



The impact of COVID-19 pandemic on air pollution: a global research framework, challenges, and future perspectives

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Abstract

As a result of extreme modifications in human activity during the COVID-19 pandemic, the status of air quality has recently been improved. This bibliometric study was conducted on a global scale to quantify the impact of the COVID-19 pandemic on air pollution, identify the emerging challenges, and discuss the future perspectives during the course of the ongoing COVID-19 pandemic. For this, we have estimated the scientific production trends between 2020 and 2021 and investigated the contributions of countries, institutions, authors, and most prominent journals metrics network analysis on the topic of COVID-19 combined with air pollution research spanning the period between January 01, 2020, and June 21, 2021. The search strategy retrieved a wide range of 2003 studies published in scientific journals from the Web of Sciences Core Collection (WoSCC). The findings indicated that (1) publications on COVID-19 pandemic and air pollution were 990 (research articles) in 2021 with 1870 citations; however, the year 2020 witnessed only 830 research articles with a large number 16,600 of citations. (2) China ranked first in the number of publications ($n = 365$; 18.22% of the global output) and was the main country in international cooperation network, followed by the USA ($n = 278$; 13.87% of the global output) and India ($n = 216$; 10.78 of the total articles). (3) By exploring the co-occurrence and links strengths of keywords “COVID-19” (1075; 1092), “air pollution” (286; 771), “SARS-COV-2” (252; 1986). (4) The lessons deduced from the COVID-19 pandemic provide defined measures to reduce air pollution globally. The outcomes of the present study also provide useful guidelines for future research programs and constitute a baseline for researchers in the domain of environmental and health sciences to estimate the potential impact of the COVID-19 pandemic on air pollution.

Keywords COVID-19 · Air pollution · Bibliometric analysis · Web of Science

Introduction

Since its outbreak in December 2019, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) or COVID-19 coronavirus pneumonia or disease labeled as “COVID-19” has caused more than 364,191,494 confirmed cases with 5.6 million deaths in 220 countries and territories (Worldometers 2020; Zhu et al. 2020). In South Africa, on November 24,

2021, a highly mutated variant of concern (VOC) G.R./484A (B.1.1.529) of the SARS-CoV-2 was detected. Questions have been raised about the source of this highly mutated strain (GISAID 2021; World Health Organization 2021). Omicron variants were reported in 38 countries in all six WHO regions as of December 3, 2021. Growing trends suggest the increased transmission in South Africa. In May 2021, the WHO classified the SARS-CoV-2 Delta variant (B.1.617.2) as a VOC due to increased transmissibility, even in the context of communities where there has been an increase in the percentage of individuals who have been fully vaccinated (Luo et al. 2021).

More recent data proposed that senior citizens, in addition to persons with underlying disease, are more likely to be hospitalized or dead as a result of COVID-19 infection (Guan et al. 2020; Pansini and Fornacca 2020; Wu et al. 2020c). According to the Centers for Disease Control and

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Prevention, there is a long list of risk factors for severe COVID-19 impact that highly overlap with the list of diseases that are recognized to be exacerbated by severe exposure to air pollution such as lung cancer, heart diseases, asthma, and chronic obstructive pulmonary disease (Mehmood et al. 2020a; Wu et al. 2020a).

Several atmospheric pollutant species such as particulate matter (PM) having sizes less than 2.5 or 10 μm ($\text{PM}_{2.5}$ and PM_{10} , respectively), ozone (O_3), nitric oxide (NO_2), and volatile organic compounds (VOCs) emitted from industries and vehicles are considered hazardous for human health. Researchers unanimously agreed that acute exposure to such air pollutants notably increased mortality or morbidity and enveloped several cardiopulmonary disorders (Cohen et al. 2017; Mehmood et al. 2020c; Wu et al. 2020a). Prodigious impacts of COVID-19 on human health, several countries implemented extensive and moderate non-pharmaceutical interventions to slow down the infection rate (Mehmood et al. 2021a; Tao et al. 2021), that has led to global change in terms of improvement in air quality due to reduction in pollutant emissions (Saadat et al. 2020; Sharma et al. 2020). The reduction in air pollution levels has been reported in several countries around the world, such as China, Portugal, Pakistan, and India. In the most polluted countries, $\text{PM}_{2.5}$ dropped by about 12% during the COVID-19 pandemic, with the most dramatic reductions occurring in America, Asia, and Africa (Rodríguez-Urrego and Rodríguez-Urrego 2020). A study conducted by Bao and Zhang (2020) examined the impact of COVID-19 lockdown on the air quality of over 44 cities in northern China. Results suggested that reduction of air pollution was strongly associated with travel restrictions. Similarly, a study conducted in São Paulo, Brazil, by Nakada and Urban (2020) also reported the reduction in CO, NO, and NO_2 by ~64.8%, ~77.3%, and ~54.3%, respectively, during a partial lockdown. These studies in different regions of the world established that implementations of certain restrictions have greatly reduced air pollution and improved air quality. A great deal of literature suggested that air pollution may be held responsible for COVID-19 severity by directly disturbing the lungs' performance to clean the viruses or pathogens and indirectly worsening the underlying pulmonary or cardiovascular diseases (Cole et al., 2020; Wu et al., 2020a, b, c). A similar theme of the study was conducted on SARS outbreak in China during 2003 and showed that chronic air pollution in terms of air pollution index had a positive relationship with SARS case-fatality rates (Cui et al. 2003).

