Systemic Review

Publication trends in research on particulate matter and health impact over a 10-year period: 2009–2018

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Abstract

Exposure to ambient particulate matter is a major health risk factor for numerous diseases, including those of the cardiovascular and respiratory varieties. The aim of this study was to estimate the latest global research activities regarding particulate matter and health impact. We performed a bibliometric analysis of this field's scientific publication trends over a decade (2009–2018). Publications were retrieved from the Scopus and Web of Science databases using the search terms "particulate matter," "fine particulate matter," "health impact," and their synonyms. The literature on health impact in the research fields of particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$) trended to significantly increase over the decade in consideration. It appears to have been led by researchers of the United States and China. Worldwide research on particulate matter and health effects has focused primarily on respiratory and cardiovascular diseases. The precursors to and components of particulate matter (such as nitrogen dioxide, polycyclic aromatic hydrocarbon, sulfur dioxide, and black carbon) were also popular research topics in this field. Research on children, older adults, and pregnant women, who are most vulnerable to the health effects of air pollution, has increased dramatically over the past 10 years. Our findings provide the information necessary to predict unmet research topics and future research needs.

Introduction

Particulate matter in which 50% of the particles have an aerodynamic diameter lower than 10 μm—PM_{10}—is a major outdoor air pollutant [1]. Its detrimental effects include causing or worsening various diseases, including those of the cardiovascular and respiratory varieties [2]. Fine particulate matter with particulate size less than 2.5 μm ($PM_{2.5}$) is more harmful to health than PM_{10} [3]. As per the Global Burden of Diseases Study 2015, long-term exposure to ambient $PM_{2.5}$ was the fifth leading worldwide cause of mortality, responsible for 4.2 million deaths (95% uncertainty interval [UI] 3.7–4.8 million) [4].

Children, older adults, and pregnant women are especially vulnerable to the health effects of air pollution [5-7]. PM_{10} [8,9] and $PM_{2.5}$ [8,10,11] have been shown to be associated with the development and worsening of asthma in about 10% of children worldwide. In the context of older adults, studies have reported a relationship between $PM_{2.5}$ exposure and increased premature mortality rates [12,13]. Further, $PM_{2.5}$ exposure during pregnancy is said to be associated with low birth weight and preterm birth [14], as well as the development of asthma at six years of age in boys [15].

Bibliometric analysis is a statistical method for analyzing research trends in a given domain, useful for comparing the contributions of countries, institutions, and journals [16]. While bibliometric studies on $PM_{2.5}$ [17] and air pollution and human health [18] have been reported, particulate matter and its health impact has not yet been the subject of such analysis. Therefore, this study aims to analyze research trends and keywords regarding the particulate matter and associated health impacts over a 10-year period (2009–2018).

Methods
Data sources and search strategy

The literature searches in Scopus and Web of Science (WoS) were performed on August 27 and September 4, 2019, respectively. The WoS database included the Science Citation Index Expanded and Emerging Sources Citation Index.

The search terms "particulate matter," "fine particulate matter," "health impact," and their synonyms were sought in the titles, abstracts, or keywords of studies available in the abovementioned databases. This study focuses only on journal articles; therefore, other document types (conference papers, reviews, notes, book chapters, conference reviews, errata, letters, short surveys, editorials, data papers, business articles, abstract reports, books, proceeding papers, meeting abstracts, editorial material, early access papers, corrections, news items, reprints, and retracted publications) were excluded.

The search process was as follows: publications on PM_{10} and $PM_{2.5}$ published from 2009 to 2018 were first retrieved from Scopus and WoS. Then, health impact-associated publications were extracted from the retrieved PM_{10} and $PM_{2.5}$-related publications. Subsequently, publications related to children, older adults, and pregnant women were retrieved from within the research field on $PM_{2.5}$ and health impacts on December 8, 2020. Data regarding retrieved articles, including subject area (research area), source title (journal), country or territory (location), and affiliation (organization) were downloaded from the databases. The data on research area, journal, and organization of the publications downloaded from WoS were analyzed using InCites, an online bibliometric analysis tool (http://incites.clarivate.com).

The key phrase analysis for particulate matter and health impact-related publications retrieved from Scopus was performed using SciVal, another online bibliometric analysis tool (https://www.scival.com) on December 8-9, 2020. It was possible to analyze the literature from only 2010 to 2018 using SciVal. Therefore, the research direction of the last 10 years was estimated using this data. Search terms and their synonyms were excluded in the top 15 keywords.

Statistical analysis

Linear regression analysis to assess publication trends in the time period of interest was conducted using SPSS version 18.0 (IBM Inc, Chicago, IL, USA). Statistical significance was set at $p < 0.05$.

Publication trends over 10 years

Using Scopus, we identified a total of 48,267 PM_{10}-related articles published from 2009 to 2018, of which 10,520 (21.8% of the total PM_{10}-related articles) concerned health impact (Figure 1). A total of 33,048 PM_{10}-related publications were retrieved from WoS, of which 9,738 (29.5%) were health impact-related. The overall number of health impact-oriented studies retrieved from Scopus (linear regression, correlation coefficient $(r) = 0.983$; $p < 0.001$) and WoS $(r = 0.965$; $p < 0.001$) increased at an annual average of 12.5% and 14.6%, respectively.

