States	33	3605	109.24	109.24	21	33
Universitat Pompeu Fabra Barcelona	33	Spain	30	2063	62.52	68.77	22	33
Centro de Investigación Biomédica en Red de Epidemiología y Salud Pública	33	Spain	30	2040	61.82	68.00	22	33
Instituto de Salud Global de Barcelona	33	Spain	30	2267	68.70	75.57	22	33
Columbia University	30	United States	28	1839	61.30	65.68	19	30
Sonoma Technology, Inc.	29	United States	29	2410	83.10	83.10	24	29
University of California, San Francisco	29	United States	28	1187	40.93	42.39	16	29
University of Washington	27	United States	26	1104	40.89	42.46	17	27
Sun Yat-Sen University	27	China	26	801	29.67	30.81	17	27
University of Montana	25	United States	19	3231	129.24	170.05	18	25
UCSF School of Medicine	25	United States	24	1160	46.40	48.33	15	25

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

Publications by countries

Table 9 presents the top 20 countries contributing to research on air quality and children's health. The United States ranks first with the highest number of total publications (467), cited publications (425), total citations (27,252), h-index (89), and g-index (146), significantly outperforming other nations. This underscores the dominant role of the United States in advancing global knowledge in this field. China is in second place with 170 publications and 4365 citations, indicating a growing body of research despite lower average citations per paper. The United Kingdom ranked third, contributing 113 total publications and 5578 citations. Despite being ranked 14th with only 45 publications, Mexico recorded the highest average citations per publication (115.49) and average citations per cited publication (140.46), reflecting the substantial impact of its research.

Table 9. Top 20 countries contributed to the publications

Country	TP	NCP	TC	C/P	C/CP	h	g
United States	467	425	27252	58.36	64.12	89	146
China	170	150	4365	25.68	29.10	41	59
United Kingdom	113	104	5578	49.36	53.63	38	73
Canada	84	78	4021	47.87	51.55	31	63
Australia	72	66	2903	40.32	43.98	30	53
Germany	69	59	3562	51.62	60.37	26	59
Netherlands	67	63	4607	68.76	73.13	34	67
Italy	63	57	1928	30.60	33.82	27	43
Japan	56	45	1061	18.95	23.58	21	31
France	54	47	1882	34.85	40.04	22	43
India	51	42	1501	29.43	35.74	21	38
Spain	48	43	2586	53.88	60.14	24	48
Taiwan	46	40	1001	21.76	25.03	18	31
Mexico	45	37	5197	115.49	140.46	29	45
Sweden	45	42	2857	63.49	68.02	24	45
Poland	37	32	610	16.49	19.06	13	24
Switzerland	34	32	1584	46.59	49.50	17	34
South Korea	31	27	784	25.29	29.04	17	28
Hong Kong	30	27	1124	37.47	41.63	19	30
Denmark	27	25	946	35.04	37.84	14	27
Brazil	25	23	951	38.04	41.35	13	25
Belgium	24	22	729	30.38	33.14	15	24
Iran	21	19	568	27.05	29.89	11	21
Malaysia	20	18	289	14.45	16.06	9	16
Norway	19	16	368	19.37	23.00	9	19

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

Fig. 3 visually represents the global distribution of publications on air quality and children's health. The pink-shaded region highlights the United States, which leads with the highest number of publications. The yellow region marks China, ranking second, while the United Kingdom is depicted as the third highest contributor in terms of publication volume.

Publications by source titles

20 most active source titles can be seen in Table 10. Environmental Research recorded the highest total publications, totalling 80 publications, far higher than other sources. This confirms its role as a major platform for disseminating research in this field. The American Journal of Respiratory and Critical Care Medicine which rank 7th with 32 total publications, but had a higher cite score (27.3), SJR 2023 (5.336) and SNIP 2023 (3.577) than other sources. This suggests that its papers receive substantial attention and citations. The European Respiratory Journal, ranked 19th with total 15 publications, had the highest cite score (27.5) with SJR 2023 and SNIP 2023, 3.81 and 2.833, respectively. This highlights its strong influence despite lower output. Archives of Environmental Health appears in top 20 despite being discontinued in Scopus in 20024. Although the impact metrics are not available, its historical inclusion reflect the foundational nature of early research published under that title. These results show that although volume contributes to visibility, impact is strongly shaped by journal prestige and audience reach. High impact journals play a key role in shaping the direction and credibility of the field, despite with fewer articles.

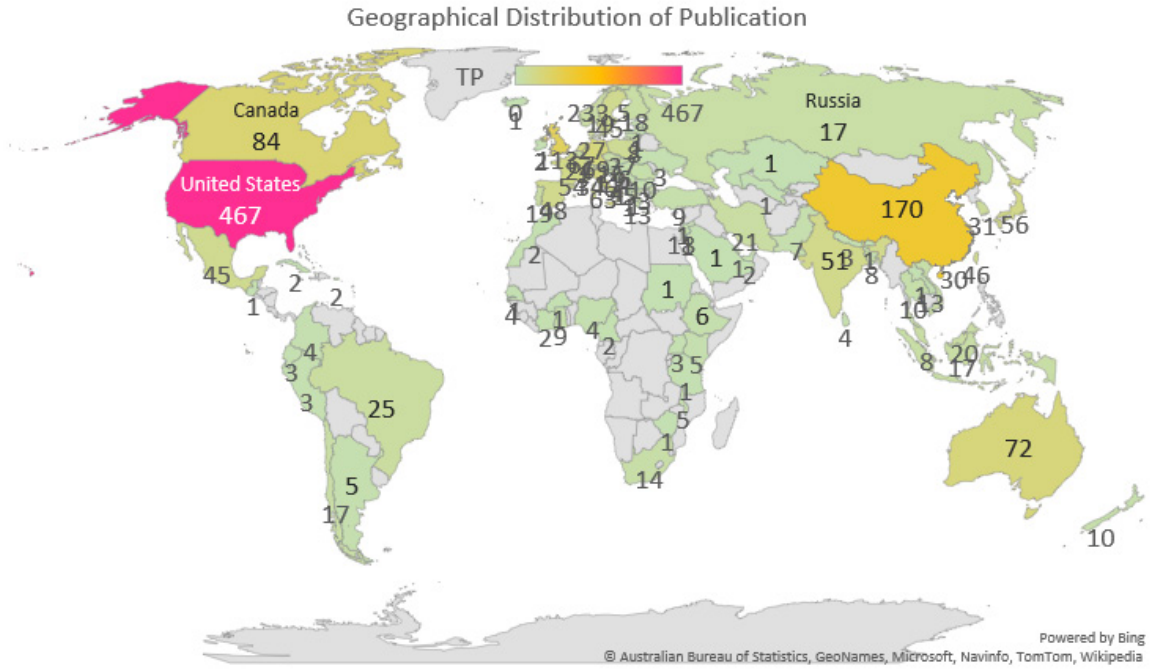

Fig. 3. Worldwide scientific production indexed by Scopus on air quality and children's health