There are some studies indicated that there might be potency between COVID-19 spread and air pollution (Coccia 2021; Pei et al. 2021). Since SARS-CoV-2 has spread in almost every country of the world, more reports are establishing the association of acute/chronic air pollution with COVID-19. A recent study by a research group at Dali University showed that air pollution exacerbated the COVID-19-associated mortality or morbidity over China,

Italy, and the USA. They employed annual indices of air quality ground and Sentinel-5 satellite data from each country and reported higher COVID-19 infection rates in study areas having higher $\text{PM}_{2.5}$, CO_2 , and NO_2 concentration levels (Pansini and Fornacca 2020). Long-term exposure to air pollutants (PM_{10} , $\text{PM}_{2.5}$, NO_2 , and O_3) was significantly correlated with COVID-19 cases across 71 Italian provinces (Fattorini and Regoli 2020). In the same vein, Wu et al. (2020b) found that long-term average exposure to $\text{PM}_{2.5}$ concentration increased the risk of COVID-19 infection in the USA. Their results suggested that the exposure of only 1 mg m^{-3} of acute $\text{PM}_{2.5}$ concentration increased the COVID-19 death rate by 15%. In terms of climatic factors, a study conducted by Mehmood et al. (2021b) indicated that $\text{PM}_{2.5}$ and temperature were positively correlated with the COVID-19 case in Lahore, Pakistan. However, the main emphasis of the studies related to COVID-19 and air pollution is identifying the impact of the COVID-19 pandemic on air pollution reduction, especially in densely and large cluster urban areas during the periods of lockdown.

The concept of bibliometric analysis refers to the objective assessment of scientific knowledge, highlighting the hot-spots in research, development trends, and key research institutions for relevant scientific research (Valérie and Pierre 2010). Based on the bibliometric analysis and evidence maps, Liu et al. (2020) developed a world graph to estimate the growth of medical literature on COVID-19 in the early stages of its emergence. This can be utilized in research tools to identify research collaboration opportunities. COVID-19-related literature analysis plays a critical role in understanding the current research on COVID-19. Therefore, the current study is the first of its kind that helps to improve our understanding on the impact of the COVID-19 pandemic on air pollution and explain the research prominence, challenges, and future perspectives on a global scale. We covered the scientific production of articles related to the topic of the study by analyzing the productivity of the research in terms of different types of keyword analysis including author keywords and keywords plus. We identified the scientific journals and main authors publishing reports regarding the impact of COVID-19 on air pollution. In addition, citations' work, impactful articles, countries, and institutions' research collaboration were analyzed quantitatively and qualitatively in order to assess the studies metrics associated with the impact of the COVID-19 pandemic on air quality as well as to propose combat strategies. This study also highlighted the impact of air pollution on the COVID-19 pandemic and discussed the current and future implications of this work. However, the main emphasis has been given to the main theme that highlights the impact of the COVID-19 pandemic on air pollution due to a large number of studies on this topic. In brief, the present study was conducted to provide first classified information on the development

of research publications merging the themes related to the impact of COVID-19 pandemic on air pollution as well as to highlight the leading themes of research which are streaming as the effect of the crisis and institute a research program for epidemiologist and environmentalist.

Material and methods

Our study employed the Web of Science Core Collation (WoSCC) database that offers an accessible version of the Science Citation Index Expanded (SCI-EXPANDED). The SCI-EXPANDED Web of Science (WoS) was selected due to its robustness to characterize search results (Vanzetto and Thomé 2019a; Usman and Ho 2020a). WoS database was utilized for studying the impact of the COVID-19 pandemic on air pollution. However, there are several variations of particular words used in the scientific literature on this subject, such as “SARS-CoV-2,” “COVID-19,” “2019-nCoV,” “coronavirus” air pollution,” “air quality,” “emissions,” and “particulate matter.” The WoS query equation (TS = (((“COVID-19” OR “SARS-CoV-2”) AND (“air quality” OR “air pollution” OR “particulate matter” OR “emissions” OR “ozone” OR “NO₂” OR “SO₂” OR “PM_{2.5}” OR “CO₂”)))) AND LANGUAGE: (English). The major spotlight is on the most important studies entailing the global scope with reliable scientific work described. The selection of key words method was refined until the desired search was completed. Afterward, the retrieved documents from WoS were screened based on our study horizon, ensuring the purpose of this study which exclusively covers the impact of the COVID-19 pandemic on air pollution. To guarantee the significance of this study design, first-class journals were prudently selected to be incorporated to evade redundant muddle. In order to cover the complete picture of research developments in this field, this study chose the research period from 2020 to 2021 that primarily emphasizes on the study research topic. By virtue of this targeted strategy, this study selected 2003 documents of six types. In order to conduct a bibliometric analysis, 1000 research articles were found good enough for the assessment of various metrics (Rogers et al. 2020).