Of the 20,462 $PM_{2.5}$-related articles published between 2009 and 2018 retrieved from Scopus, 4,708 (23.0% of the total $PM_{2.5}$-related articles) were health impact-related. In WoS, of the 21,526 $PM_{2.5}$-related publications identified, 5,711 (26.5%) were health impact-related. The overall numbers of health impact-oriented studies retrieved from Scopus $(r = 0.955$; $p < 0.001$) and WoS $(r = 0.957$; $p < 0.001$) demonstrated an increasing annual trend over 10 years, with average rates of 16.7% and 19.0%, respectively. Among the number of publications on particulate matter (both PM_{10} and $PM_{2.5}$), the proportion of publications on health impact trended to increase every year.

Country, organization-stratified, and journal analyses

Furthermore, we analyzed the data on countries, institutions, and journals that have directed research on the health effects of particulate matter, focusing on the period during 2014-2018 to observe the recent trends. Researchers from more than 100 countries or territories (Scopus = 132; WoS = 109) published articles on PM_{10} and health impact between 2014 and 2018 (Figure 2). By country, the maximum volume was associated with the United States (Scopus = 2,362, 35.0% of all publications on PM_{10} and health impact; WoS = 2,409, 37.1%) and China (Scopus = 1,728, 25.6%; WoS = 1,747, 26.9%). Health impact-related publications from the United States and China alone accounted for more than 30% (Scopus = 32.1%; WOS = 38.7%) and 18% (Scopus = 18.7%; WoS = 27.9%) of all PM_{10}-related articles, respectively.

Approximately 100 countries or territories (Scopus = 103; WoS = 94) contributed to research related to $PM_{2.5}$ and its health impact between 2014 and 2018. By country, the maximum volume was associated with the United States (Scopus = 1,281, 38.2% of all publications on $PM_{2.5}$ and health impact; WoS = 1,654, 40.1%) and China (Scopus = 1,082, 32.3%; WoS = 1,311, 31.8%). Health impact-related publications from the United States and China alone represented about 40% (Scopus = 39.2%; WoS = 41.3%) and over 19% (Scopus = 19.1%; WoS = 25.1%) of all $PM_{2.5}$-related articles, respectively.

We also investigated the 10 organizations that published the most articles on PM_{10} and health impact between 2014 and 2018 (Table 1a). In Scopus, the Chinese Academy of Sciences had the highest number of articles (278, 4.1% of all publications on PM_{10} and health impact), followed by the Harvard School of Public Health (235, 3.5%) and Peking University (194, 2.9%). In WoS, Harvard University had the highest number of articles (389, 6.0%), followed by the University of California system (303, 4.7%) and Chinese Academy of Sciences (297, 4.6%).

