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RESEARCH ARTICLE

Scientometric analysis: identification of research trends for ozone as an air pollutant for 2011–2019

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Abstract

Ground level ozone is a major air pollutant with known toxic effects on humans. The research field is well established with many scientists from developed and developing countries contributing original research articles. Strict regulations for ozone air pollution are being implemented worldwide based on supporting scientific literature. In this scientometric analysis, we have analyzed the research trends in the field of ozone air pollution during 2011–2019. The collected SCOPUS data was analyzed using common scientometric analysis methods for known indicators to identify top ten rankings and scientific collaborations important for the field. Our result demonstrates that the USA is leading the field as USEPA and American regulatory authorities have funded most of the research. Two scientists, Russell A.G. and Schwartz J., working in American institutions, are leading with the most publications. Our assessment of ozone and PM together shows a significant impact on research direction in the last years to accommodate the study of both air pollutants together. In addition, we have analyzed the possible disease trends in the field for the last 3 years and identified that cardiovascular system, nervous system, and diabetes are upcoming disease areas that would be studied in the coming future.

Keywords Ozone air pollution · Disease trends · Scientific collaborations · Publication analysis · Co-author analysis · Ozone and PM air pollution

Introduction

Ozone is currently classified under six principal air pollutants by USEPA, and majority of regulatory agencies worldwide (Laumbach 2010). Although ozone is a natural part of the environment with protective effect in stratosphere, it is proven toxicant when inhaled by humans in troposphere (Madronich et al. 2015). Ground level ozone is produced by photochemical reaction between volatile organic compounds and nitrogen oxidative species in presence of sunlight (Weinhold 2008). Upon human exposure, respiratory health decline is commonly observed with inflammation and cytotoxicity as the main cellular mechanisms triggered after ozone exposure (Gonzalez-Guevara et al. 2014; Poma et al. 2017; Stenfors et al. 2010; Yang et al. 2017). While the strict air pollution regulation in developed countries has decreased the ozone human exposure in these countries, the increasing levels of ozone are still a huge problem in developing countries due to rapid industrial growth (Chen and Kan 2008; Gordon et al. 2018). Although a large number of reports on ozone exposure and human health effects are currently available, a scientometric study analyzing the trends in the field of ozone air pollution for the last decade is missing (Analitis et al. 2018; IARC 2016). Such a study could help identify possible research trends and thus direction of research in the future. Our study outlines such a scientometric analysis where we have identified the overall impact of the field in air pollution research area, the scientists, and funding agencies leading the field as well as the most active collaborations. We have also assessed whether studying ozone and pm together has an impact on scientific information (available to regulatory authorities especially in developing countries). In addition, we have analyzed the possible new disease trends as observed for the last 3 years (2017–2019) to identify the research direction in the coming future.

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Methodology

Data acquisition

We used SCOPUS as a valid source for acquisition of data for our scientometric analysis. This selection is based on the fact that SCOPUS is among major international databases for health sciences, and the terminology in the database can be used to search scientific topics successfully. All documents for our study were retrieved from SCOPUS and refined (as indicated below). A search with words "ozone air pollution" as descriptor was performed for the years 2011–2019 to retrieve publications that contained these words in publications' titles, keyword lists, and abstracts. As it is possible that there may be other terminologies, perhaps more specific for the field, the search terms were kept broad to ensure that all the right matches would be included. To focus the search results to scientific findings, document type "articles or reviews" was selected and other document types such as book chapter, data paper, and proceedings abstracts were not included. Once the search was done, all the documents were selected and data for citation information (Author(s), document title, year, source title, volume, issue, pages, citation count, source and document type), bibliographical information (affiliations, serial identifiers (e.g., ISSN), PubMed ID, publisher, editor(s), language of original document, correspondence address, abbreviated source title, DOI), abstract and keywords (abstract, author keywords, index keywords), and funding details (number, acronym, sponsor, funding text) were exported as CSV files for further analyses. The electronic search was executed on November 29, 2019, and data of articles (original and review) with an aggregate of 16,642 was retrieved. No limit based on language of articles was applied although only a minor percentage of total articles was non-English (< 5%). The above data was further assessed and indexed for recognizing the most cited articles, highest published researchers/authors, most influential funding agencies and top ten countries, etc.

Refined search with word combination "ozone air pollution pm" with document type "article or review" was also performed to assess the reporting of scientific advancement in linking ozone and particulate matter (PM). Search resulted in 1491 articles. For a second assessment, search in this category was limited to the keyword "particulate matter" which resulted in 1202 articles. A refined search with words "ozone air pollution disease" and "ozone air pollution PM" in document type "article" for the years 2017–2019 was performed in our collected data to identify the forthcoming trends in ozone-associated diseases in original research articles in the last 3 years. Furthermore, we identified the detailed information of the top authors and assessed and compared with available data.

Scientometric analysis methods

The above data was utilized for the calculation of all indicators such as most prolific authors, publications on yearly basis, country wise publications, funding sponsors of publications, publications with respect to author affiliation, most cited articles, publications with respect to journal, top prolific authors, top author clusters, top organizational clusters, and top trends in diseases. In order to determine the total research impact, we have calculated the total number of citations for the top 10 articles and compared with total number of citations for top 10 articles of other air pollutants (carbon monoxide, sulfur dioxide, lead, nitrogen oxide) in the air pollution field between the years 2011 and 2019 using search terms, e.g., "carbon monoxide air pollution."

Scientific activity and collaboration

In order to quantify research collaborations at an international level, we reviewed all institutions that have a publication in Scopus within the 9-year time window of 2011–2019 in this field. We classified thousands of records of collaborations based on 2011–2019 publications to a list of institution pairs. Data analysis and visualizations was performed using the VOS viewer (version 1.6.14). Briefly, we used map-based bibliographical data method on data extracted through SCOPUS (CSV files as described above). Full counting method was utilized in the study to assess all the organizations simultaneously. Minimum of 5 documents per organization criteria was selected and 281 organizations were obtained. Co-authorship analysis was done with respect to organizational networks with 227 out of 281 after exclusion due to lack of link strength in organizations. In the organizational network, the initial 18,170 organizations were reorganized to 227 significant organizations.