Based on the preliminary screening, data were accessed on August 4, 2021, by applying the above keywords within TS (topic), author (AU), author keywords (AK), author keywords plus, PY (year published), AD (address), and SU (research area) in the advanced search option. We used quotation marks (“”) to screen out the exact search term by evading the lemmatization and synonym in the WoS database that are by default “ON” in the search sites tab case. In addition, we used “AND” to connect the keywords and “OR” was utilized to find the exact expression match in the search (Vanzetto and Thomé 2019a).

This study considered the number of published documents as a quantitative indicator which specifies the research productivity of the country, source, institution, authors, etc. Additionally, the assessment of published work was performed by applying several qualitative indicators that included average citation, single country production (SCP) and multiple countries production (MCP), frequency of articles published by each country, h-index, m-index, and g-index analysis for both authors and journals, number of citations, and highly impactful articles based on recent citations. The h-index, g-index, and m-index measure both citation and the efficiency of the researcher in terms of citation (Hirsch 2005). The g-index estimates the top ten publications of an author that have been cited hundred times (Egghe 2006). We employed VOSviewer software (version 1.6.15) and R package 4.0.4 for preparing interactive plots, tabulation, and different kinds of visualization. This study used visualizing bibliographic networks to explore country scientific collaboration, keyword co-occurrence, and conceptual structure map for co-word analysis and three-field biplot. Network, overlay, and density visualizations with a variety of colors were applied to reflect different types of items such as links, total link strength, and clusters. The cloud circles demonstrated the magnitude of each studied variable. The detailed information can be found in the study of van Eck and Waltman (2014).

Results and discussion

The characteristic of scientific production

This study retrieved a total of 2003 documents printed in the English language, which were gathered from the WoS database during 2020 and 2021. Similar to other publications (Vanzetto and Thomé 2019b; Bao et al. 2021), the leading number of retrieved publications were original research articles (1468), contributing to 73.29% of the total yield, followed by review papers (215; 10.73%), articles with early access (151; 7.53%), editorial materials (73; 3.64%), letter (40; 1.99%), review articles with early access (24; 1.19%), proceeding papers (10; 0.49%), and other types of documents (Table 1).

We used a 100% stacked column to compare the percentage contribution (%) of articles and citations between 2020 and 2021. A total of 830 articles were published in 2020, with a huge number of 16,600 citations (Fig. 1). However, in the year 2021, the number of articles reduced to 990 with 1870 citations. An extensive number of citations for the documents published in 2020 may be reasoned to the increased number of articles published in 2020. Research on COVID-19 in response to air pollution is still at the infancy stage and receives a large number of citations from scholars.

Table 1 Basic information of scientific publication used in this study

Description	Results
Main information about data	
Timespan	2020:2021
Sources (journals, books, etc.)	705
Documents	2003
Average years from publication	0.457
Average citations per documents	9.289
Average citations per year per doc	5.582
References	68,563
Document types	
Article	1468
Article; data paper	7
Article; early access	151
Article; proceedings paper	4
Book review	1
Correction	1
Editorial material	73
Editorial material; early access	3
Letter	40
Letter; early access	3
Meeting abstract	1
News item	2
Proceedings paper	10
Review	215
Review; early access	24
Document contents	
Keywords plus (ID)	2702
Author's Keywords (DE)	4452
Authors	
Authors	9675
Author appearances	11,827
Authors of single-authored documents	125
Authors of multi-authored documents	9550
Authors collaboration	
Single-authored documents	136
Documents per author	0.207
Authors per document	4.83
Co-authors per documents	5.9
Collaboration index	5.12

For document content analysis, a total number of keyword plus (ID) and author keyword (DE) were recorded: 2702 and 4452, respectively. In this study, total authors, author appearances, single-author documents, and multi-author documents were found: 9675, 11,827, 125, and 9550, respectively. In terms of authors' collaboration and collaboration index, there were found 5.12 for this study. It can be seen that a large number of authors participated in the COVID-19 pandemic and air pollution that emphasized the importance of this research theme.

Scientific collaboration of countries

Based on the affiliation of a minimum of one author of the article, the scientific collaboration of different countries was investigated. Interestingly, the authors from 78 countries contributed to the publication of articles pertaining to COVID-19 and air pollution. China's documents output (365) ranked first, accounting for 18.22% of the total output. The single country publication (SCP) and multiple country publications (MCP) were 232 and 133, respectively, with a 0.364 MCP ratio (Table 2). The USA ranked second with 278 documents accounting for 13.87% of the total output along with 191 SCP and 87 MCP and 0.313 MCP ratio (Table 2). India stood third in the ranking, with 216 documents contributing 10.78% of the total documents from 2020 to 2021. On a qualitative basis, China, the United States, and Italy publications have received 5899, 4710, and 3178 citations, respectively. This indicates that China is the pioneer country to initiate the research on the theme related to the impact of COVID-19 on air pollution.

For countries' analysis, we performed the bibliographic coupling using the full counting method. Findings demonstrated that both China and the USA had developed 60 links. However, the total link strength of China and the USA were found: 453,695 and 406,213, respectively (Fig. 2). Globally, both China and the USA contributed significantly to the COVID-19 and air pollution research. This is due to the fact that the pandemic first emerged from the Chinese city, Wuhan, in late December 2019 (Zhu et al. 2020) and then spread to all over the world.