Scopus

Web of Science

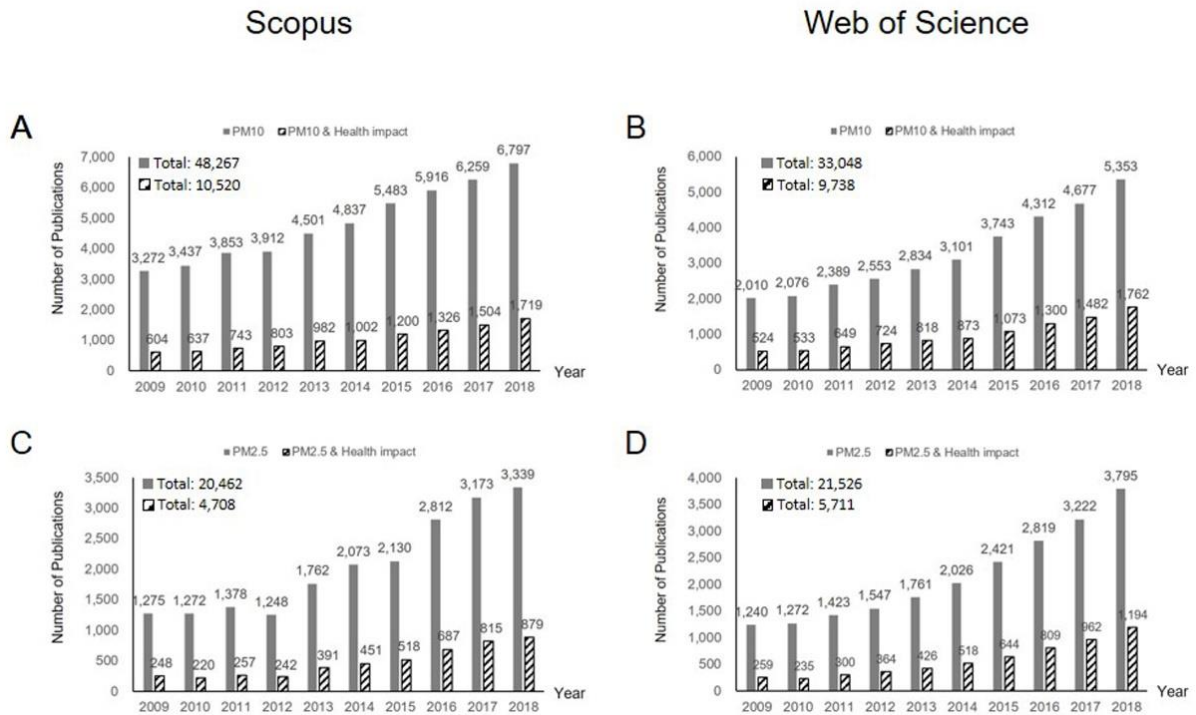Figure 1. Publication trends of research on particulate matter and health impact. (A, C): Scopus data; (B, D): Web of Science data.
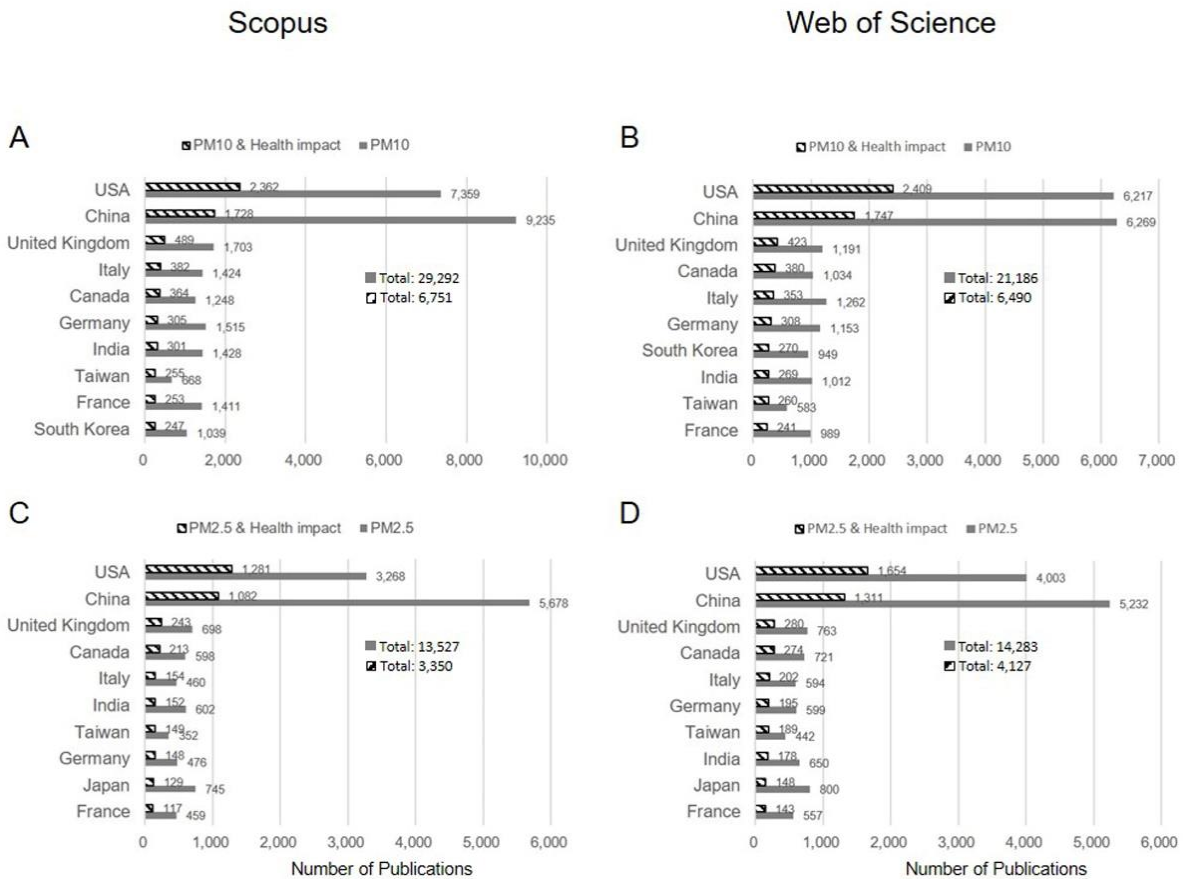
Scopus

Web of Science

Figure 2. Top 10 countries regarding publication contribution. (A, C): Scopus data; (B, D): Web of Science data.

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Table 1a. Top 10 organizations and journals regarding research on PM_{10} and health impact (2014–2018).

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Scopus database				Web of Science database			
Organization		Journal		Organization		Journal	
Total number of publications : 6,751				Total number of publications : 6,490			
Chinese Academy of Sciences	278	Science of the Total Environment	376	Harvard University	389	Science of the Total Environment	341
Harvard School of Public Health	235	Atmospheric Environment	281	University of California system	303	Atmospheric Environment	284
Peking University	194	Environmental Pollution	249	Chinese Academy of Sciences	297	International Journal of Environmental Research and Public Health	249
Ministry of Education China	173	Environmental Research	249	Harvard T.H. Chan School of Public Health	294	Environmental Pollution	245
United States Environmental Protection Agency	153	International Journal of Environmental Research and Public Health	244	Peking University	215	Environmental Research	235
Fudan University	148	Environment International	239	United States Environmental Protection Agency	189	Environment International	222
University of Washington, Seattle	131	Environmental Science and Pollution Research	189	Fudan University	154	Environmental Science and Pollution Research	203
Utrecht University	115	Environmental Health Perspectives	161	University of Washington Seattle	144	Environmental Health Perspectives	170
Tsinghua University	114	Environmental Science and Technology	158	University of Washington	144	Environmental Science & Technology	146
Swiss Tropical and Public Health Institute Swiss TPH	107	PLOS ONE	134	University of London	127	PLOS ONE	140

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5   Table 1b. Top 10 Organizations and journals regarding research on PM$_{2.5}$ and health impact (2014–2018).