Table 10. Most active source titles

Source Title	TP	Publisher	Cite Score	SJR 2023	SNIP 2023
Environmental Research	80	Elsevier	12.6	1.679	1.496
Gigiena I Sanitariia	55	F.F. Erisman Federal Research Center for Hygiene	0.8	0.238	0.339
Environmental Health Perspectives	48	Public Health Services, US Dept of Health and Human Services	14.4	2.525	2.154
International Journal of Environmental Research and Public Health	46	Multidisciplinary Digital Publishing Institute (MDPI)	7.3	0.808	1.077
Environment International	43	Elsevier	21.9	3.015	2.312
Science of the Total Environment	36	Elsevier	17.6	1.998	1.82
American Journal of Respiratory and Critical Care Medicine	32	American Thoracic Society	27.3	5.336	3.577
Environmental Pollution	22	Elsevier	16	2.132	1.554
Archives Of Environmental Health	19	Taylor & Francis			
Epidemiology	19	Wolters Kluwer Health	6.7	0.655	1.313
Environmental Science and Pollution Research	18	Springer Nature	8.7	1.006	1.141
Indoor Air	18	Hindawi	10.8	0.997	1.257
Pediatrics	18	American Academy of Pediatrics	12.8	2.437	2.389
Plos One	18	Public Library of Science	6.2	0.839	1.084
Atmospheric Environment	17	Elsevier	9.4	1.169	1.158
Environmental Health a Global Access Science Source	16	Springer Nature	10.1	1.228	1.348
European Respiratory Review	16	European Respiratory Society	14.4	2.893	2.633
International Journal of Hygiene and Environmental Health	16	Elsevier	11.5	1.211	1.415
European Respiratory Journal	15	European Respiratory Society	27.5	3.81	2.833
Pediatric Pulmonology	15	John Wiley & Sons	6	0.907	0.858

Notes: TP=total number of publications; TC=total citations; CiteScore = average citations received per document published in the source title; SJR = SCImago Journal Rank measures weighted citations received by the source title; SNIP = source normalised impact per paper measures actual citations received relative to citations expected for the source title's subject field.

Highly cited documents

Table 11 shows the top 20 highly cited articles conducted on air pollution and its impact on children's health. The article by Calderón-Garcidueñas et al. (2008) is the most cited article with 779 citations and an annual citation rate of 48.69 [17]. This article is a landmark study in the field, highlighting the neurological effects of chronic air pollution exposure in children and continuing to serve as a foundational reference for neuroinflammation and cognitive re-search. Smith et al. (2000) ranks second with 668 citations, maintaining a citation rate of 27.83 per year [18]. This article plays a critical role in linking indoor air pollution to acute lower respiratory infections among children, contributing to both academic understanding and policy interventions. The top three rank article by Chay & Greenstone (2003) had a total citation of 651 and a citation rate 31 per year [19]. The article examines the relationship between air pollution and infant mortality using economic shock data that provide evidence of pollution's severe public health impact. Sunyer et al. (2015) at rank 10th however had second high-est citation rate per year (46.22) [20], emphasizing the growing focus on cognitive develop-ment in children. Their study supported an emerging research domain that investigates learn-ing and behavioural effects of environmental exposures. Overall, these articles reflect the di-versity of topics in the field from respiratory outcomes, cognitive function, neurological dam-age, and infant mortality. The citation patterns show both historical milestones and evolving frontiers in air pollution research focuses on children's health.

Table 11. Top 20 highly cited articles

Author(s)	Title	TC	C/Y
Calderón-Garcidueñas et al., 2008	Long-term air pollution exposure is associated with neuroinflammation, an altered innate immune response, disruption of the blood-brain barrier, ultrafine particulate deposition, and accumulation of amyloid β-42 and α-synuclein in children and young adults [17].	779	48.69
Smith et al., 2000	Indoor air pollution in developing countries and acute lower respiratory infections in children [18].	668	27.83
Chay & Greenstone, 2003	The impact of air pollution on infant mortality: Evidence from geographic variation in pollution shocks induced by a recession [19].	651	31
Brauer et al., 2002	Air pollution from traffic and the development of respiratory infections and asthmatic and allergic symptoms in children [21].	562	25.55
Schwartz, 2004	Air Pollution and Children's Health [22].	536	26.8
Brunekreef et al., 1997	Air pollution from truck traffic and lung function in children living near motorways [23].	533	19.74
Morgenstern et al., 2008	Atopic diseases, allergic sensitization, and exposure to traffic-related air pollution in children [24].	464	29
Calderón-Garcidueñas et al., 2008	Air pollution, cognitive deficits and brain abnormalities: A pilot study with children and dogs [25].	457	28.56

Table 11. Continued

Author(s)	Title	TC	C/Y
Dherani et al., 2008	Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: A systematic review and meta-analysis [26].	440	27.5
Sunyer et al., 2015	Association between Traffic-Related Air Pollution in Schools and Cognitive Development in Primary School Children: A Prospective Cohort Study [20].	416	46.22
Currie & Neidell, 2005	Air pollution and infant health: What can we learn from California's recent experience? [27].	390	20.53
Gauderman et al., 2000	Association between air pollution and lung function growth in southern California children [28].	370	15.42
Kim et al., 2004	Traffic-related air pollution near busy roads: The East Bay Children's Respiratory Health Study [29].	365	18.25
Woodruff et al., 1997	The relationship between selected causes of postneonatal infant mortality and particulate air pollution in the United States [30].	327	12.11
Gehring et al., 2013	Air pollution exposure and lung function in children: The ESCAPE project [31].	326	29.64
Orellano et al., 2017	Effect of outdoor air pollution on asthma exacerbations in children and adults: Systematic review and multilevel meta-analysis [32].	315	45
Gauderman et al., 2002	Association between air pollution and lung function growth in Southern California children: Results from a second cohort [33].	308	14
Barnett et al., 2005	Air pollution and child respiratory health: A case-crossover study in Australia and New Zealand [34].	307	16.16
Tanaka, 2015	Environmental regulations on air pollution in China and their impact on infant mortality [35].	306	34
Currie, Neidell, & Schmieder, 2009	Air pollution and infant health: Lessons from New Jersey [36].	300	20

Top keywords

Top 20 keywords used in the publications are shown in Table 12 below. The most frequent keywords used is human which is found in 1250 (78.62%) publications, followed by air pollution (75.60%), and child (68.74%). This reflects the central research themes of human health and children vulnerability to air pollution. Specific pollutants like particulate matter and nitrogen dioxide are highlighted in 37.61% and 25.03% of the publications, highlighting the specific pollutants most frequently examined in the research.