On the basis of countries analysis, both China and the USA were the leading countries working on the COVID-19 and air pollution research, whereas India, Italy, the United Kingdom, Spain, Germany, Canada, and Australia also contributed significantly on this topic. As seen in Table 2, except for China and India, the majority of the productive countries were from Europe. This disparity may reveal the strong collaborative network among European countries and poor collaboration and may be due to lower funding, among the rest of the countries, especially in Asian countries. However, higher productivity of research in China and the USA was attributed to funding availability in these countries. Since India is badly hit by the twin menace of air pollution and the COVID-19 pandemic, collective efforts are urgently needed to address this issue in terms of COVID-19 research with respect to air pollution (Mehmood et al. 2020b). Recent estimates (IQAir 2019) revealed that the top-most polluted cities of the world mostly belonged to India, and therefore, unmanaged air pollution could worsen the situation of COVID in India and neighboring countries.

Fig. 1 Staked column analysis for documents and citations during 2020–2021

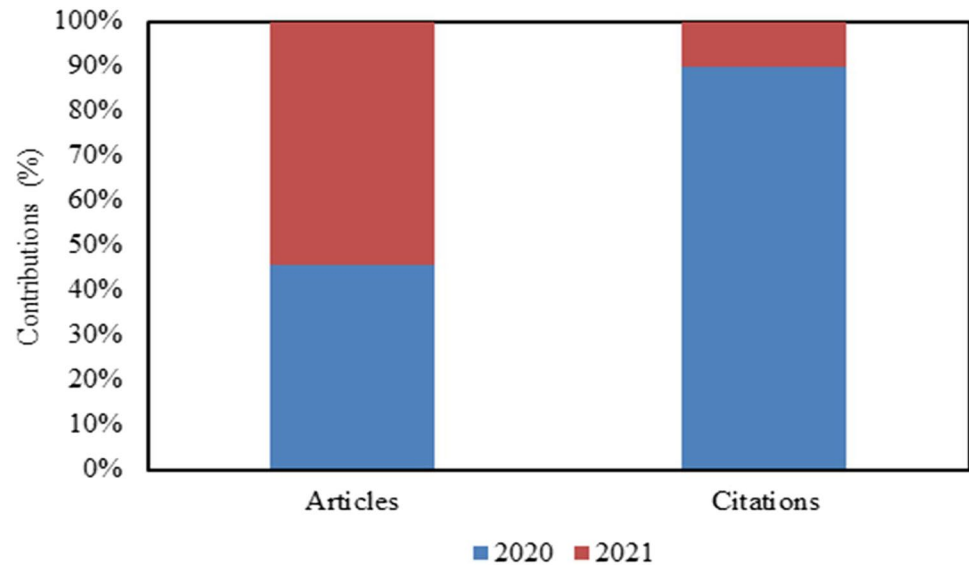
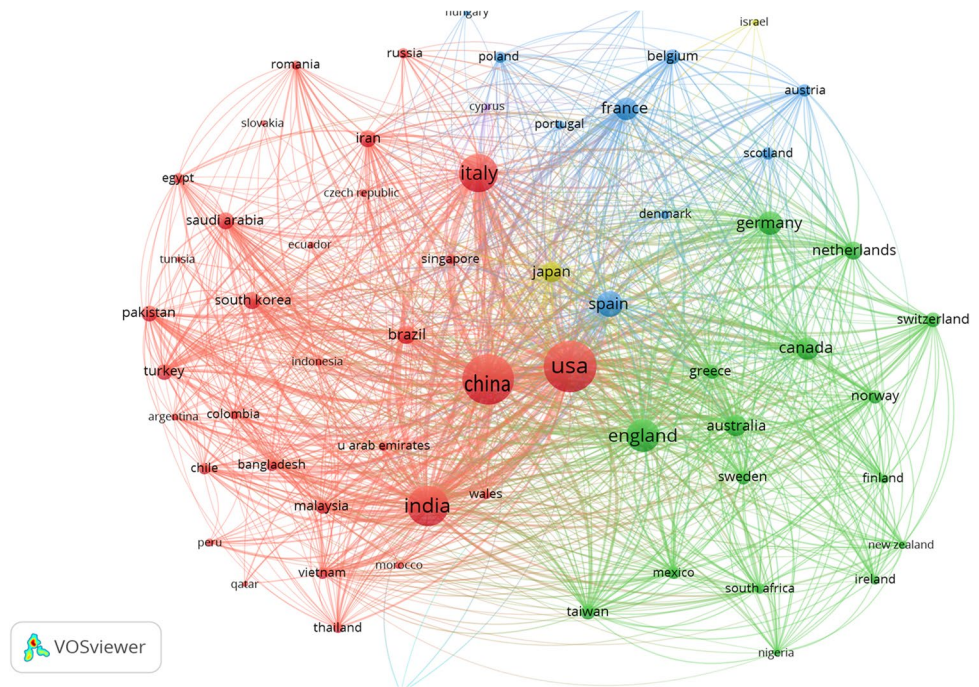


Table 2 Countries scientific productivity based on no. of article, frequency, single country production (SCP), and multi-country production (MCP)

