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 (PM2.5) and fine particulate matter (PM2.5) 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.

Keywords: air pollution, particulate matter, PM10, PM2.5, public health, publication trends

Introduction

Particulate matter in which 50% of the particles have an aerodynamic diameter lower than 10 μm—PM10—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 (PM2.5) is more harmful to health than PM10 [3]. As per the Global Burden of Diseases Study 2015, long-term exposure to ambient PM2.5 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]. PM10 [8,9] and PM2.5 [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 PM2.5 exposure and increased premature mortality rates [12,13]. Further, PM2.5 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 PM2.5 [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 PM10 and PM2.5 published from 2009 to 2018 were first retrieved from Scopus and WoS. Then, health impact-associated publications were extracted from the retrieved PM10 and PM2.5-related publications. Subsequently, publications related to children, older adults, and pregnant women were retrieved from within the research field on PM2.5 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 PM10-related articles published from 2009 to 2018, of which 10,520 (21.8% of the total PM10-related articles) concerned health impact (Figure 1). A total of 33,048 PM2.5-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 PM2.5-related articles published between 2009 and 2018 retrieved from Scopus, 4,708 (23.0% of the total PM2.5-related articles) were health impact-related. In WoS, of the 21,526 PM2.5-related publications identified, 5,711 (26.3%) 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 PM10 and PM2.5), 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 PM10 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 PM10 and health impact; WoS = 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 PM10-related articles, respectively.

Approximately 100 countries or territories (Scopus = 103; WoS = 94) contributed to research related to PM2.5 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 PM2.5 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 PM2.5-related articles, respectively.

We also investigated the 10 organizations that published the most articles on PM10 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 PM10 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%).
Figure 1. Publication trends of research on particulate matter and health impact. (A, C): Scopus data; (B, D): Web of Science data.

Figure 2. Top 10 countries regarding publication contribution. (A, C): Scopus data; (B, D): Web of Science data.
Table 1a. Top 10 organizations and journals regarding research on PM$_{10}$ and health impact (2014–2018).

| Organization                                      | Journal                                      | Total number of publications | Scopus database | Journal                                      | Total number of publications | Web of Science database |
|--------------------------------------------------|----------------------------------------------|------------------------------|-----------------|----------------------------------------------|------------------------------|-------------------------|
| Chinese Academy of Sciences                      | Science of the Total Environment            | 278                          | 376             | Harvard University                          | 389                          | 341                     |
| Harvard School of Public Health                  | Atmospheric Environment                      | 235                          | 281             | University of California system             | 303                          | 284                     |
| Peking University                                | Environmental Pollution                      | 194                          | 249             | Chinese Academy of Sciences                 | 297                          | 249                     |
| Ministry of Education China                      | Environmental Research                       | 173                          | 249             | Harvard T.H. Chan School of Public Health   | 294                          | 245                     |
| United States Environmental Protection Agency    | International Journal of Environmental Research and Public Health | 153                          | 244             | Peking University                           | 215                          | 235                     |
| Fudan University                                 | Environment International                    | 148                          | 239             | United States Environmental Protection Agency | 189                          | 222                     |
| University of Washington, Seattle Utrecht        | Environmental Science and Pollution Research | 131                          | 189             | Fudan University                            | 154                          | 203                     |
| Tsinghua University                              | Environmental Health Perspectives            | 115                          | 161             | University of Washington Seattle            | 144                          | 170                     |
| Swiss Tropical and Public Health Institute Swiss TPH | Environmental Science and Technology PLOS ONE | 107                          | 134             | University of Washington                   | 144                          | 146                     |
|                                                  |                                              |                              |                 |                                              |                              |                         |
Table 1b. Top 10 Organizations and journals regarding research on PM$_{2.5}$ and health impact (2014–2018).

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

The 10 journals that published the most articles on particulate matter (PM$_{10}$ and PM$_{2.5}$) and health impact between 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$_{10}$ and health impact were published in the top 10 journals. As per Scopus data, Science of the Total Environment (impact factor = 5.589, 2018) was the most preferred journal (376, 5.6% of all publications on PM$_{10}$ and health impact), followed by Atmospheric Environment (impact factor = 4.012, 2018) with 281 articles (4.2%), Environmental Pollution (impact factor = 5.714, 2018) with 249 articles (3.7%), and Environmental Research (impact factor = 5.026, 2018) with 249 articles. In WoS, Science of the Total Environment was the most common journal (341, 5.3%), followed by Atmospheric Environment with 284 publications (4.4%) and International Journal of Environmental Research and Public Health (impact factor = 2.468, 2018) with 249 publications (3.8%).

More than 35% (Scopus = 1,208, 36.1%; WoS = 1,569, 38.0%) of articles on PM$_{2.5}$ and health impact were published in the top 10 journals (Table 1b). In both Scopus and WoS, Science of the Total Environment was the most preferred journal (Scopus = 173, 5.2% of all publications on PM$_{2.5}$ and health impact; WoS = 205, 5.0%), followed by Atmospheric Environment with 156 (4.7%) and 201 articles (4.9%), and International Journal of Environmental Research and Public Health with 142 (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.