Scopus database				Web of Science database			
Organization		Journal		Organization		Journal	
Chinese Academy of Sciences	179	Science of the Total Environment	173	Harvard University	254	Science of the Total Environment	205
Harvard School of Public Health	166	Atmospheric Environment	156	Chinese Academy of Sciences	223	Atmospheric Environment	201
Peking University	118	International Journal of Environmental Research And Public Health	142	University of California system	209	International Journal of Environmental Research and Public Health	184
Ministry of Education China	111	Environmental Research	141	Peking University	154	Environment International	179
Fudan University	94	Environment International	139	Harvard T.H. Chan School of Public Health	143	Environmental Pollution	179
United States Environmental Protection Agency	86	Environmental Pollution	139	United States Environmental Protection Agency	118	Environmental Research	161
University of Washington, Seattle	83	Environmental Health Perspectives	93	University of Washington Seattle	113	Environmental Health Perspectives	133
Tsinghua University	81	Environmental Science and Pollution Research	84	University of Washington	113	Environmental Science and Pollution Research	123
Emory University	72	Environmental Science And Technology	78	Fudan University	110	Environmental Science & Technology	110
Harvard Medical School	67	PLOS ONE	63	Tsinghua University	102	Aerosol and Air Quality Research	94

7   The 10 journals that published the most articles on particulate matter (PM$_{10}$ and PM$_{2.5}$) and health impact between
8 2014 and 2018 are presented in Table 1a. More than 30% (Scopus = 2,280, 33.8%; WoS = 2,235, 34.4%) of the articles on PM$_{10}$
9 and health impact were published in the top 10 journals. As per Scopus data, Science of the Total Environment (impact
10 factor = 5.589, 2018) was the most preferred journal (376, 5.6% of all publications on PM$_{10}$ and health impact), followed by
11 Atmospheric Environment (impact factor = 4.012, 2018) with 281 articles (4.2%), Environmental Pollution (impact factor =
12 5.714, 2018) with 249 articles (3.7%), and Environmental Research (impact factor = 5.026, 2018) with 249 articles. In WoS,
13 Science of the Total Environment was the most common journal (341, 5.3%), followed by Atmospheric Environment with
14 284 publications (4.4%) and International Journal of Environmental Research and Public Health (impact factor = 2.468, 2018)
15 with 249 publications (3.8%).
16   More than 35% (Scopus = 1,208, 36.1%; WoS = 1,569, 38.0%) of articles on PM$_{2.5}$ and health impact were published
17 in the top 10 journals (Table 1b). In both Scopus and WoS, Science of the Total Environment was the most preferred journal
18 (Scopus = 173, 5.2% of all publications on PM$_{2.5}$ and health impact; WoS = 205, 5.0%), followed by Atmospheric Environment
19 with 156 (4.7%) and 201 articles (4.9%), and International Journal of Environmental Research and Public Health with 142
20 (4.2%) and 184 articles (4.5%), respectively.

Keyword analyses

In order to identify directions and key themes in the research on particulate matter (PM$_{10}$ and PM$_{2.5}$) and health impact, we analyzed the top 15 keywords used in publications published between 2010 and 2018 available in Scopus. In PM$_{10}$–related articles, the most frequently used keyword was "mortality" (3,327, 33.2% of all publications on PM$_{10}$ and health impact) (Table 2 and Supplemental Figure 1). Disease-related terms such as "cardiovascular disease" (1,865, 18.6%), "asthma" (1,727, 17.2%), and "respiratory tract infection" (1,709, 17.0%) were ranked in the top 15. Air pollutant-related terms (such as "nitrogen dioxide", "polycyclic aromatic hydrocarbon", and "sulfur dioxide") were also included in the top 15.

In case of PM$_{2.5}$–related articles, the most frequently used keywords in these articles were "ozone" (895, 18.7% of all publications on PM$_{2.5}$ and health impact), followed by "asthma" (883, 18.4%) and "environmental exposure" (872, 18.2%) (Table 3 and Supplemental Figure 2). The terms "respiratory tract infection" (827, 17.3%), "chronic obstructive lung disease" (419, 8.7%), and "lung neoplasm" (354, 7.4%) were ranked 4th, 11th, and 15th, respectively. Air pollutant-related terms (such as "nitrogen dioxide", "polycyclic aromatic hydrocarbon", "exhaust gas" and "black carbon") and "indoor air pollution" were also included in the top 15.

PM$_{2.5}$ is more harmful to health than PM$_{10}$ [3]. Thus, the keyword analysis was conducted to identify key research topics especially in the United States and China, as they appear to have been leading the global research on the health effects of PM$_{2.5}$. Keywords used in PM$_{2.5}$ and health–related publications from the United States and China were compared. "Mortality" (438, 23.0%; 222, 16.7%), "respiratory tract infection" (193, 10.1%; 173, 13.0%), and "indoor air pollution" (174, 9.1%; 72, 5.4%) were the main keywords in publications from both countries. "Cardiovascular disease" (327, 17.2%), "asthma" (203, 10.7%), "ozone" (286, 15.0%), "nitrogen dioxide" (163, 8.6%), and "black carbon" (148, 7.8%) were the high-frequency keywords in publications from the United States but not China. "Polycyclic aromatic hydrocarbon" (111, 8.4%), "heavy metal" (91, 6.9%), "lung neoplasm" (91, 6.9%), and "chronic obstructive lung disease" (67, 5.0%) were highly frequent only in Chinese publications.

Table 2. Keyword analysis of articles on PM$_{10}$ and health impact (2000–2018).

Keywords	Count	%
Mortality	3,327	33.2
Cardiovascular Disease	1,865	18.6
Environmental Exposure	1,809	18.0
Ozone	1,789	17.8
Asthma	1,727	17.2
Respiratory Tract Infection	1,709	17.0
Exhaust Gas	1,535	15.3
Nitrogen Dioxide	1,463	14.6
Polycyclic Aromatic Hydrocarbon	1,274	12.7
Indoor Air Pollution	1,141	11.4
Sulfur Dioxide	1,095	10.9
Smoke	897	8.9
Time Series Analysis	876	8.7
Chronic Exposure	820	8.2
Beijing	722	7.2

Table 3. Keyword analysis of articles on PM$_{2.5}$ and health impact (2000–2018).