Table 12. Top keywords

Keywords	TP	%
Human	1250	78.62%
Air Pollution	1202	75.60%
Child	1093	68.74%
Article	962	60.50%
Female	814	51.19%
Male	761	47.86%
Particulate Matter	598	37.61%
Air Pollutant	595	37.42%
Environmental Exposure	562	35.35%
Major Clinical Study	450	28.30%
Priority Journal	415	26.10%
Nitrogen Dioxide	398	25.03%
Preschool Child	391	24.59%
Asthma	382	24.03%
Child Health	372	23.40%
Controlled Study	371	23.33%
Adolescent	360	22.64%
Child, Preschool	350	22.01%
Infant	336	21.13%
Atmospheric Pollution	330	20.75%

Co-authorship analysis

Co-authorship by author

Fig. 4 presents a co-authorship network that illustrates the collaborative relationships among researchers in air pollution and children's health. In this visualization, each node represents an author, and the links connecting them indicate a co-authorship on a publication. The size of each node is proportional to the author's number of publications, signifying their productivity. The colors group authors into distinct clusters, highlighting communities that collaborate frequently with each other.

To ensure the visualization's clarity, a threshold was applied: of the 6,719 authors in the dataset, only the 151 who had authored a minimum of five documents are displayed. The network reveals several large, dense clusters. For example, Bert Brunekreef (purple cluster) and Jordi Sunyer (green cluster) appear as central hubs, indicated by their large node sizes and high number of connections. This suggests they are highly influential figures within extensive collaborative networks. Similarly, Donghui and Joel Swartz are central to the brown and red clusters, respectively. Links between these different colored clusters signify cross-collaboration between research groups. In contrast, smaller and more isolated clusters, such as the one containing Lyndsey A. Darrow, likely represent more specialized research topics or teams with fewer collaborations outside their core group. Overall, the network reveals a densely connected group of researchers collaborating across institutions and countries, particularly sharing interest in children environmental health.

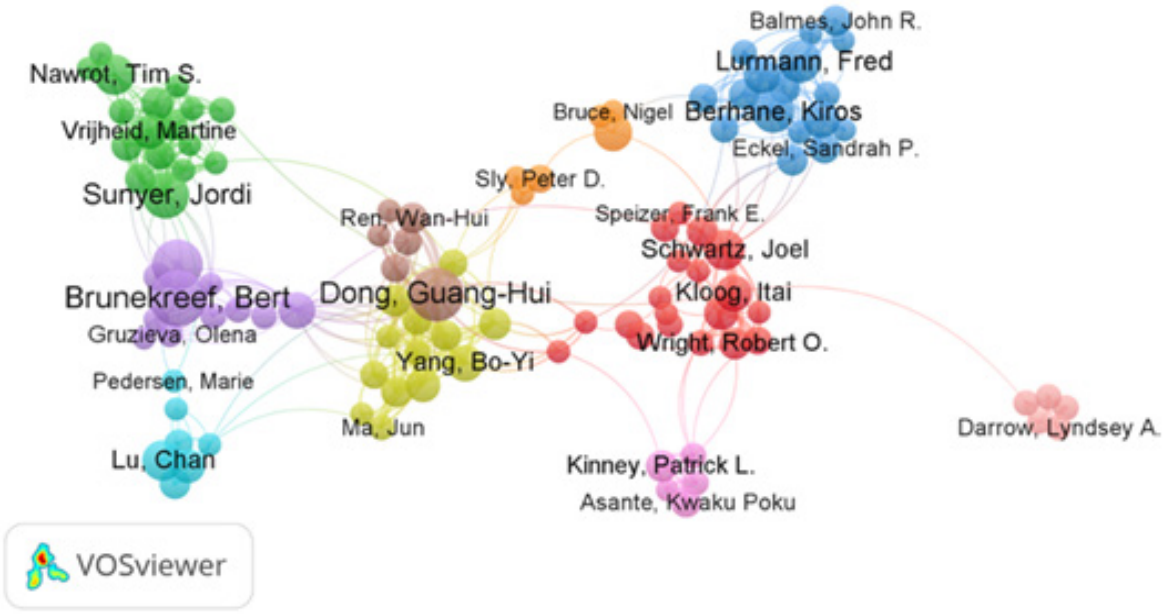

Fig. 4. Network visualisation map of the co-authorship by authors

Co-authorship by countries

The network visualization map in Fig. 5 depicts co-authorship relationships among countries, highlighting the structure of international collaboration in air pollution and children's health research. A minimum of five documents per country was set as the selection criterion; of 136 countries, 54 met this threshold. The map reveals a highly interconnected web, which is critical for advancing research by facilitating the exchange of diverse datasets, harmonizing methodologies, and enabling large-scale analyses that no single country could conduct alone.

The United States and China are central nodes, reflecting their prominent roles as hubs for research partnerships. This centrality allows them to drive global research agendas and synthesize findings from various geographic and demographic contexts, leading to more robust and generalizable conclusions. Strong regional clusters, such as among European countries (United Kingdom, Spain, Italy) and East Asian countries (Japan, South Korea, China), foster cooperation that is crucial for investigating region-specific pollution sources and genetic susceptibilities. Finally, the map highlights extensive cross-continental networks, which are vital for conducting powerful comparative studies. By comparing data from different continents, researchers can distinguish universal health effects from those influenced by local factors, thereby strengthening the evidence base for global health organizations like the WHO.