Country	Articles	Frequency	SCP	MCP	MCP_Ratio	Country	Articles	Freq	SCP	MCP	MCP_Ratio
China	365	0.184250	232	133	0.364	Bangladesh	11	0.005553	8	3	0.273
USA	278	0.140333	191	87	0.313	Romania	11	0.005553	7	4	0.364
India	216	0.109036	169	47	0.218	Austria	10	0.005048	5	5	0.500
Italy	197	0.099445	139	58	0.294	Egypt	10	0.005048	5	5	0.500
United Kingdom	102	0.051489	62	40	0.392	Netherlands	10	0.005048	3	7	0.700
Spain	71	0.035840	51	20	0.282	Singapore	10	0.005048	4	6	0.600
Germany	53	0.026754	31	22	0.415	Sweden	10	0.005048	3	7	0.700
Canada	51	0.025745	39	12	0.235	Chile	9	0.004543	7	2	0.222
Australia	41	0.020697	19	22	0.537	Ireland	9	0.004543	6	3	0.333
Japan	39	0.019687	31	8	0.205	Nigeria	9	0.004543	5	4	0.444
Brazil	37	0.018677	30	7	0.189	South Africa	9	0.004543	4	5	0.556
France	37	0.018677	18	19	0.514	Vietnam	9	0.004543	2	7	0.778
Korea	33	0.016658	23	10	0.303	Argentina	8	0.004038	2	6	0.750
Iran	32	0.016153	17	15	0.469	United Arab Emirates	8	0.004038	2	6	0.750
Turkey	32	0.016153	27	5	0.156	Czech Republic	7	0.003534	0	7	1.000
Saudi Arabia	23	0.011610	12	11	0.478	Morocco	7	0.003534	5	2	0.286
Greece	16	0.008077	10	6	0.375	Portugal	7	0.003534	5	2	0.286
Norway	16	0.008077	6	10	0.625	Colombia	6	0.003029	5	1	0.167
Pakistan	16	0.008077	8	8	0.500	Denmark	6	0.003029	4	2	0.333
Malaysia	15	0.007572	9	6	0.400	Ecuador	6	0.003029	2	4	0.667
Mexico	15	0.007572	12	3	0.200	Hungary	5	0.002524	5	0	0.000
Thailand	15	0.007572	9	6	0.400	Israel	5	0.002524	5	0	0.000
Belgium	13	0.006562	8	5	0.385	Russia	5	0.002524	3	2	0.400
Switzerland	13	0.006562	9	4	0.308	Cyprus	4	0.002019	1	3	0.750
Poland	12	0.006058	9	3	0.250	Kazakhstan	4	0.002019	2	2	0.500

Fig. 2 Country scientific production during 2020–2021



Keyword analysis and research hotspots

Both keywords and keyword plus analyses are offering a resourceful approach to finding new horizons of research on a particular theme (Zhang et al. 2010). The author keyword is the list of keywords given in the author documents and is considered a valuable piece of information for the scientific community on research dynamics and perspectives. The keyword plus is generated from the titles of the cited documents and could implicit the insides of the documents with larger details multiplicity (Usman and Ho 2020b; Bao et al. 2021).

The data show that the most recurrently occurred author keywords were “COVID-19” (1075), “air pollution” (286), “SARS-COV-2” (252), “lockdown” (189), “air quality” (186), “coronavirus” (126), “particulate matter” (92), “PM_{2.5}” (90), “pandemic” (82), and “NO₂” (72) entailing the significance of analyzing the impact of COVID-19 on air pollution topic. Likewise, the keyword plus network indicated that the most frequent words were “pollution” (170), impact (162), air pollution (141), emissions (104), and exposure (90) (Table 3).

Figure 3 shows author keyword co-occurrence (a), word cloud network (b), thematic map (c), and words cloud network plot data (d). The keyword “COVID-19” generated total link strength of 1092 with 2301 links and one cluster. In the same vein, “air pollution” developed total link strength of 771 with 127 links and seven clusters. Likewise, “SARS-COV-2” completed total link strength of 6048 with 1986 links and thirteen clusters. On an overall basis, 198 items were made with total link strength of 6048 and 13 clusters.

Most productive journals

Most active journal analysis helps the scholar to understand how COVID-19 information is circulated across journals and to choose the top journals to publish and disseminate their research work. It was noticed that most of the publications were documented in the environmental sciences domain (1057 articles), followed by public environmental occupational health (240 articles), science technology and other topics (235 articles), engineering (193 articles), and meteorology atmospheric sciences (138 articles). Total 956 documents were available in 30 journals, contributing 47.72% of all documents. *Science of the Total Environment* (IF₂₀₂₀ 7.96) published the highest documents ($n = 176$, 8.78%), followed by *Aerosol and Air Quality Research* ($n = 72$, 3.59%; IF₂₀₂₀ 3.13) and *International Journal of Environmental Research and Public Health* ($n = 71$, 3.54%; IF₂₀₂₀ 3.36). *Science of the Total Environment* recorded the most h-index (42), g-index (78), and m-index (21), with 6500 TC and 18 NP scores (Table 4). Most productive journals, especially *Science of the Total Environment*, *Aerosol, Air Quality Research*, and *International Journal of Environmental Research and Public Health*, in this research domain are generally interdisciplinary, covering the total environment that interfaces the biosphere, atmosphere, lithosphere and anthroposphere, air quality, atmospheric chemistry, global change, effects on the environment, environmental health sciences, and public health. We utilized a Sankey three-field plot in order to encapsulate the associations among top journals, top authors, and top keywords (Fig. 4a) and bibliographic