Rank	All countries	Count	%	USA	Count	%	China	Count	%
1	Ozone	895	18.7	Mortality	438	23.0	China	769	58.0
2	Asthma	883	18.4	Environmental Exposure	435	22.8	City	308	23.2
3	Environmental Exposure	872	18.2	Cardiovascular Disease	327	17.2	Beijing	241	18.2
4	Respiratory Tract Infection	827	17.3	Ozone	286	15.0	Mortality	222	16.7
5	Nitrogen Dioxide	644	13.4	Chronic Exposure	211	11.1	Respiratory Tract Infection	173	13.0
6	Indoor Air Pollution	634	13.2	Asthma	203	10.7	Environmental Exposure	163	12.3
7	Polycyclic Aromatic Hydrocarbon	588	12.3	Respiratory Tract Infection	193	10.1	Polycyclic Aromatic Hydrocarbon	111	8.4
8	Chronic Exposure	531	11.1	Exhaust Gas	191	10.0	Time Series Analysis	93	7.0
9	Exhaust Gas	508	10.6	Indoor Air Pollution	174	9.1	Heavy Metal	91	6.9
							Lung Neoplasm	91	6.9
10	Beijing	507	10.6	Nitrogen Dioxide	163	8.6	Haze	88	6.6
11	Chronic Obstructive Lung Disease	419	8.7	Black Carbon	148	7.8	Exhaust Gas	85	6.4
12	Smoke	412	8.6	Premature Mortality	142	7.5	Chronic Exposure	75	5.7
13	Black Carbon	399	8.3	California	135	7.1	Indoor Air Pollution	72	5.4
14	Hospital Admission	366	7.6	Smoke	133	7.0	Air Pollution Control	71	5.4
15	Lung Neoplasm	354	7.4	Cooking	112	5.9	Chronic Obstructive Lung Disease	67	5.0

Subject area

We analyzed the subject areas (Figure 3) of publications on PM$_{2.5}$ and health impact published between 2014 and 2018. According to the distribution of subject categories, environmental science (2,046, 61.1% of all publications on PM$_{2.5}$ and health impact) and medicine (1,135, 33.9%) were the most common as per Scopus. In case of WoS, environmental science (2,489, 60.3%) and public, environmental, and occupational health (1,054, 25.5%) were the most common categories. The respiratory system (130, 3.1%) and cardiac and cardiovascular systems (76, 1.8%) stood at the seventh and ninth spots, respectively.
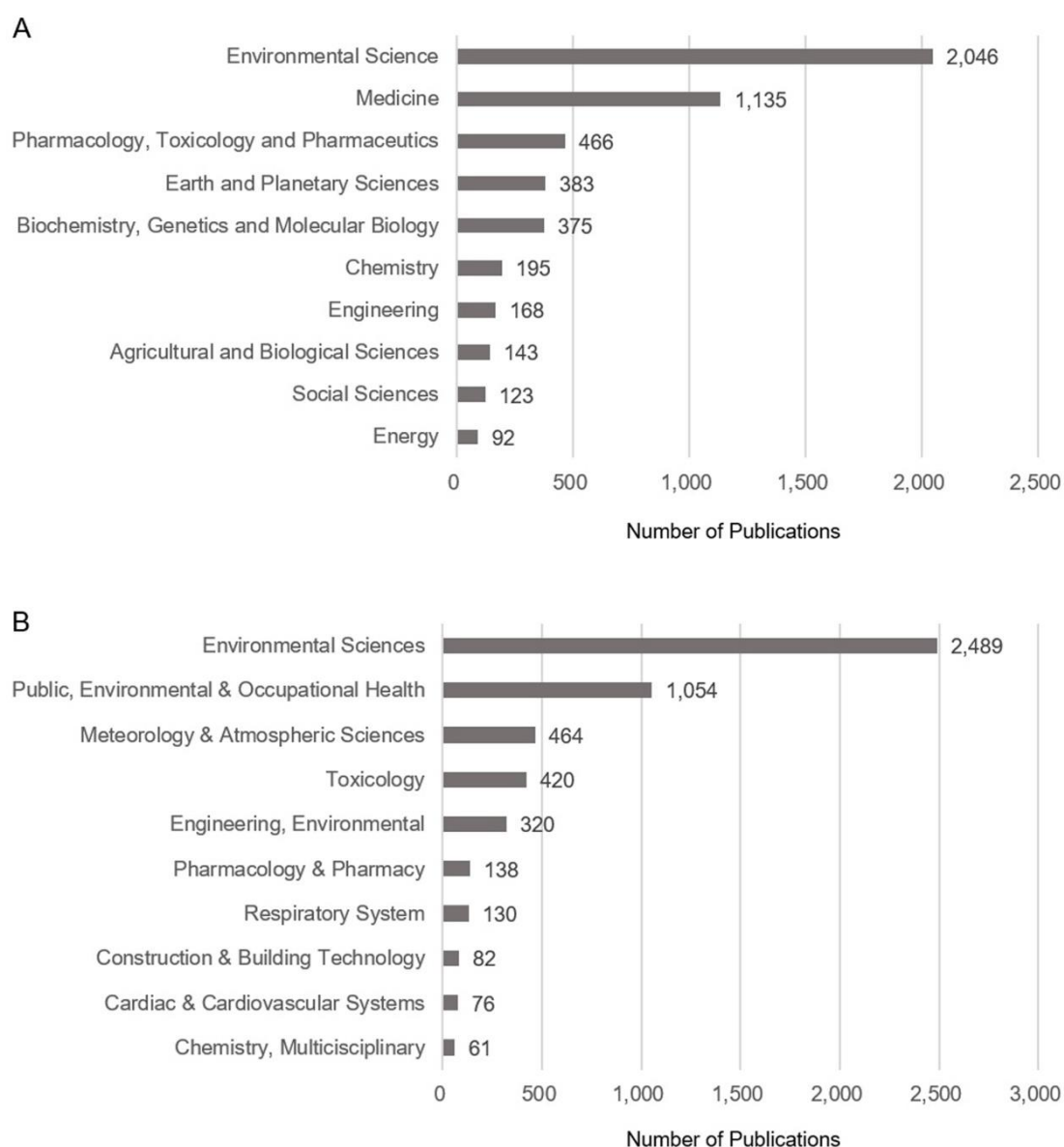
A