Characteristics of main research clusters and leading researchers

We recognized the most prolific authors, organizations, and country clusters in the field, which we denoted graphically within a co-authorship network. A research cluster can be explained as a group of investigators with a high density of interrelationship, having certain similarity and differentiating them from other clusters. To determine the most prolific authors, countries, and organizations influence in the network, we calculated their betweenness and citation numbers through VOS viewer (version 1.6.14) to measure the degree to which a node (in this case, an author) enables connections between other nodes. We used map-based bibliographical data method on data extracted through SCOPUS (CSV files earlier as described above). Full counting method was utilized in the study to assess the top authors, countries, and top organizations

simultaneously. Minimum of 57, 19, and 229 documents were selected as a criterion for top authors, organizations, and countries, respectively, and 10 authors, 12 organizations, and 10 countries were obtained. Co-authorship analysis was done with respect to top authors, organizations, and countries. We used Pajek program to describe this indicator with respect to link strength, documents, and citations. Briefly, we compiled the network, partition, and cluster files saved from the VOS viewer, inserted in Pajek program and visualized and reordered the results in decreasing order of citations and documents.

Research trends in ozone-associated diseases

Disease trends were identified through the extensive cataloging of the research publications according to certain disease. We excluded the publications related to monitoring air pollution, economic impact studies, environment studies, sensors, and engineering. We analyzed the data for 2017–2019 for "ozone air pollution" and "ozone air pollution PM" and found that there are 453 and 218 articles, respectively, that discuss impact of these air pollutants on diseases. These findings were further classified into categories with respect to diseases of a certain organ system.

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We recognized the most prolific authors, organizations and country clusters in the field, which we denoted graphically within a co-authorship network. A research cluster can be explained as a group of investigators with a high density of interrelationship, having certain similarity and differentiating them from other clusters. To determine the most prolific authors, countries and organizations influence in the network, we calculated their betweenness and citation numbers through VOS viewer (version 1.6.14) to measure the degree to which a node (in this case, an author) enables connections between other nodes. We used map based bibliographical data method on data extracted through SCOPUS (CSV files earlier as described above). Full counting method was utilized in the study to assess the top authors, countries and top organizations simultaneously. Minimum 57, 19 and 229 documents were selected as a criterion for top authors, organizations and countries respectively, and 10 authors, 12 organizations and 10 countries were obtained. Co-authorship analysis was done with respect to top authors, organizations and countries. We used Pajek program to describe this indicator with respect to link strength, documents and citations. Briefly, we compiled the network, partition and cluster files saved from the VOS viewer, inserted in Pajek program and visualized and reordered the results in decreasing order of citations and documents.

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Results

Scientometry for "ozone in air pollution"

We have analyzed the top ten cited articles of all time for the major air pollutants (Table 1) to assess whether ozone is a major air pollutant based on the publication count for publications recorded for the years 2011–2019 and beyond. We observed that ozone (13,745 citations) stands second in terms of citations to lead (20,579 citations) and indicate its major role and research-based influence for the covered years. As ozone comes under major air pollutants, in this study, we present the extracted scientometric data with respect to known scientometric parameters such as publication trend for countries, affiliations, and funding agencies. It incorporates 16,642 and 1491 articles obtained using search terms "ozone air pollution" and "ozone air pollution PM," respectively, for the years 2011–2019. In addition, we analyzed for the top publications, most prolific authors and active collaborations in the field.

Global publication trend

Figure 1 shows the trend of annual publications in the field of "ozone air pollution" from 2011 to 2019. Publications

Table 1 Total number of citations for the top 10 articles for different air pollutants

Air pollutant	Total citations on 4.12.2019 for top 10 articles
Lead	20,579
Ozone	13,745
Sulfur dioxide	11,845
Carbon monoxide	3217

Top ten articles based on the citation count were identified for major air pollutants (lead, sulfur dioxide, and carbon monoxide). The citations for all top 10 articles were compiled and compared to identical data for ozone

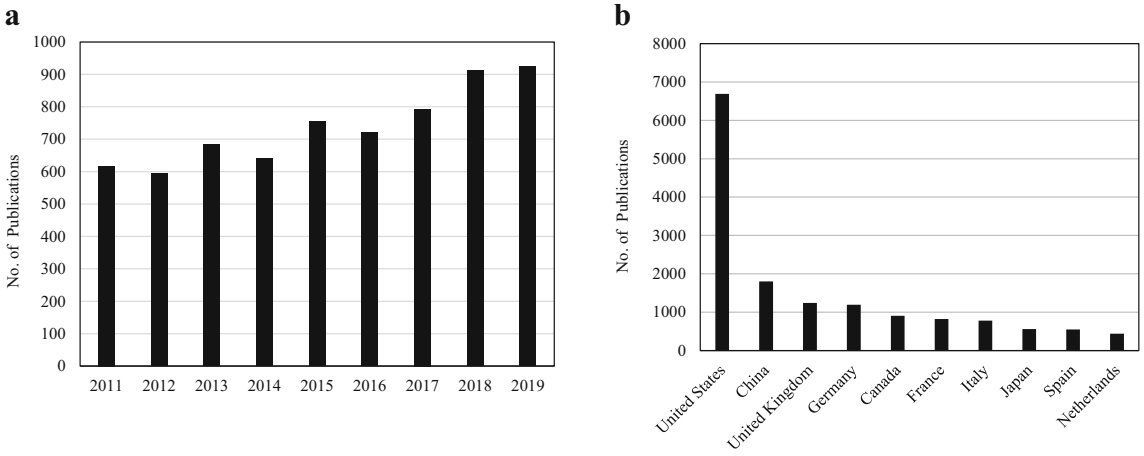

Fig. 1 Trend of publications from 2011 to 2019 in ozone pollution. **a** SCOPUS search for original research articles and review articles on "ozone pollution" from 2011 to 2019 was plotted in to a bar-graph and evaluated for trend in research publications number over the years. **b** Bar graphs were made for top ten countries based on publication count for the selected time period in the field of "ozone air pollution"

were collected for the years from the raw data and plotted into the bar graph. The peak of productivity was observed in the most recent year, 2019 with 924 publications (13.91% of the total), whereas least number of publications were observed in 2012 with 595 publications (8.95% of the total) (Fig. 1a).