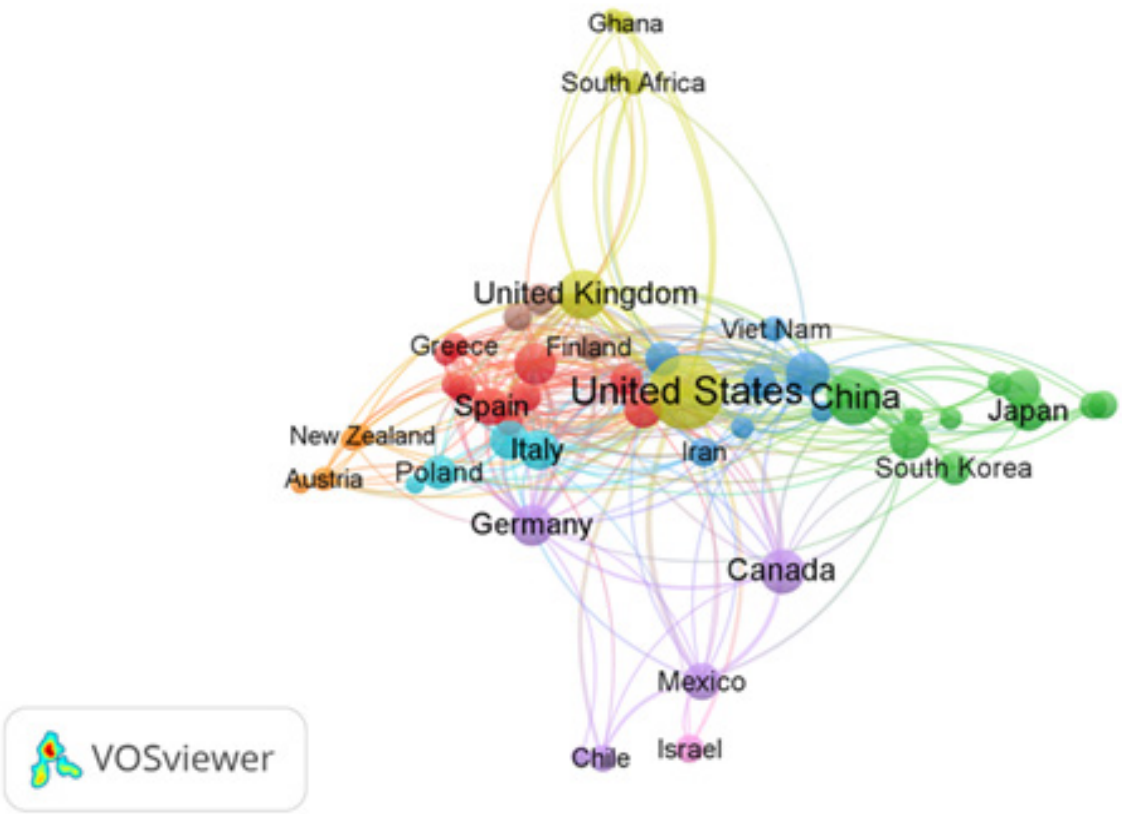

Fig. 5. Network visualisation map of the co-authorship by countries

Co-occurrence analysis

Co-occurrence analysis of author's keywords

The network visualisation of author's keywords is shown in Fig. 6. Minimum number of occurrences selected was 5. Of the 1860 keywords, 169 met the threshold in which there are 71 items under 5 clusters. Air pollution, children and asthma had the strongest link strength with other keywords. The central keyword, "air pollution", is connected to a wide range of related terms such as "asthma", "respiratory health", "$PM_{2.5}$", and "indoor air quality", indicating that these are major focus areas within the field. Clusters formed around specific topics, like "respiratory symptoms", "nitrogen dioxide", and "sulfur dioxide", show interconnected research themes, showing focus on specific pollutants and associated health effects. Terms like "biomass", "carbon monoxide", and "infant mortality" are also prominent, reflecting health concerns linked to specific pollutants. Keywords such as "meta-analysis" and "panel study" represent common research methodologies used to analyze exposure-response relationship. The map indicated a well-connected network of research topics with "air pollution" serving as the core focus, linking to various health outcomes, pollutants, and research methods.