Table 3 Author keyword and author keyword plus networks

Author keywords	Articles	Keywords plus	Articles
COVID-19	1075	Pollution	170
Air pollution	286	Impact	162
SARS-CoV-2	252	Air-pollution	141
Lockdown	189	Emissions	104
Air quality	186	Exposure	90
Coronavirus	127	Quality	87
Particulate matter	92	Air-quality	84
PM _{2.5}	90	Mortality	84
Pandemic	82	PM _{2.5}	84
NO ₂	72	Ozone	80
Ozone	69	China	73
Climate change	49	Particulate matter	71
Nitrogen dioxide	43	Health	69
PM ₁₀	38	Transmission	66
COVID-19 pandemic	36	Coronavirus	62
Pollution	36	Association	48
Mortality	35	Temperature	48
India	33	COVID-19	47
Temperature	33	Urban	45
China	32	Model	44
Air quality index	31	Aerosol	42
Public health	30	Outbreak	39
Aerosol	29	Trends	38
Air pollutants	29	Risk	35
Environment	29	Source apportionment	35
Sustainability	27	Disease	33
PM _{2.5}	25	Infection	33
Aerosols	24	Nitrogen-dioxide	33
COVID-19 lockdown	24	Virus	32
Environmental pollution	23	Climate	30
Humidity	22	Pollutants	30
Indoor air quality	22	NO ₂	29
Machine learning	22	Aerosols	28
O ₃	19	Climate-change	26
Airborne transmission	18	Impacts	25
AQI	18	Performance	25
Ventilation	18	Wuhan	25
Black carbon	17	Particles	24
Health	17	City	23
Remote sensing	17	Survival	23
COVID	16	Black carbon	22
Italy	16	Transport	22
Epidemiology	15	Cities	21
Social distancing	15	Influenza	21
Traffic	15	Humidity	20
TROPOMI	15	Inactivation	20
Virus	15	SARS	20
Climate	14	SARS-COV-2	20
Emission reduction	14	Air	19

coupling with source analysis applying the full counting method (Fig. 4b). The bibliographic coupling results showed that *Science of the Total Environment* received 102,521 total strengths with 6500 citations, followed by *Aerosol and Air Quality Research* (533 citations with 49,474 total strengths) and *Environmental Research IF₂₀₂₀* 6.28 (47,209 total strengths with 912 citations). Maximum productivity of *Science of the Total Environment* could be ascribed to their special issue on COVID-19 and its impact on the environment.

Active institutional analysis

To analyze the contribution of various institutions to the research on the topic related to COVID-19 and air pollution, we isolated active institutions on the basis of the maximum quantity of documents associated with the affiliations of at least the contribution of one author. Of the 3319 institutions, only those institutions were selected that published more than five documents (232 institutions). Since COVID-19 first case reported from Wuhan that forced to initiate research on this topic much earlier than the rest of the world, all of the top five institutions belonged to China. Moreover, Wuhan is located in Central China which were already experiencing heavy air pollution due to the past few years (Zhang et al. 2014; Zhu et al. 2020). Figure 5 illustrates overlay visualization of active journals using bibliographic coupling with organization applying full counting method. The leading institutions were the Chinese Academy of Sciences with 55 documents, 55,063 total link strength with 521 citations, followed by the Nanjing University of Information Science and Technology having 39 documents, 42,776 total link strength with 385 citations; University Chinese Academy of Sciences having 28 documents, 28,413 total link strength with 126 citations; Fudan University having 25 documents, 24,249 total link strength with 883 citations; and Shanghai Jiao Tong University having 19 documents, 20,648 total link strength with 332 citations (Fig. 5). The highest productivity in the Chinese Academy of Sciences is due to the substitutes nationwide, and all the data of these sub-institutes were combined into CAS research work. This is one of the reasons the Chinese Academy of Science ranked first on COVID-19 research and air pollution research. Most of the COVID-19 research is funded by the National Natural Science Foundation of China (NSFC) has grabbed 202 projects for this research.

Author analysis and highly impactful work

The scientific community has a significant role in the research developments, and their published research productivity reflects the scale of their investigation. Moreover, the co-citation and citation linkages characterize the metrics

Table 4 Journals metrics analysis related to the impact of COVID-19 pandemic and air pollution