Countries distribution

Figure 1b shows top ten countries based on the number of publications in the field during 2011–2019. The USA had the maximum publications with a total of 6688 (44.60% of the total) publications, followed by China and the UK with 1802 (12.01%) and 1242 (8.28%) publications.

Funding agency distribution

Top ten funding agencies are given in Fig. 2a. National Natural Science Foundation of China (NNSFC) had funded 701 publications (28.67% of the total) and stands first followed by US Environmental Protection Agency (USEPA) with 474 publications (19.38%) and National Science Foundation (NSF) with 258 publications (10.55%). Half of the top 10 funding sponsors were from USA followed by China with 3 funding agencies. Other top 10 funders are Belgium and the UK.

Journal distribution

The top ten journals are given in Fig. 2b. The journal "Atmospheric Environment" was the most productive journal

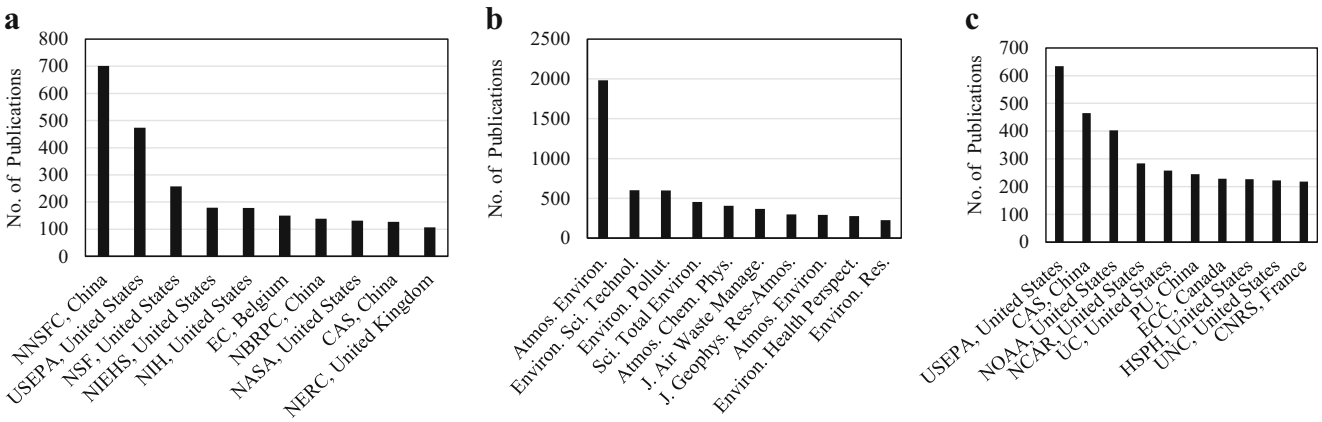

Fig. 2 Bar graph analysis for top 10 funding agencies, Journals and author affiliations in the field of "ozone air pollution." **a** Number of publications sponsored by the top 10 funding agencies in the field of 'ozone air pollution' were obtained and plotted in to a bar graph between years 2011 to 2019. The full names of funding agencies are given in Supplementary Table 1. **b** Journals were ordered on the basis of publication count into top 10 journals and plotted in to a bar graph. The full names of journals with impact factor and country are given in Supplementary Table 2. **c** Author affiliations attached to publications were ordered with respect to the publication count and plotted in to a bar graph. The full names of author affiliations are given in Supplementary Table 3

with 1984 (36.02% of total) publications followed by "Environmental Science and Technology" with 601 publications (10.91%) and "Environmental Pollution" with 599 publications (10.87%). In the top 10 journals, "Environmental Health Perspectives" and "Environmental Science and Technology" had the highest impact factor of 8.05 and 7.15, respectively. In addition, the highest number of journals in our top ten list originated from the USA. The total impact factor of the journals published from the USA was 23.86 including the highest impact factor journal in this field.

Affiliation distribution

Our data proves active participation of institutions from the USA in research in this field (Fig. 2c). Six institutions in the top ten list were from the USA. US Environment Protection Agency USEPA (634 publications) was the top contributor with respect to publications followed by the Chinese Academy of Sciences CAS (465 publications) and National Oceanic and Atmospheric Administration NOAA (403). Top 10 contributors also included institutions from China, Canada, and France.

Scientific collaborations between research organizations

Scientific collaborations between research organizations in the field of ozone pollution between 2011 and 2019 were analyzed. Publications count varied from 31 to 5 publications whereas citation count ranged from 1081 to 40, respectively, (Fig. 3). NASA goddard space flight center or NASA GSFC USA is among the top collaborator with 31 documents, 1081 citations, and total link strength of 85 followed by the National Center for Atmospheric Research or NCAR USA (39 documents, 1225 citations, and total link strength of 67) and Dalla lana school of public health or DLSPH Canada (14 documents, 300 citations, and total link strength of 59). Out of 281 research organizations, 24 had no collaborations with any other organization.

Co-authorship cluster analysis based on countries

Co-authorship of a publication is the involvement of two or more authors or organizations in publication of a research article. In co-authorship analysis for countries, i.e., author based out of a country, the USA (58,838 citations) had the