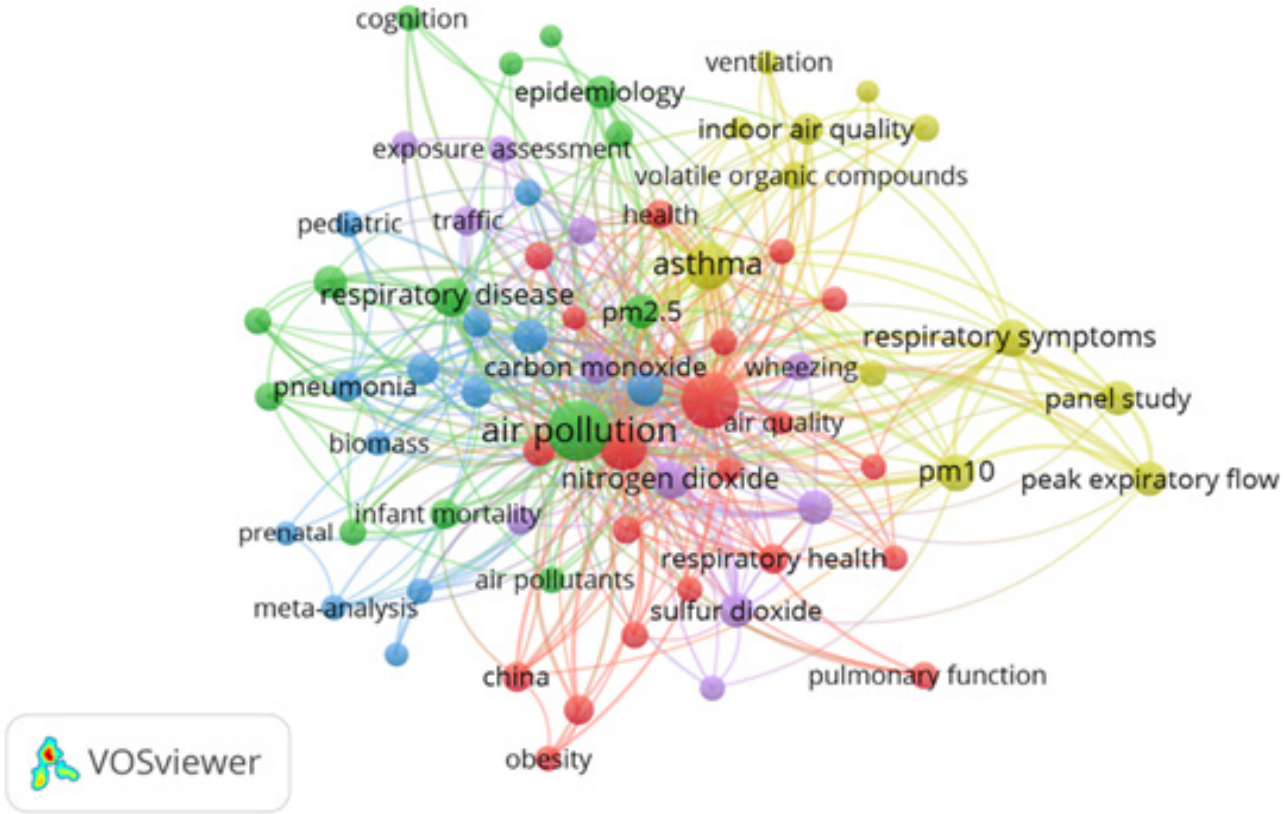

Fig. 6. Network visualisation of the author's keywords

Co-occurrence analysis of terms based on title and abstract

Minimum number of occurrences of a term is 15. Of the 24234 terms, 592 meet the threshold. There are 6 clusters that presents a term co-occurrence network related to studies on air pollution and health impacts on the children which can be seen in Fig. 7. The red cluster is centred around terms like "questionnaire", "indoor air quality", "respiratory health", "survey", "outdoor smoke" and "health status", suggesting research focused on observational and cross-sectional studies that focused on air quality exposure and respiratory outcomes. The blue cluster is centred around terms like "air pollution", "prevention", and "childhood", suggesting research addressing broad population level impacts and preventive measures for children. "Air pollution exposure", "birth", "preterm birth", and "trimester" are resolved in green cluster, indicating a focus on prenatal and perinatal exposure and developmental outcomes. Yellow clusters are prominent with terms "Sulfur dioxide (SO_2)", "short term effect", "weather", and "emergency department", linked to time-series and event-based studies. Finally, purple cluster is centred with terms "respiratory symptom", "peak expiratory flow", "winter", and "pollen", suggesting seasonal or allergen-related research. Terms like "lung function", "particle", and "respiratory health" appear as bridge terms that connect multiple clusters. These terms appear in multiple clusters that connect distinct thematic areas, indicating their relevance across a broader range of research topics within the field. They function as conceptual connectors that integrate findings across the field themes like pollutant-specific effects, methodological approaches, and population vulnerabilities.

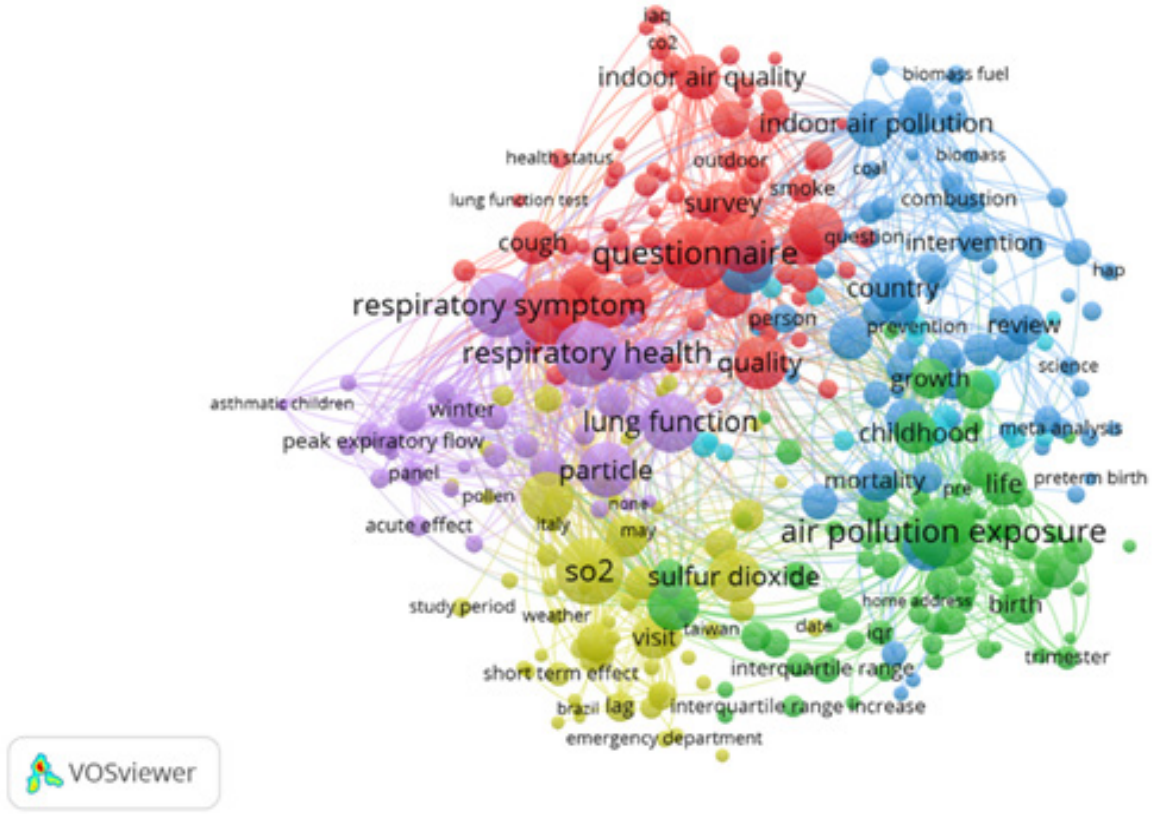

Fig. 7. Network visualisation of a term co-occurrence network based on title and abstract fields

Citation analysis

Citation analysis by documents

Fig. 8 shows a network visualisation map of the citation by documents. To visualize more meaningful citation strength by documents, 30 minimum number of citations of a document was selected, resulted in 415 documents connections. Using minimum cluster size of 10, there are 20 clusters developed. The red clusters encompass key papers by Brunekreef (1997), Romieau (1996), Janssen (2001), and Gehring (2013) which likely focusing on foundational research in pollution and health outcomes [23, 31, 37, 38]. The blue cluster includes studies by Smith (2000), Dherani (2008), Baumgatner (2011), and Currie (2005) [18, 26, 27, 39]. This cluster may be linked to socioeconomic factors and indoor air quality. Brauer (2002), Leon (2015), and Sunyer (2015) are included in green cluster which addressed childhood health and exposure to air pollution [20, 21, 40]. The yellow cluster further work by Thiering (2015) and Forns (2018) which might focus on newer research trends in air pollution's long-term impacts [41, 42]. Finally, the purple and orange clusters might represent interconnected but distinct research areas, possibly focusing on specific pollutants or health risks. Overall, the citation map provides insight into evolution and thematic depth of the field including citation-based connections among highly cited publications. It demonstrates the foundational influence of earlier studies and the emergence of new research in recent years.