Subject Area	Number of Publications
Environmental Science	2,046
Medicine	1,135
Pharmacology, Toxicology and Pharmaceutics	466
Earth and Planetary Sciences	383
Biochemistry, Genetics and Molecular Biology	375
Chemistry	195
Engineering	168
Agricultural and Biological Sciences	143
Social Sciences	123
Energy	92

B

Subject Area	Number of Publications
Environmental Sciences	2,489
Public, Environmental & Occupational Health	1,054
Meteorology & Atmospheric Sciences	464
Toxicology	420
Engineering, Environmental	320
Pharmacology & Pharmacy	138
Respiratory System	130
Construction & Building Technology	82
Cardiac & Cardiovascular Systems	76
Chemistry, Multicisciplinary	61

Figure 3. Top 10 subject categories of research on particulate matter and health impact. (A) Subject areas of publications on PM_{10} and health impact; (B) Subject areas of publications on $PM_{2.5}$ and health impact.

Publication trends regarding vulnerable population groups

As mentioned previously, children, older adults, and pregnant women can be more vulnerable to the health impact of particulate matter than other populations. Thus, we examined how much research attention the health impact of $PM_{2.5}$ in these groups has received over 10 years. Articles on children, older adults, and pregnant women were extracted from studies on $PM_{2.5}$ and health impact published between 2009 and 2018 (Figure 4). In Scopus, the number of publications on children, older adults, and pregnant women were 732 (15.5% of total publications on $PM_{2.5}$ and health impact), 406 (8.6%), and 196 (4.2%) and increased 5.0, 5.1, and 7.2 times in 10 years, respectively. In WoS, the number of publications on children, older adults, and pregnant women were 721 (12.6%), 263 (4.6%), and 178 (3.1%) and increased 4.1, 3.4, and 6.3 times in 10 years, respectively. Thus, the increase in publications on pregnant women over the past 10 years is greater than the growth in the literature on $PM_{2.5}$ and health effects; publications on $PM_{2.5}$ and health effects increased 3.5 and 4.6 times in Scopus and WoS data, respectively.
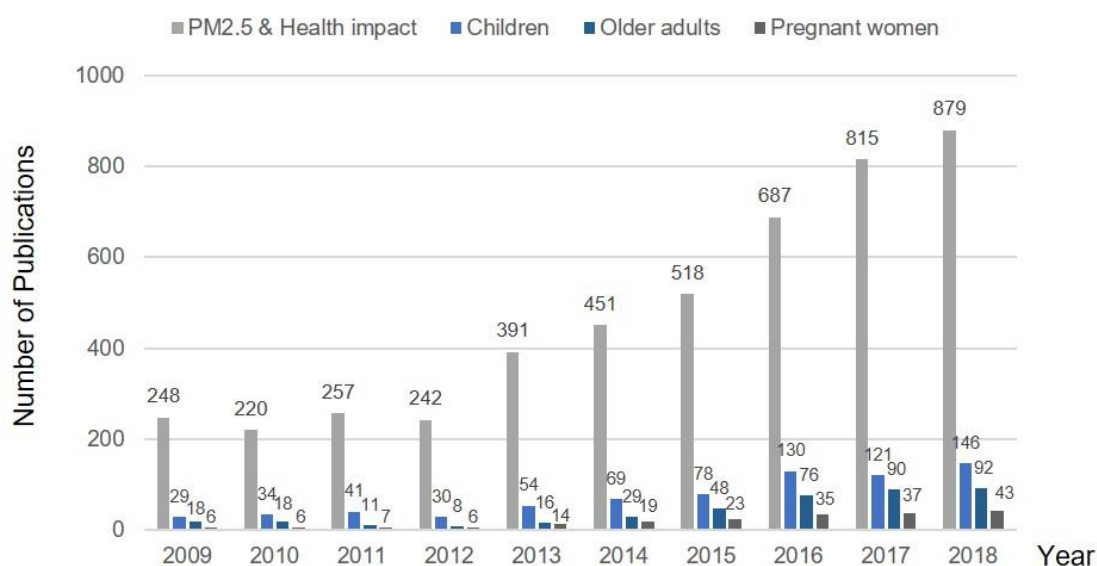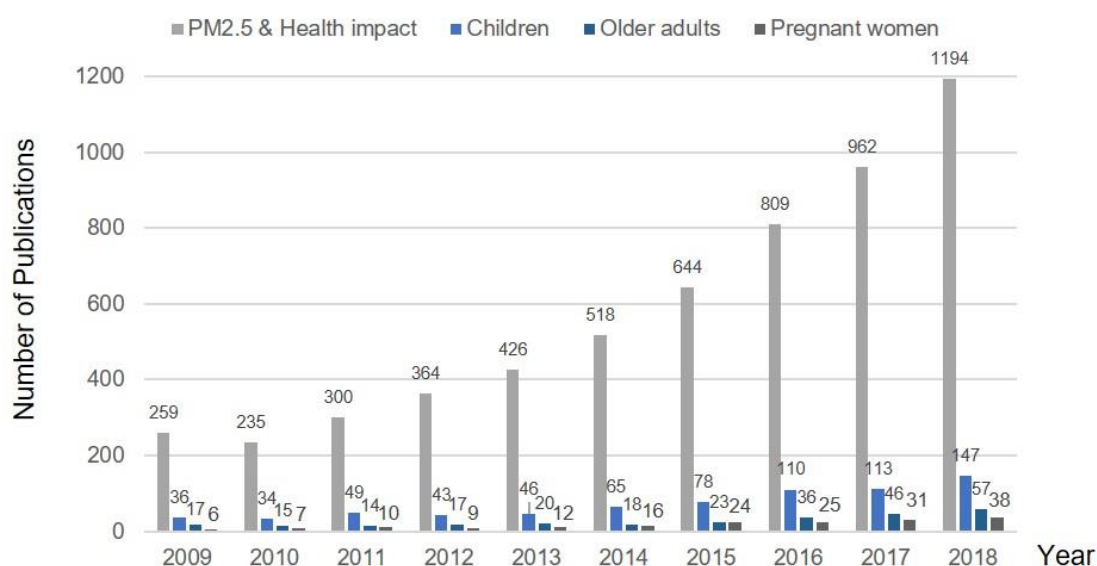
Figure 4. Trends of publications on PM2.5 and health impact in children, older adults, and pregnant women. (A) Scopus data; (B) Web of Science data.