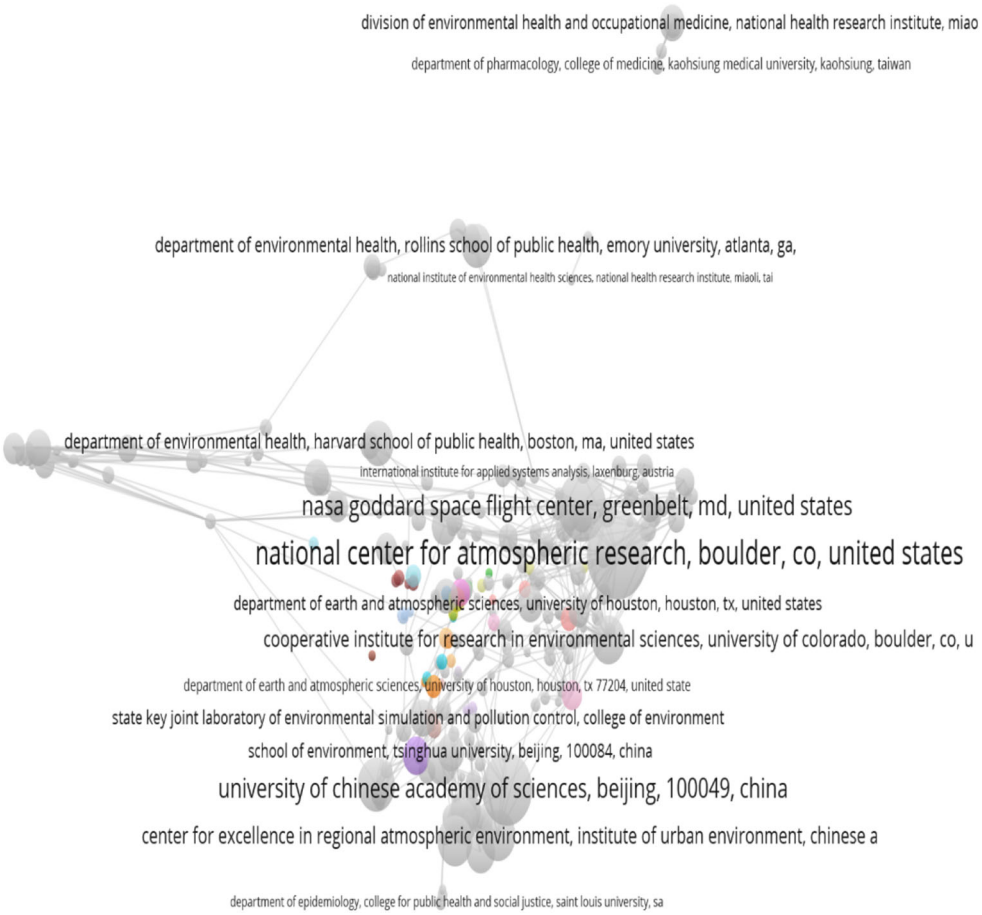

Fig. 3 Scientific Collaborations between research organizations in the field of ozone pollution for the years 2011–2019. Scientific collaborations between the world research organizations/ institutions are represented by the number of clusters. Thickness of line represents the strength of collaboration obtained from analyzing the publication count for that cluster while circle size and text size is directly proportional to number of citations and publications for a cluster

highest citations followed by China (24,134 citations) and UK (18,124 citations) (Fig. 4a). In addition, the USA had total link strength of 1201, followed by China (total link strength = 674), and the UK (total link strength = 548) (Supplementary Table 4). Total link strength indicates the co-authorship link of researcher with other researchers around the world. The data confirms the findings seen in Fig. 1b.

Co-authorship cluster analysis on the basis of organization

Organization cluster with the top ten institutions is given in Fig. 4b. University of Chinese Academy of Sciences or UCAS China topped for co-authorship collaborations between the affiliation organizations with the highest publications link strength (14) followed by Center for Excellence in Regional Atmospheric Environment or CERAE China (10) and National Center for Atmospheric Research or NCAR USA (8). In terms of number of publications, NCAR USA (39 publications) led followed by UCAS (32 publications) and CERAE China (22 publications). In terms of citations, NCAR USA (1225 citations) topped followed by NASA Goddard Space Flight Centre or NASA GSFC USA (1081 citations) and Cooperative Institute for Research In Environment Sciences or CIRES USA (926 citations) (Supplementary Table 5).

Authorship and co-authorship distribution

Top 10 authors are given in Fig. 5(a). Russell A.G. was the most productive author with 77 publications. Schwartz J. was in second place with 72 publications followed by Burnett R.T. with 68 publications. We had done the co-citation analysis with the authors through VOS viewer and graphically represented in Pajek program (Fig. 5(b)). Zhang Y. with 145 research publications was the most prolific author. Wang Y. was in second place with 143 publications followed by Wang X. with 120 publications, respectively. Zhang Y had top most total link strength with a score of 68 and citations of 3536 followed by Wang Y. and Wang X. with total link strength of 60 and 52 and citations of 3415 and 2478, respectively (Supplementary Table 6).

Top cited documents

In this section, the top 10 highly cited documents of all time in the field of ozone air pollution are given (Table 2). Article titled "Air Pollution and health" by Brunekreef B published in the year 2002 in The Lancet was the top cited article with the total citations of 2241.Two of the articles published in the recent decade also made their place in the top 10 cited articles. These include the articles titled "Contribution of outdoor air pollution sources to premature mortality on a global scale" by Lelieveld J and "Enhanced nitrogen deposition over China" by Liu X published in the year 2015 and 2013 in Nature with citation count of 1227 and 1072, respectively.

Upcoming research trend: "ozone and PM in air pollution"

During this study, we have recognized that the current research trend is increasingly directed towards investigation of mixture of air pollutants, to reproduce actual pollution conditions. Such a finding is given below where a similar pattern was observed for research on ozone and particulate matter (PM) together.

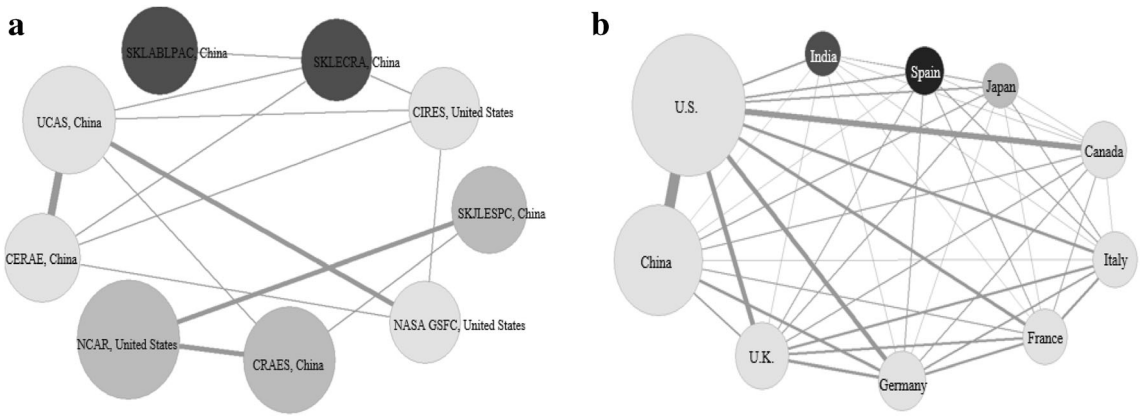

Fig. 4 Co-author Cluster analysis on the basis of country and organization. **a** Top ten countries on the basis of the number of citations, link strength and documents are represented by each cluster. Thickness of line represents the number of countries association and circle size is directly proportional to number of citations and research documents. Countries citations, documents, and link strength are given in Supplementary Table 4. **b** Top nine organizations on the basis of the number of citations, link strength, and documents are represented by each cluster. Thickness of line represents the number of organizational or institutional associations and circle size is directly proportional to number of citations and research documents. Full names of organizations and their citations, documents, and link strength are given in Supplementary Table 5