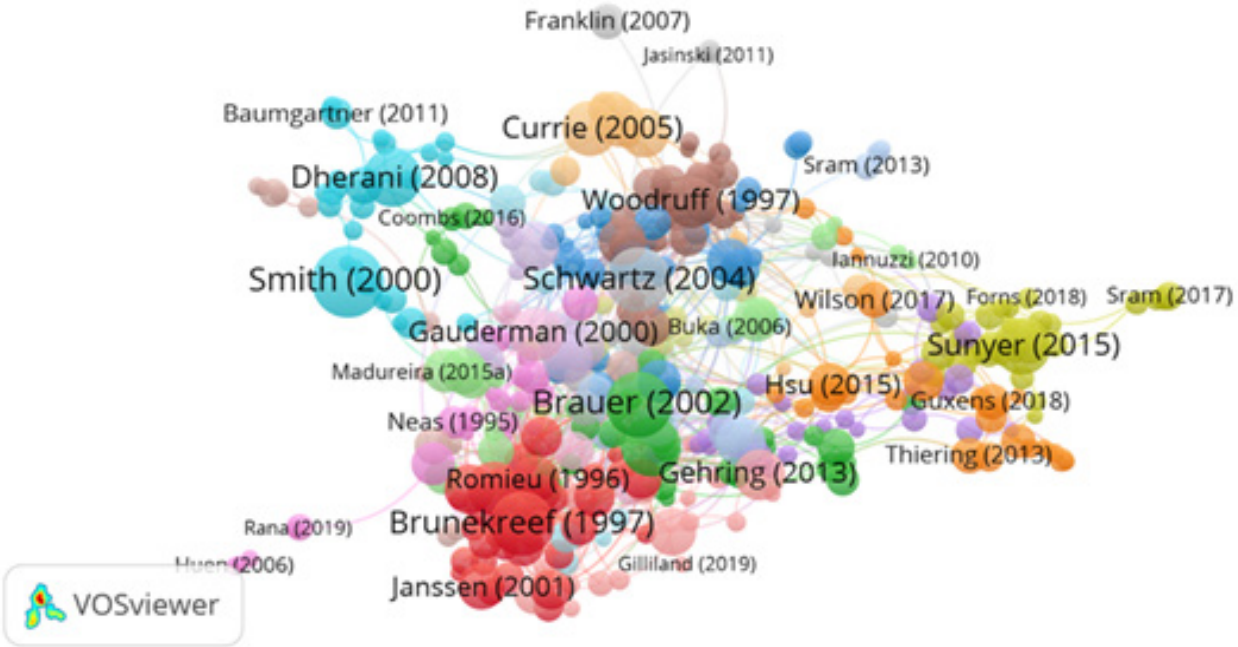

Fig. 8. Network visualisation map of the citation by documents

Citation analysis by sources

Fig. 9 shows the network visualisation map of citations by source titles, illustrating the journals with the highest influence in the field of air pollution and children's health. Minimum number of documents of a source selected was 5 with minimum number of citations 0. Of the 599 sources, 55 meet the threshold and 51 items were connected to each other. 3 clusters were observed from the analysis. Each cluster represents thematic alignment among sources. The red cluster includes major sources like the International Journal of Environmental Research and Public Health, Environmental Research, and proceedings from the 12th International Conference on Indoor Air Quality and Climate 2011. These sources are central to research on indoor air quality, environmental health, and public health impacts. The green cluster contains journals such as Pediatrics, BMJ Open, and the Archives of Environmental Health while the blue cluster includes sources like Environmental Epidemiology. Scientific Reports, and Ceskoslovenska Hygiena. This network highlights the interdisciplinary dissemination of findings, with citations linking environmental science journals to clinical and public health citations. The dominance helps guide researchers on where to publish impactful work.

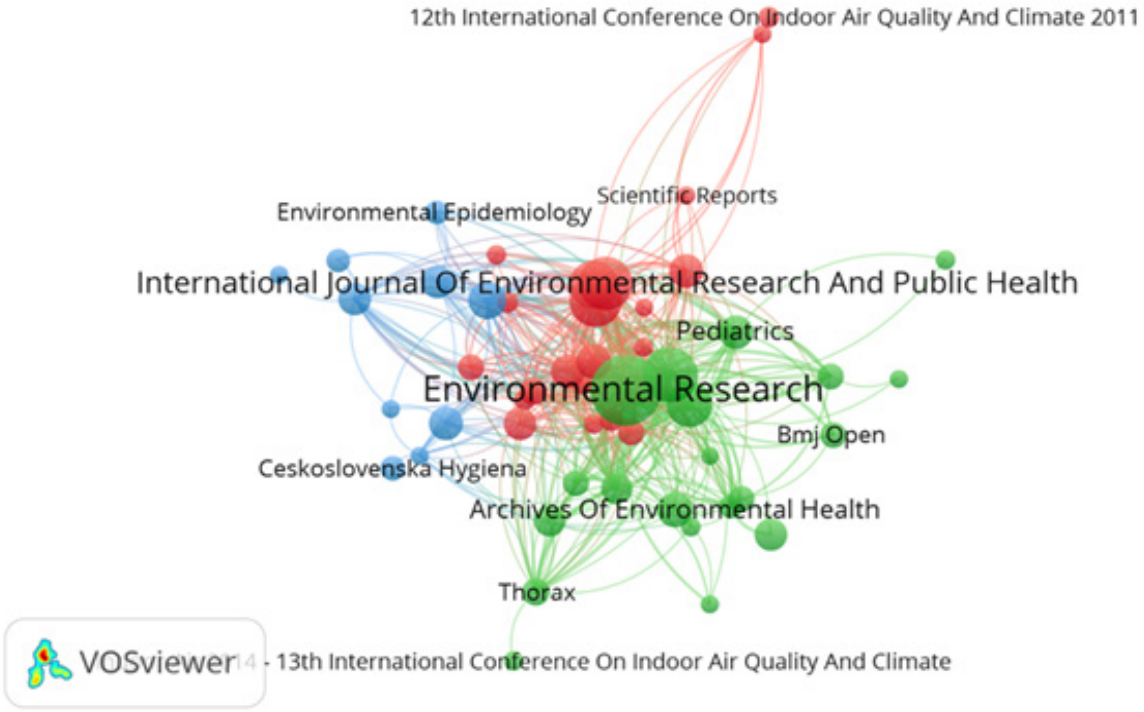

Fig. 9. Network visualisation map of the citation by source titles

Citation analysis by organisations

Fig. 10 shows a network visualisation map that illustrates the citation relationship among various organisations such as universities, departments and institutes based on their published works. Minimum number of documents by organisations selected was 5 with minimum number of citations of an organisation of 0. Of the 4831 organisations, 39 meet the thresholds. The links between the organisations shows the citation relationships where thicker and numerous links indicate stronger citation ties. University of Basel has the biggest node in red cluster which highlights it as a central institution in this research field. The extensive citation connections with other institutions highlight its significant influence and contribution. Department of Environmental Health and Department of Preventive Medicine in green cluster are shown to be strongly interconnected with other organisations indicating collaboration in the research themes. Sonoma Technology Inc. is a private entity which collaborates with other organisations in their respective fields. This suggests productive collaborations across academic and industry sectors. Overall, the citation network highlights the concentration of influential work among group of institutions and showcases the inter-organisational collaborations that shaped the current landscape of research in this field.