Element	h_index	g_index	m_index	Total citation (TC)	No. of publications (NP)	Publication year (PY_start)
Science of the total environment	42	78	21	6500	145	2020
Environmental research	16	29	8	912	51	2020
Aerosol and air quality research	13	21	6	533	45	2020
Air quality atmosphere and health	11	20	5	457	31	2020
Environmental pollution	11	31	5	987	31	2020
International journal of environmental research and public health	11	22	5	569	43	2020
Geophysical research letters	9	19	4	380	21	2020
Atmosphere	8	15	4	228	18	2020
Environmental and resource economics	7	13	4	175	15	2020
Environment development and sustainability	6	11	3	134	17	2020
Environmental chemistry letters	6	9	3	126	9	2020
Remote sensing	6	11	3	143	20	2020
Sustainability	6	11	3	190	40	2020
Applied energy	5	7	2	62	8	2020
Environment international	5	7	2	161	7	2020
Science advances	5	6	2	169	6	2020
Scientific reports	5	10	2	103	12	2020
Sustainable cities and society	5	7	2	87	7	2020
Atmospheric chemistry and physics	4	7	2	60	12	2020
Bulletin of environmental contamination and toxicology	4	4	2	100	4	2020
Energy research and social science	4	4	2	96	4	2020
Environmental science and technology letters	4	7	2	75	7	2020
Frontiers in public health	4	5	2	30	7	2020
Global journal of environmental science and management-gjesm	4	4	2	102	4	2020
Journal of cleaner production	4	7	2	67	7	2020
Journal of infection	4	4	2	294	4	2020
Urban climate	4	6	2	41	6	2020
Atmospheric environment	3	4	3	21	6	2021
Atmospheric pollution research	3	5	3	31	5	2021
Chemosphere	3	6	1	49	8	2020

the basis of their impact of COVID-19 on air pollution during 2020–2021. Mahato et al. (2020) examined the effect of COVID-19 lockdown on air quality in Delhi, India. The findings suggested that air quality is significantly improved during the lockdown period and pollutants ($PM_{2.5}$ and PM_{10}) reduction ($> 50\%$) that have been recorded in comparison to the pre-lockdown phase. In the case of the USA, Berman and Ebisu have observed the changes in air pollution levels ($PM_{2.5}$ and NO_2). Findings suggested that both $PM_{2.5}$ and NO_2 significantly reduced during COVID-19 in the USA. Similarly, Giani et al. (2020) found both short- and long-term health benefits due to decreased air pollution during COVID-19 containments over Europe using methods similar to the Global Burden of Disease (GBD) project. On the basis of the $PM_{2.5}$ reduction scenario of $2.2 \mu g m^{-3}$ (17%) over Europe, it is an estimation that 2190 premature fatalities

were prevented during COVID-19 restriction measures from February to May 2020. Long-term averted premature deaths attributed to decreased $PM_{2.5}$ levels could start from 13,600 to 29,500 for Europe, subject to the projected scenarios of the COVID-19 pandemic and exit plans scenarios and further improved air quality over this region (Venter et al. 2020).

On the basis of community intervention scenarios, Adams (2020) observed a significant reduction in NO_2 and NO_x during the different courses of five-week lockdown periods in Canada. In a similar vein, Tobías et al. (2020) reported the variations in air pollution levels in response to the community intervention adopted by the Barcelona government. Their findings found that levels of pollutant gases dropped about 45% after two weeks of containment measures. In addition, Zangari et al. (2020) reported a decrease