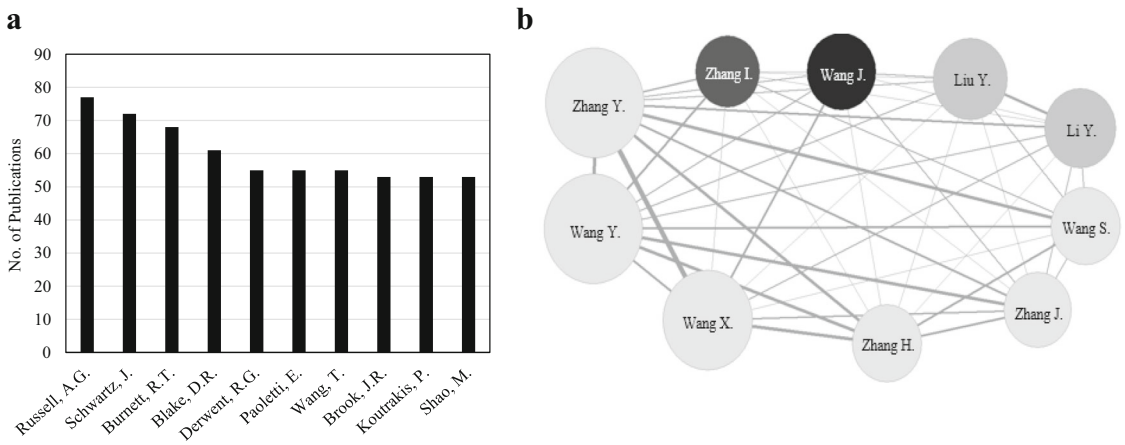

Fig. 5 Top authors bar graph and co-authorship Cluster analysis on the basis of author from 2011 to 2019 in the field of ozone air pollution. **a** Top 10 Author attached to publications were ordered with respect to the publication count and plotted in to a bar graph. **b** Top ten authors on the basis of the number of citations, link strength, and documents are represented by each cluster. Thickness of line represents the number of author associations and circle size is directly proportional to number of citations and research documents. Author names and their citations, documents, and link strength are given in Supplementary Table 6

Global publication trend

Figure 6a shows the trend of annual publications in the field of ozone and PM in air pollution from 2011 to 2019. The peak of productivity was observed in 2018 with 154 publications (17.68% of the total) whereas least number of publications were observed in 2013 with 60 publications (6.88%).

Table 2 Top 10 cited articles in the field of "ozone air pollution"

Article	Year of publishing	No. of citations
Brunekreef B, Holgate ST. Air pollution and health. The lancet. Oct 19;360(9341):1233–42.	2002	2241
Samet JM, Dominici F, Curriero FC, Coursac I, Zeger SL. Fine particulate air pollution and mortality in 20 US cities, 1987–1994. New England journal of medicine. Dec 14;343(24):1742–9.	2000	1719
Atkinson R. Atmospheric chemistry of VOCs and NOx. Atmospheric environment. Jan 1;34(12–14):2063–101.	2000	1706
Chan CK, Yao X. Air pollution in mega cities in China. Atmospheric environment. Jan 1;42(1):1–42.	2008	1533
Brook RD, Franklin B, Cascio W, Hong Y, Howard G, Lipsett M, Luepker R, Mittleman M, Samet J, Smith Jr. SC, Tager I. Air pollution and cardiovascular disease: a statement for healthcare professionals from the Expert Panel on Population and Prevention Science of the American Heart Association. Circulation. Jun 1;109(21):2655–71.	2004	1461
Finnveden G, Hauschild MZ, Ekvall T, Guinée J, Heijungs R, Hellweg S, Koehler A, Pennington D, Suh S. Recent developments in life cycle assessment. Journal of environmental management. Oct 1;91(1):1–21.	2009	1450
Kampa M, Castanas E. Human health effects of air pollution. Environmental pollution. Jan 1;151(2):362–7.	2008	1414
Grell GA, Peckham SE, Schmitz R, McKeen SA, Frost G, Skamarock WC, Eder B. Fully coupled "online" chemistry within the WRF model. Atmospheric Environment. Dec 1;39(37):6957–75.	2005	1336
Lelieveld J, Evans JS, Fnais M, Giannadaki D, Pozzer A. The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature. Sep;525(7569):367.	2015	1227
Liu X, Zhang Y, Han W, Tang A, Shen J, Cui Z, Vitousek P, Erisman JW, Goulding K, Christie P, Fangmeier A. Enhanced nitrogen deposition over China. Nature. Feb;494(7438):459.	2013	1072

Top ten articles on the basis of citation count in the field of "ozone air pollution" with publishing year and author are listed