Keyword analyses of publications on vulnerable population groups

The most frequently used keywords in articles on children, older adults, and pregnant women, which were published between 2010 and 2018, were "asthma" (209, 29.7% of children-related articles), "mortality" (139, 35.8% of the articles on older adults), and "exposure" (169, 88.9% of pregnant women -related articles), respectively (Table 4 and Supplemental Figure 3). "Asthma", "respiratory tract infection" (158, 22.5%), "cardiovascular disease" (65, 9.2%), and "respiratory tract disease" (61, 8.7%) were the main keywords in children-related publications. Air pollutant-related terms such as "nitrogen dioxide" (112, 15.9%) and "polycyclic aromatic hydrocarbon" (54, 7.7%) also ranked in the top 15. Six disease-associated terms including "cardiovascular diseases" (126, 32.5%), "respiratory tract infection" (64, 16.5%), "chronic obstructive lung disease" (43, 11.1%), "stroke" (34, 8.8%), "asthma" (31, 8.0%), and "respiratory tract disease" (28, 7.2%) were among the top 15 keywords in the publications on older adults. Fetal growth-related terms such as "birth weight" (40, 21.1%), "low birth weight infant" (30, 15.8%), and "low birth weight" (18, 9.5%) were among the main keywords in publications on pregnant women.

Table 4. Keyword analysis of articles on PM2.5 and health impact in children, older adults, and pregnant women (2000–2018).

Rank	Child	count	%	Older adults	count	%	Pregnant women	count	%
1	Asthma	209	29.7	Mortality	139	35.8	Exposure	169	88.9
2	Child Health	202	28.7	Environmental Exposure	138	35.6	Maternal Exposure	91	47.9
3	Environmental Exposure	178	25.3	Cardiovascular Disease	126	32.5	Mother	82	43.2
4	Respiratory Tract Infection	158	22.5	Chronic Exposure	78	20.1	Prenatal Exposure	59	31.1
5	Ozone	118	16.8	Nitrogen Dioxide	65	16.8	Pregnancy Outcome	54	28.4
				Ozone	65	16.8			
6	Nitrogen Dioxide	112	15.9	Respiratory Tract Infection	64	16.5	Cohort Study	49	25.8
7	Indoor Air Pollution	110	15.6	Hospitalization	61	15.7	Environmental Exposure	41	21.6
				Time Series Analysis	61	15.7			
8	School	75	10.7	Hospital Admission	58	14.9	Birth Weight	40	21.1
9	School child	69	9.8	Chronic Obstructive Lung Disease	43	11.1	Premature Labor	32	16.8
10	Cardiovascular Disease	65	9.2	Crossover Procedure	36	9.3	Birth Cohort	30	15.8
							Low Birth Weight Infant	30	15.8
11	Exhaust Gas	64	9.1	Stroke	34	8.8	Nitrogen Dioxide	28	14.7
12	Lung Function	63	9.0	Sulfur Dioxide	32	8.2	Child Health	27	14.2
	Time Series Analysis	63	9.0						
13	Hospital Emergency Service	61	8.7	Asthma	31	8.0	Land Use	25	13.2
	Respiratory Tract Disease	61	8.7				Maternal Welfare	25	13.2
14	Hospital Admission	58	8.3	Respiratory Tract Disease	28	7.2	Early Life	19	10.0
15	Polycyclic Aromatic Hydrocarbon	54	7.7	Mortality Risk	25	6.4	Low Birth Weight	18	9.5

Discussion and conclusion

In this study, we analyzed the trends in scientific publications on the health impact of PM10 and PM2.5 over 10 years (2009–2018). The number of studies on health impacts in both the PM10 and PM2.5 research fields increased rapidly over the period under consideration.