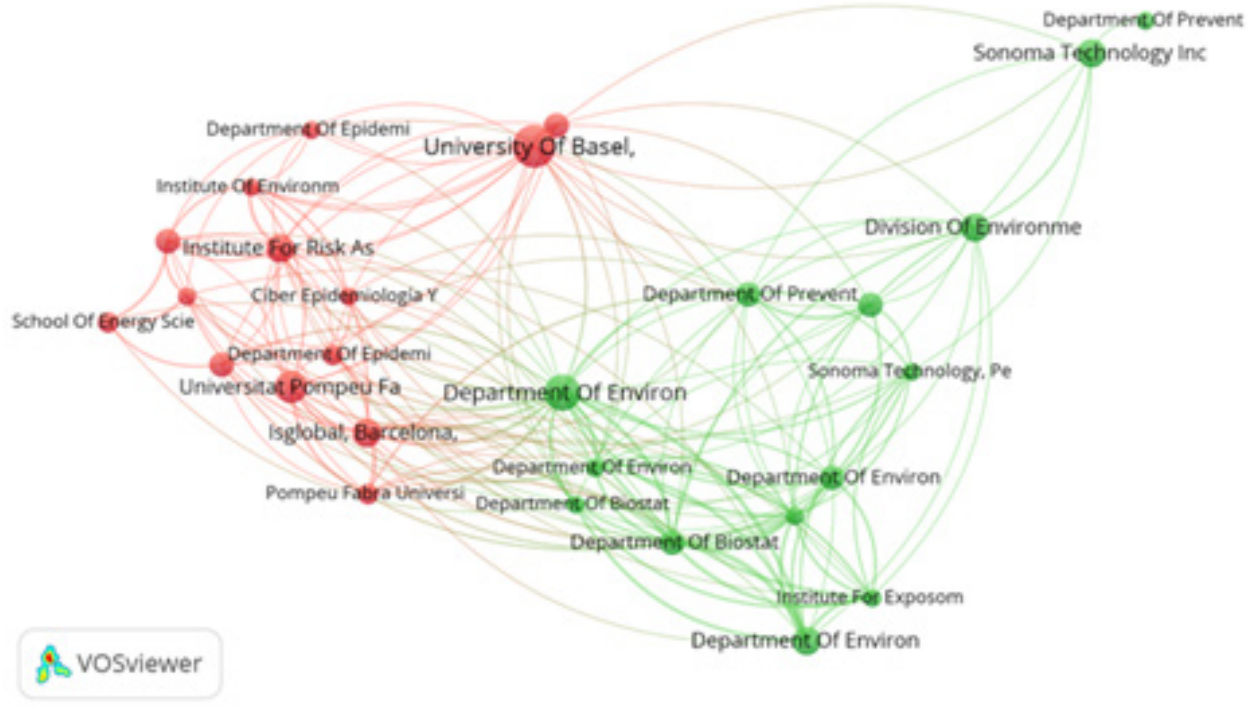

Fig. 10. Network visualisation map of the citation by organisations

Citation analysis by countries

Fig. 11 shows a network visualisation map of the citation by countries. Countries with larger nodes indicates a higher number of documents and citation. Minimum number of documents of a country selected was 5 with minimum number of citations of 0. Of the 136 countries, 54 meet the thresholds. In the red cluster, China, Switzerland, Italy, and Denmark had strong mutual citation links, highlighting regional collaborations and shared research focus areas in the field. The United States in green cluster has the largest node in the network, reflecting its dominant role in the field. The strong citation ties with countries like the United Kingdom, Canada and Australia which demonstrate its global influence and partnerships. The blue cluster although is relatively smaller includes countries like Turkey and Thailand, suggesting growing research contributions in this domain. Overall, this citation analysis emphasized the global and interconnected nature of research that contribute to the advancement of air pollution and children's field.