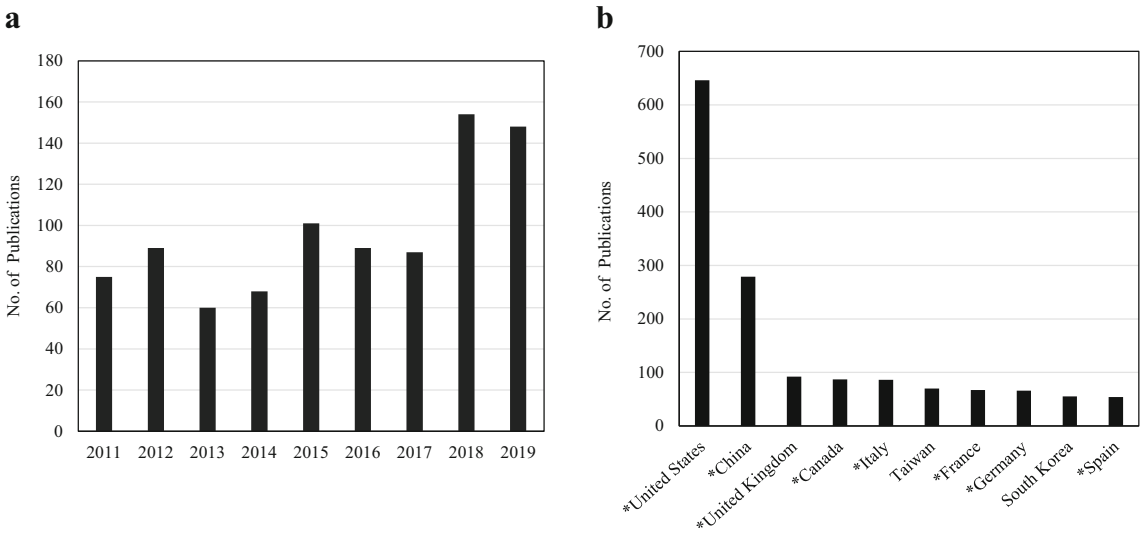

Fig. 6 Trend of publications from 2011 to 2019 on "ozone air pollution PM." **a** SCOPUS search for original research articles and review articles on "ozone air pollution PM" was plotted in to a bar-graph and evaluated for trends in research publications number over the years. **b** Bar graphs were made for top ten countries based on publication count for the selected time period in the field of "ozone air pollution." * represents the countries common to both the search terms "ozone air pollution" and "ozone air pollution PM"

Country territory distribution

Figure 6b shows top 10 countries with publications associated to "ozone air pollution PM." The USA had the maximum publications with a total of 646 (43.01% of the total) publications followed by China and the UK with 279 (18.57%) and 92 (6.12%) publications.

Funding wise distribution

Top 10 funding agencies are given in Fig. 7a. National Natural Science Foundation of China (NNSFC) had funded 89 publications (21.60% of the total) stands first followed by US Environmental Protection Agency (USEPA) with 64 publications (15.33% of the total) and National Institute of Environmental Health Sciences (NIEHS) with 52 publications (12.62% of the total). Most of the top 10 funding sponsors are from the USA (5) followed by China (3). Other top 10 funding agencies included Belgium and India.

Journal distribution

The top 10 journals are given in Fig. 7b. The journal "Atmospheric Environment" was the most productive journal with 166 (28.92% of the total) publications followed by "Science of the Total Environment" with 75 publications (13.07%) and "Environmental Health Perspectives" with 67 publications (11.67%). In the top 10 journals, "Environmental Health Perspectives" and "Environment International" had the highest impact factor of 8.05 and 7.94, respectively. Interestingly, maximum number of journals were distributed in Europe. The total impact factor of the journals published from Europe was 35.75 and the highest impact factor journal was published from Europe.

Affiliation distribution

The institutions from the USA and China were observed to actively participate in research publications (Fig. 7c) in this research area during 2011–2019. Four top institutions were from the USA and three from China. US Environmental Protection Agency or USEPA (89 publications) was the top contributor followed by the Chinese Academy of Sciences or CAS (64) and Harvard School of Public Health or HSPH (52). Other top 10 contributors included institutions from Taiwan and Mexico.

Authors distribution

Top 10 authors for ozone and PM air pollution are given in Fig. 7d. Russell A.G. was the most productive author with 19 publications. Schwartz J. was in second place with 18 publications followed by Torres-Jardon, R. with 15 publications.

Top cited documents

In this section, we have given the top 10 highly cited documents in the field of ozone and PM air pollution in all times (Table 3). Air pollution in mega cities in China by Chan C. K. published in the year 2008 in journal "Atmospheric environment" was the top cited article until date with the total citations of 1533. Two of the articles published in the recent decade made their place in the top 10 cited articles. These include the "outdoor air pollution and asthma" by Guarnieri M. and