| 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.
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 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 PM$_{2.5}$ 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 PM$_{2.5}$ 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 Exposure| 202 | 28.7| Environmental| 138   | 35.6| Maternal Exposure| 91    | 47.9|
| 3    | Environmental Exposure| 178 | 25.3| Cardiovascular Disease| 126   | 32.5| Mother Prenatal Exposure| 82    | 43.2|
| 4    | Respiratory Tract Infection| 158 | 22.5| Chronic Exposure| 78    | 20.1| Pregnancy Outcome| 59    | 31.1|
| 5    | Ozone| 118   | 16.8| Nitrogen Dioxide | 65    | 16.8| Ozone | 65    | 16.8|
| 6    | Nitrogen Dioxide| 112 | 15.9| Respiratory Tract Infection| 64    | 16.5| Cohort Study Environmental Exposure| 49    | 25.8|
| 7    | Indoor Air Pollution| 110 | 15.6| Hospitalization| 61    | 15.7| Exposure| 41    | 21.6|
| 8    | School| 75    | 10.7| Time Series Analysis| 61    | 15.7| Hospital Admission| 58    | 14.9|
| 9    | School child| 69    | 9.8| Chronic Obstructive Lung Disease| 43    | 11.1| Birth Weight Premature Labor| 32    | 16.8|
| 10   | Cardiovascular Disease| 65    | 9.2| Crossover Procedure| 36    | 9.3| Birth Cohort 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|
| 13   | Time Series Analysis| 63    | 9.0| Hospital Emergency Service| 61    | 8.7| Asthma| 31    | 8.0|
| 14   | Respiratory Tract Disease| 61    | 8.7| Land Use Maternal Welfare| 25    | 13.2|
| 15   | Polycyclic Aromatic Hydrocarbon| 54    | 7.7| Respiratory Tract Disease| 28    | 7.2| Early Life Low Birth Weight| 19    | 10.0|

Discussion and conclusion

In this study, we analyzed the trends in scientific publications on the health impact of PM$_{10}$ and PM$_{2.5}$ over 10 years (2009–2018). The number of studies on health impacts in both the PM$_{10}$ and PM$_{2.5}$ 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 PM$_{2.5}$ exposure [4]; PM$_{2.5}$ 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 PM$_{2.5}$ 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 PM$_{10}$ and PM$_{2.5}$ 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.
Science of the Total Environment and Atmospheric Environment published the most articles (about 10%) on 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 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 study of particulate matter and its health effects.

To identify the major topics in research on particulate matter and health effects, we performed a keyword analysis. Air pollutants such as “nitrogen dioxide”, “polycyclic aromatic hydrocarbon”, “sulfur dioxide”, and “black carbon” were high-frequency keywords in global publications on particulate matter (PM_{10} or PM_{2.5}) and health effects. This finding indicates that the precursors to and components of particulate matter have been frequently studied in this field. Respiratory 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 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 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 organs through the circulatory system [2], thereby posing a greater threat [3]. In global publications, the terms “asthma”, “respiratory tract infection”, “chronic obstructive lung disease”, and “lung neoplasm” were frequently used as keywords in the literature on PM_{2.5} and health impact. “Cardiovascular disease” was the high-frequency keyword in publications from the United States. Many researchers have reported that ambient PM_{2.5} is an important risk factor for cardiovascular disease [4,20] and respiratory diseases including lung cancer [4,21], chronic obstructive pulmonary disease [4,22], and asthma [23,24]. In addition, PM_{2.5} can play a role in depressive symptoms [25,26], stroke [20,26-29], dementia [29], Alzheimer’s disease [29], diabetes mellitus [30], and ocular diseases [31,32], but there is a lack of research in this regard. To better understand the health effects of PM_{2.5}, research on various diseases should be actively conducted. We also identified that articles published in the United States and China had different keyword patterns; for example, “cardiovascular disease” and “asthma” were frequently used only in American publications, while “lung neoplasm” and “chronic obstructive lung disease” were highly frequent in only Chinese publications.

The number of publications related to the susceptible groups of children, older adults, and pregnant women in the field of PM_{2.5} and health effects has increased significantly over 10 years but remains small, indicating the possibility of expansion of such research. As per keyword analysis, the major research topics for these three populations differed. In studies on children, respiratory diseases such as asthma were a popular topic. Air pollutants such as nitrogen dioxide and polycyclic aromatic hydrocarbon, of which diesel engines are the main source, also seem to have attracted scholarly attention. A previous study has reported that PM_{2.5} and nitrogen dioxide are involved in the exacerbation of childhood asthma [8]. In studies on older adults, mortality was the most popular research topic, and the names of diseases (“cardiovascular diseases”, “respiratory tract infection”, “chronic obstructive lung disease”, “stroke”, “asthma”, and “respiratory tract disease”) were highly frequent. Studies on pregnant women seemed to focus on fetal health rather than the health of the women.

Despite the fact that it revealed some important trends, our bibliometric approach had certain limitations. First, all scientific publications in the fields of particulate matter (both PM_{10} and PM_{2.5}) and health impact were not necessarily included. Second, the weight of importance of each article was not reflected. Third, bibliometric databases might contain erroneous data [18]. Fourth, the literature extracted may differ slightly depending on the time of search. Nevertheless, the bibliometric method is an objective and comprehensive way to analyze publication trends [33]. Moreover, we used two bibliometric tools, thereby increasing the credibility of the data.

We have demonstrated that, worldwide, there has been an impressive increase in the number of scientific publications in the fields of particulate matter and health impact over 10 years. This increase appears to be led by world-class research institutes in the United States and China. A large amount of work on particulate matter and health effects has focused 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 core research topics. Studies on children, older adults, and pregnant women in the field of PM_{2.5} and health impact are expected to expand greatly in the future.

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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, Funding acquisition.
Supplementary Material
Add short descriptions of supplementary material. This material is available online at www.eaht.org.

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