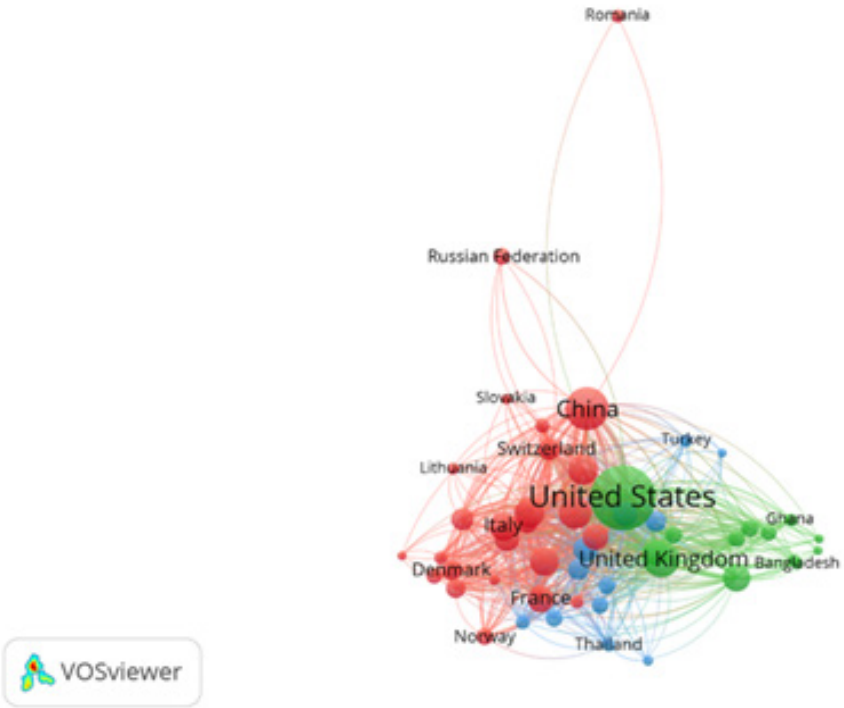

Fig. 11. Network visualisation map of the citation by countries

Research on air pollution and children's health has been continuously studied, showing not only growth of publication trends but also influence, collaboration, and emerging priorities. Since 1956, the field has growing substantially, reflecting an increasing global awareness of environmental health issues and the prioritization of children's vulnerability to air pollution. The trend analysis reveals that during the years, there has been a steady increase in the number of publications which reached a significant peak in 2021. This is likely as a result of increasing global awareness on environmental health matters. Citation metrics also show that old publications, particularly those from late 2000s and early 2010s have had higher citation impacts because they laid down critical foundations for the discipline. For instance, it is anticipated that recent publications' citations will be lower especially those of 2023 as these articles are still new and gradually accumulating academic recognition [16]. Interestingly, the year 2008 is remarkable due to having the most citations total. This implies that publications made in this period were enormously significant and probably indicate basic but highly important research works still being cited extensively today. Besides that, an upward trend in publications with substantial impacts was noted from 2008 according to the h-index and g-index values, which have continued to provide significant contributions to the field. The increase of these indices indicates continued increase in both quantity and quality of research, as some publications tend to become more influential over time.

Articles dominated, underscoring the academic preference for rapid, peer-reviewed dissemination. They are more common than other document types because early career researchers face pressure to publish more frequently to establish their reputation, with journal articles are more accessible than books [43]. The emphasis on rapid publication, performance-based research assessments, and the collaborative nature of research further drives the preference for journal articles over books, which take longer to produce and have less immediate impact [43]. Influential journal reinforces the dual narrative of volume and impact. International Journal of Environmental Research and Public Health, Environmental Research, Pediatrics, BMJ Open, and Archives of Environmental Health lead in research articles output. These journals provide key platforms for high-quality, peer-reviewed evidence on air pollution and children's health. The major use of English in publications also reflects global scientific norms, although other languages suggest regional engagement with localized research. Articles that are published in English will have higher number of citations than other languages due to English articles are accessible to larger audience [44]. While English as the global scientific language challenges non-native speakers, using native languages in publications is unlikely to advance their careers or scientific agendas [44].

The distribution across subject areas indicates interdisciplinary nature of air pollution and children's health research, with medicine and environmental science dominated the field. A bibliometric analysis on indoor air quality study similarly found environmental science to be dominant research area, after medicine [15, 16]. These findings indicate a strong focus on understanding both the health impacts and environmental factors related to air pollution. Sun et al. (2020) in their bibliometric analysis study also agreed that most papers on air pollution and children were found predominantly published in environmental journals, suggesting that researchers in this field should consider submitting their work to these journals [45]. Keyword co-occurrence

analysis confirms the interdisciplinary nature of this research domain including environmental science, public health and paediatric medicine. “Human”, “air pollution”, and “child” are the most frequent used keywords, reinforcing the central focus on how air pollution affects human health, particularly children. The prominence of health-related terms such as “asthma” and “respiratory health” indicates the field’s strong focus on respiratory outcomes in children due to air pollution. Specific pollutants such as “particulate matter” and “nitrogen dioxide” reflect the respiratory impacts of air pollutants. Additionally, keywords like “meta-analysis" and “panel study” indicates a growing reliance on robust, data-intensive research designs. These findings suggest that the field is growing toward stronger causal inference and evidence based, supporting more effective policy development and intervention strategies.

Influential publications continue to shape the trajectory of the field. High impact articles by Calderón-Garcidueñas et al. (2008), Smith et al. (2000), and Sunyer et al. (2015) reflect thematic shifts from acute respiratory conditions to chronic developmental and neurological effects from long-term air pollution exposure on children. The findings also span a wide range of air pollution topics, including lung function growth, and cognitive developmental impacts [17, 18, 20].

Author and institutional productivity reveal a concentration of expertise in a few leading countries and organizations. Brunekreef, B., Hoek, G., and Lurmann, F. stand out for both output and citation influence, indicating their prominent influence in the field [23, 46, 47]. The Harvard T. H. Chan School of Public School, the University of Southern California, and Keck School of Medicine of USC emerged as research hubs on air pollution and children’s health. Interestingly, the majority of influential institutions are based in the United States, showcasing the country’s dominance in the research area. While countries like the United States, China, and the United Kingdom dominate in publication volume, countries like Mexico, Germany, Netherlands, Sweden, and Spain demonstrate high average citations per cited publication, emphasizing their influence within the research community.

International co-authorship and citation networks indicate a highly collaborative global community. Visualizations highlight the central roles of the United States, China, and European countries in fostering partnerships. These networks facilitate data sharing, methodological harmonization, and ensure broader applicability of findings across diverse socio-environmental contexts.

The field of air pollution and children’s health is likely to see continued growth in research output. Increasing attention to prenatal and early childhood exposures are likely to contribute to deeper insights of the field. The findings of this bibliometric analysis suggest that future research will benefit from a more integrated approach, bridging disciplines, countries and data sources to address the multifactorial risks air pollution poses to children’s health.

Conclusion

This bibliometric analysis underscores the steady evolution and growing importance of research on air pollution and children’s health. Since its emergence in 1956, the field has expanded significantly, particularly from 2008 onward, reflecting rising global concern over environmental health and the vulnerability of children. The steady increase in publication volume, peaking in 2021, highlights both intensified scientific interest

and the urgency of the issue. Research output is predominantly disseminated through peer-reviewed journal articles, reinforcing the academic preference for timely and accessible scientific communication. English remains the dominant language, enhancing global reach, though regional contributions in other languages remain valuable. The field is deeply interdisciplinary, with medicine and environmental science leading contributions, supported by strong public health, social science, and methodological foundations. Keyword analyses emphasize a consistent focus on respiratory and neurodevelopmental outcomes linked to specific pollutants such as particulate matter and nitrogen dioxide. Influential authors, institutions, and journals especially those based in the United States, China, and the United Kingdom play central roles in shaping the field. Citation patterns reveal the enduring impact of foundational studies, while emerging research increasingly adopts robust analytical methods like meta-analyses and longitudinal studies. International collaborations are well-established, fostering global data integration and knowledge exchange. As the research landscape continues to mature, future investigations are expected to focus on prenatal and early life exposures, long-term cognitive effects, and cross-disciplinary solutions. Strengthening international partnerships and methodological rigor will be essential in developing effective interventions and informing policies aimed at safeguarding children's health in the face of ongoing air pollution challenges.

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Competing interests

The authors declares that there is no conflict of interest associated with the research presented in the submitted manuscript. All authors affirm that they have no financial, personal, or professional interests that could be construed as influencing the content of the article. The authors have complied with ethical standards and transparency in reporting any potential conflicts of interest.

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Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely ob-served by the authors.

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