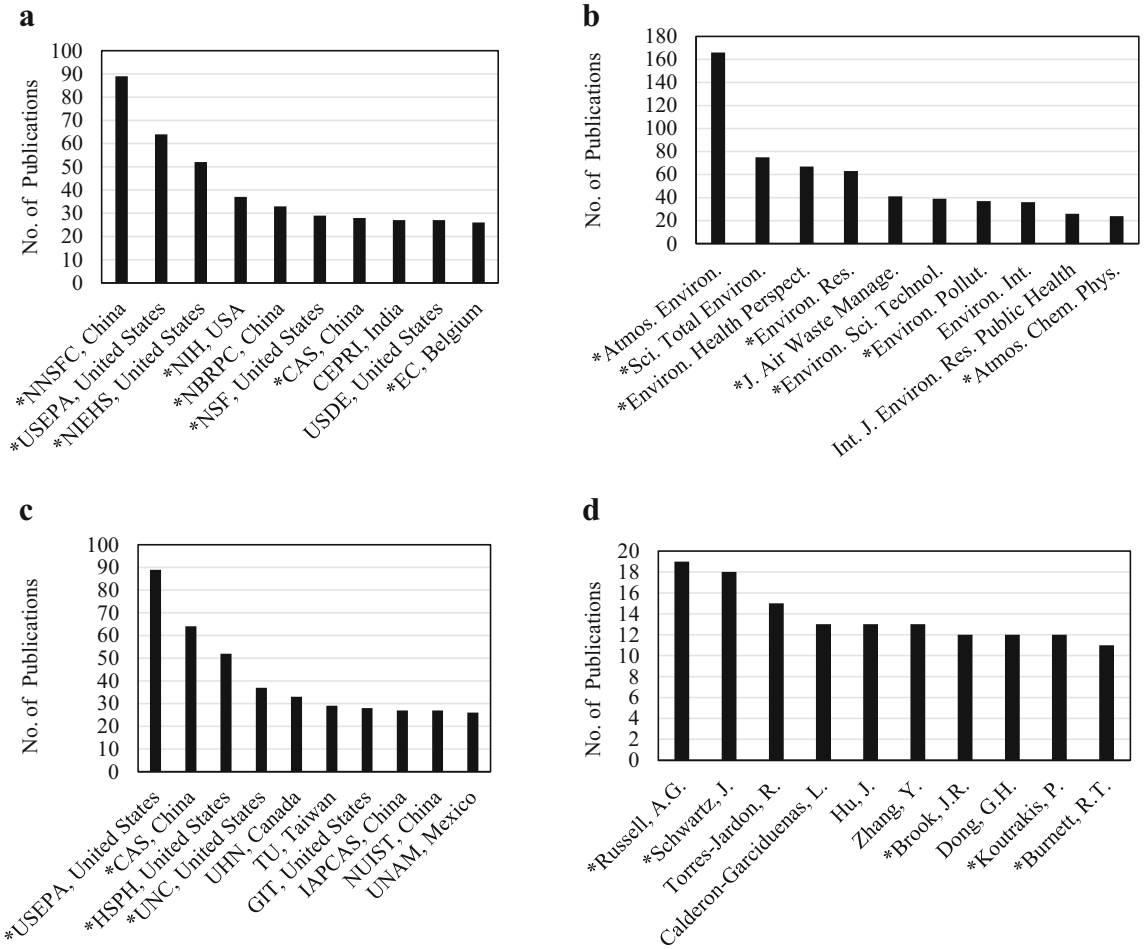

Fig. 7 Bar graph analysis for top 10 funding agencies, journals, author affiliations, and authors in field of "ozone air pollution PM." **a** Number of publications sponsored by the top 10 funding agencies in the field of "Ozone air pollution PM" were obtained and plotted in to a bar graph between years 2011 to 2019. Table provides the full names of the funding agencies that are abbreviated in the graph. * represents the funding agencies common to both the search terms "ozone air pollution" and "ozone air pollution PM." **b** Journals were ordered on the basis of publication count into top 10 journals and plotted in to a bar graph. Table provides the full names of the journals that are abbreviated in the graph. * represents the countries common to both the search terms "ozone air pollution" and "ozone air pollution PM." **c** Author affiliations attached to publications were ordered with respect to the publication count and plotted in to a bar graph. Table displays full affiliations with abbreviations utilized in the graph. * represents the countries common to both the search terms 'ozone air pollution' and 'ozone air pollution PM'. **d** Top 10 Author attached to publications were ordered with respect to the publication count and plotted in to a bar graph

"Exposure assessment for estimation of the global burden of disease attributable to outdoor air pollution" by Brauer M. published in the year 2014 and 2012 in journal "The Lancet" and "Environmental Science & Technology" with citation count of 399 and 364, respectively.

Diseases trend in the two fields during 2017–2019

Disease trend in terms of publication count in the field of "ozone air pollution" and "ozone air pollution PM" for various diseases during 2017–2019 is depicted in Fig. 8. Respiratory diseases were prominent in both the fields followed by cardiovascular diseases and brain diseases. Other top diseases included inflammation, reproductive neonatal diseases, and diabetes. Diseases that were less common but were researched during 2011–2019 are classified under other diseases and include cancer, skin diseases, atherosclerosis, eye, and ear diseases.

Discussion

Ozone is gaining significance these days, as researchers are more focused on understanding and controlling air pollution to reduce mortality rate and harmful health effects in human beings. Our thorough analysis demonstrated that researchers are now actively working on cellular mechanisms of air pollutants and thus, expanding the knowledge of ozone and PM air pollution rapidly. The research is rapidly shifting toward understanding the role and health effects of more than one air pollutant when studied together. The field has evolved significantly over the last few years as visible from high

Table 3 Top 10 cited articles in the field of "ozone air pollution PM"

Article	Year of publishing	No. of citations
*Chan CK, Yao X. Air pollution in mega cities in China. Atmospheric environment. Jan 1;42(1):1–42.	2008	1533
Jacob DJ, Winner DA. Effect of climate change on air quality. Atmospheric environment. Jan 1;43(1):51–63.	2009	800
Jerrett M, Burnett RT, Ma R, Pope III CA, Krewski D, Newbold KB, Thurston G, Shi Y, Finkelstein N, Calle EE, Thun MJ. Spatial analysis of air pollution and mortality in Los Angeles. Epidemiology. Nov 1:727–36.	2005	636
Sun Y, Zhuang G, Tang A, Wang Y, An Z. Chemical characteristic of PM2. 5 and PM10 in haze− fog episodes in Beijing. Environmental Science & Technology. May 15;40(10):3148–55.	2006	561
Pope III CA, Schwartz J, Ransom MR. Daily mortality and PM10 pollution in Utah Valley. Archives of Environmental Health: An International Journal. Jun 1;47(3):211–7.	1992	495
Srogi K. Monitoring of environmental exposure to polycyclic aromatic hydrocarbons: a review. Environmental Chemistry Letters. Nov 1;5(4):169–95.	2007	444
Streets DG, Fu JS, Jang CJ, Hao J, He K, Tang X, Zhang Y, Wang Z, Li Z, Zhang Q, Wang L. Air quality during the 2008 Beijing Olympic games. Atmospheric environment. 2007 Jan 1;41(3):480–92.	2007	406
Guarnieri M, Balmes JR. Outdoor air pollution and asthma. The Lancet. 2014 May 3;383(9928):1581–92.	2014	399
Brauer M, Amann M, Burnett RT, Cohen A, Dentener F, Ezzati M, Henderson SB, Krzyzanowski M, Martin RV, Van Dingenen R, Van Donkelaar A. Exposure assessment for estimation of the global burden of disease attributable to outdoor air pollution. Environmental Science & Technology. 2012 Jan 6;46(2):652–60.	2012	364
Schwartz J, Neas LM. Fine particles are more strongly associated than coarse particles with acute respiratory health effects in schoolchildren. Epidemiology. 2000 Jan 1;11(1):6–10.	2000	360

Highest cited articles in the field of 'ozone air pollution PM' with publishing year and author are indexed to produce top ten articles. * represents the articles common to both the search terms "ozone air pollution" and "ozone air pollution PM"