This increase appears to be spearheaded by researchers from the United States and China. China contributed approximately half of the number of studies published by researchers from the United States. According to the 2015 Global Burden of Disease study, China ranked highest with regard to the global disease burden attributable to ambient PM2.5 exposure [4]; PM2.5 caused 1.1 million (95% UI 1.0 million–1.8 million) deaths in China, accounting for more than 26% of the 4.2 million (95% UI 3.7 million–4.8 million) deaths worldwide. In the United States, the number of PM2.5 deaths was 88,400 (95% UI 66,800–115,000), approximately one-twelfth of the deaths in China. It can, thus, be assumed that awareness of the seriousness of the health effects of particulate matter is higher in the United States than in China.

The top 10 organizations that contributed to articles on the health impact of PM10 and PM2.5 from 2014 to 2018 were mostly from the United States and China, demonstrating that world-class research institutions play an important role in improving national research performance.

106   Science of the Total Environment and Atmospheric Environment published the most articles (about 10%) on
107 health effects of PM_{10} and $PM_{2.5}$ from 2014 to 2018. The top 10 journals have contributed to more than 30% of the literature
108 on health effects in both the PM_{10} and $PM_{2.5}$ research fields and are expected to continue to lead the way with regard to the
109 study of particulate matter and its health effects.
110   To identify the major topics in research on particulate matter and health effects, we performed a keyword analysis.
111 Air pollutants such as "nitrogen dioxide", "polycyclic aromatic hydrocarbon", "sulfur dioxide", and "black carbon" were
112 high-frequency keywords in global publications on particulate matter (PM_{10} or $PM_{2.5}$) and health effects. This finding
113 indicates that the precursors to and components of particulate matter have been frequently studied in this field. Respiratory
114 diseases seem to have been key topics in the field of research on the health impact of PM_{10} and $PM_{2.5}$. While "mortality" was
115 most often used in publications related to PM_{10} and health effects, it was not included in the top 15 in $PM_{2.5}$ and health
116 effects. Since $PM_{2.5}$ is smaller than PM_{10}, it is able to reach small airways and pulmonary alveoli [19] and move to other
117 organs through the circulatory system [2], thereby posing a greater threat [3]. In global publications, the terms "asthma",
118 "respiratory tract infection", "chronic obstructive lung disease", and "lung neoplasm" were frequently used as keywords
119 in the literature on $PM_{2.5}$ and health impact. "Cardiovascular disease" was the high-frequency keyword in publications from
120 the United States. Many researchers have reported that ambient $PM_{2.5}$ is an important risk factor for cardiovascular disease
121 [4,20] and respiratory diseases including lung cancer [4,21], chronic obstructive pulmonary disease [4,22], and asthma [23,24].
122 In addition, $PM_{2.5}$ can play a role in depressive symptoms [25,26], stroke [20,26-29], dementia [29], Alzheimer's disease [29],
123 diabetes mellitus [30], and ocular diseases [31,32], but there is a lack of research in this regard. To better understand the
124 health effects of $PM_{2.5}$, research on various diseases should be actively conducted. We also identified that articles published
125 in the United States and China had different keyword patterns; for example, "cardiovascular disease" and "asthma" were
126 frequently used only in American publications, while "lung neoplasm" and "chronic obstructive lung disease" were highly
127 frequent in only Chinese publications.
128   The number of publications related to the susceptible groups of children, older adults, and pregnant women in
129 the field of $PM_{2.5}$ and health effects has increased significantly over 10 years but remains small, indicating the possibility of
130 expansion of such research. As per keyword analysis, the major research topics for these three populations differed. In
131 studies on children, respiratory diseases such as asthma were a popular topic. Air pollutants such as nitrogen dioxide and
132 polycyclic aromatic hydrocarbon, of which diesel engines are the main source, also seem to have attracted scholarly attention.
133 A previous study has reported that $PM_{2.5}$ and nitrogen dioxide are involved in the exacerbation of childhood asthma [8]. In
134 studies on older adults, mortality was the most popular research topic, and the names of diseases ("cardiovascular diseases",
135 "respiratory tract infection", "chronic obstructive lung disease", "stroke", "asthma", and "respiratory tract disease") were
136 highly frequent. Studies on pregnant women seemed to focus on fetal health rather than the health of the women.
137   Despite the fact that it revealed some important trends, our bibliometric approach had certain limitations. First,
138 all scientific publications in the fields of particulate matter (both PM_{10} and $PM_{2.5}$) and health impact were not necessarily
139 included. Second, the weight of importance of each article was not reflected. Third, bibliometric databases might contain
140 erroneous data [18]. Fourth, the literature extracted may differ slightly depending on the time of search. Nevertheless, the
141 bibliometric method is an objective and comprehensive way to analyze publication trends [33]. Moreover, we used two
142 bibliometric tools, thereby increasing the credibility of the data.
143   We have demonstrated that, worldwide, there has been an impressive increase in the number of scientific
144 publications in the fields of particulate matter and health impact over 10 years. This increase appears to be led by world-
145 class research institutes in the United States and China. A large amount of work on particulate matter and health effects has
146 focused on respiratory and cardiovascular diseases. The precursors to and components of particulate matter (such as
147 nitrogen dioxide, polycyclic aromatic hydrocarbon, sulfur dioxide, and black carbon) were also core research topics. Studies
148 on children, older adults, and pregnant women in the field of $PM_{2.5}$ and health impact are expected to expand greatly in the
149 future.
150

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Conflict of interest

The authors have no conflicts of interest associated with the material presented in this paper.

CRediT author statement

JEL: Conceptualization, Methodology, Writing - Original, Writing - Reviewing and Editing, Visualization. HJL: Writing -
Reviewing and Editing, Supervision, Project administration, Funding acquisition. YYK: Supervision, Project administration,
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Supplementary Material

Add short descriptions of supplementary material. This material is available online at www.eaht.org.

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