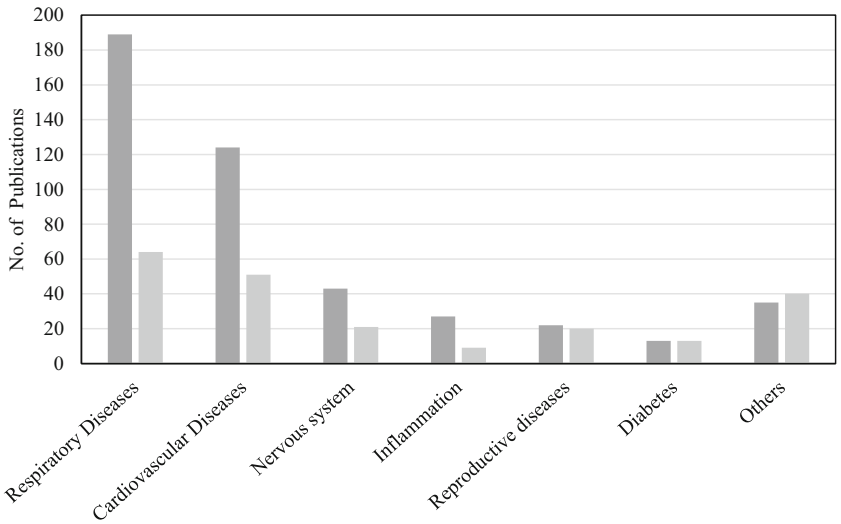

Fig. 8 Comparison between disease trends in the field of "ozone air pollution" and "ozone air pollution PM" between 2017 to 2019. Bar graph shows the comparison between publication counts of the two search terms for identified top diseases on the basis of organ systems. Others category involves publications for less common diseases under the two search terms, i.e., eye and ear disease, cancer, skin, GI tract disease, atherosclerosis and mortality burden prediction, etc. Dark gray indicates data for Ozone air pollution and light gray shows data for ozone air pollution PM

productivity for "ozone and PM in air pollution" in the last years. Most of the literature in the field was contributed by the USA, China, and European countries, with small contributions from the developing countries. We assume that this is due to higher funding available in these countries as well as more emphasis on air pollution regulations in developed countries.

Our co-authorship analysis using country as a unit for the field of "ozone air pollution" demonstrated the USA as the leader in the field with highest number of publications, citations, and link strength. Higher link strength means the country having maximum number of co-author association between the researchers all around the world. Similar trends were observed in the regional distribution of funding agencies and authors contributing to both fields. Several US-based funding agencies were present in the top ten funding agencies in "ozone air pollution" as well as in the upcoming research area of "ozone and PM together in air pollution." This confirms our previous assumption of higher funding in these countries.

During this study, we could identify authors who contributed heavily in ozone research and delineating novel research areas (Table 4). Russell A.G. topped with 77 publications in the field of "ozone air pollution" and 20 publications in the newer area of "ozone and PM together in air pollution" followed by Schwartz J. having 72 but even higher publications (24) in the latter research area. This demonstrates a greater role for a different author in leading the field of two air pollutants and perhaps, a direction switch in the last years. Interestingly, top author based on co-author analysis using author as a unit in the field of "ozone air pollution" showed Zhang Y. from China as a highly collaborative author with 145 publications and 3536 citations. Russell A.G. and Schwartz J. did not show up in the top ten co-author analysis. An analysis of journals displayed atmospheric environment had the maximum number of publications in both the fields. This journal mainly publishes articles on atmospheric phenomenon and events occurring in the atmosphere. Impact factors of the top journals showed environmental health perspectives as the highest impact factor 8.05 journal. Maximum journals were from European countries and the USA. Interestingly but not surprisingly, USEPA is leading affiliation by a significant margin over other affiliations. USEPA is the main body for air pollution research and enforcing guidelines on air pollution in the USA. In addition, most of the funding, as visible from our results, is available to American scientists working in this field. Co-authorship analysis presented UCAS China as the leader in collaborations in organizations followed by CERAE China and NCAR USA. Top cited articles of all time show that the current trend is mainly focused on the key elements in air pollution, responsible for mortality and/or that potentiate the disease state in humans.

Table 4 Comparison between author contributions using keywords 'Ozone air pollution' and 'Ozone air pollution PM'

Author	No. of publications	
	"Ozone air pollution"	"Ozone air pollution PM"
Russell, A.G.	77	20
Schwartz, J.	72	24
Burnett, R.T.	68	13
Blake, D.R.	61	
Derwent, R.G.	55	
Paoletti, E.	55	
Wang, T	55	
Brook, J.R.	53	13
Koutrakis, P.	53	14
Shao, M.	53	
Torres-Jardón, R.		16
Zhang, Y.		16
Calderón-Garcidueñas, L.		14
Hu, J.		13
Dong, G.H.		12

Table shows comparison on the basis of the publication count in both search terms to assess the involvement of authors in both categories

Research trends based on disease area

Our analysis of disease trend demonstrated a major health impact on respiratory system upon ozone exposure in humans. The trend did not change when ozone and PM air pollution effects were studied together. It can be hypothesized that as both ozone and PM (PM 2.5 and PM 10) are generated by same reactions, they will be present in the atmosphere at the same time and thus result in synergistic disease progression [9]. In addition, ozone and PM are the primary constituents of Smog and developing countries such as China and India are still struggling with its rapid increase and related health effects [10,11]. Our analysis displays that other organ systems, i.e., cardiovascular system and nervous system are also impacted upon exposure. Finally, we believe that our findings demonstrate the USA as the leader in research for ozone air pollution. Our data also suggests that co-study of ozone and PM is rapidly gaining momentum and redefining the research direction of the field. Diseases other than respiratory disorders are also being highlighted after ozone exposure. Furthermore, our analysis demonstrated that as other organ systems (cardiovascular system and nervous system) are also affected, a systems biology approach to combine the human health effects will be beneficial to the field and studies concentrating to only one organ system should be avoided. Finally, we believe that our findings demonstrate the USA as the leader in research for

ozone air pollution. Our data also suggests that co-study of ozone and PM is rapidly gaining momentum and redefining the research direction of the field. Diseases other than respiratory disorders are also being highlighted after ozone exposure. Furthermore, our analysis demonstrated that as other organ systems (cardiovascular system and nervous system) are also affected, a systems biology approach to combine the human health effects will be beneficial to the field and studies concentrating to only one organ system should be avoided.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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