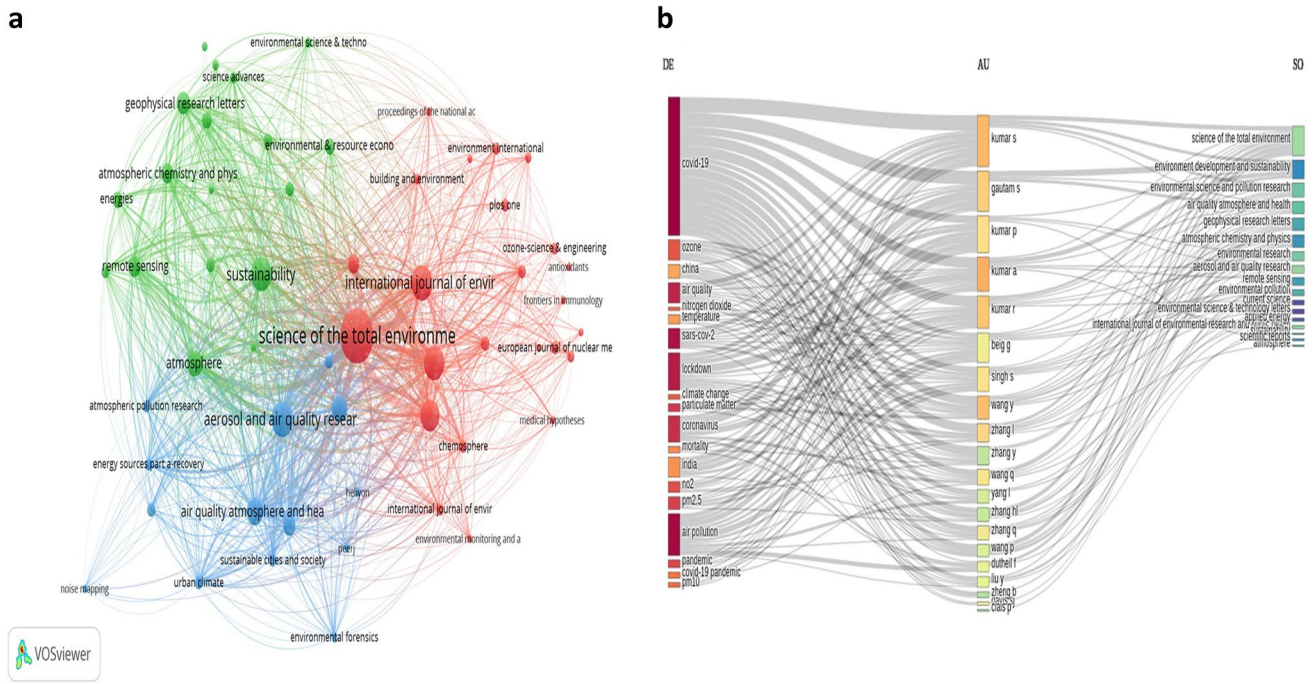
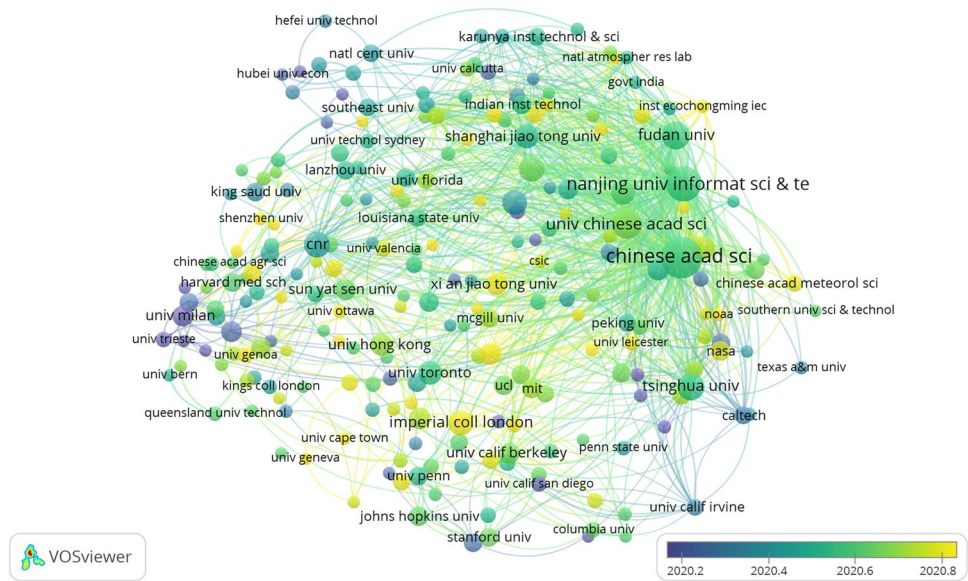


Fig. 4 Most productive journal through network visualization applying bibliographic coupling with sources using full counting method (a). Sankey three-field plot exploring the relationship among top keywords, authors, and productive journals (b)

Fig. 5 Overlay visualization of the most active institutions



of NO₂ (51%) and PM_{2.5} (36%) levels in New York after lockdown. There are several other studies that reported the reductions in both air pollutant and fossils fuel emission in response to community interventions in countries like China (Zhang et al. 2020), Japan (Ma and Kang 2020), and Iran (Broomandi et al. 2020).

However, the analysis conducted by Giani et al. (2020) and Venter et al. (2020) should be designated as baseline lessons for the impact of the COVID-19 pandemic on air

pollution reduction and can help to avoid deaths due to COVID-19. However, tangible impacts on the burden of disease should include for the entirety of the community intervention such as alterations in lifestyle conducts, economic changes, mental health, and slowness in disease management processes. These alternations can balance or exceed the recorded decrease in disease burden due to the abridged level of air pollution during COVID-19 community intervention. Intrinsically, there is no bright side of the COVID-19

Table 5 Highly impactful articles based on total citations and average citation during 2020–2021

Title	Authors	Source Title	Publication Year	DOI	Total Citations	Average per Year	2020	2021
Temporary reduction in daily global CO ₂ emissions during the COVID-19 forced confinement	Le Quéré et al. (2020)	Nature climate change	2020	10.1038/s41558-020-0797-x	355	177.5	152	202
Turbulent Gas Clouds and Respiratory Pathogen Emissions Potential Implications for Reducing Transmission of COVID-19	Bourouiba (2020)	Journal of the American medical association	2020	10.1001/jama.2020.4756	351	175.5	222	129
Effect of restricted emissions during COVID-19 on air quality in India	Sharma et al. (2020)	Science of the total environment	2020	10.1016/j.scitotenv.2020.138878	293	146.5	127	166
Can atmospheric pollution be considered a co-factor in extremely high level of SARS-CoV-2 lethality in Northern Italy?	Conticini et al. (2020)	Environmental pollution	2020	10.1016/j.envpol.2020.114465	279	139.5	159	120
COVID-19 pandemic and environmental pollution: A blessing in disguise?	Muhammad et al. (2020)	Science of the total environment	2020	10.1016/j.scitotenv.2020.138820	270	135	116	154
Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India	Mahato et al. (2020)	Science of the total environment	2020	10.1016/j.scitotenv.2020.139086	259	129.5	101	158
Assessing nitrogen dioxide (NO ₂) levels as a contributing factor to coronavirus (COVID-19) fatality	Ogen (2020)	Science of the total environment	2020	10.1016/j.scitotenv.2020.138605	259	129.5	134	125
Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China	Zhu et al. (2020)	Science of the total environment	2020	10.1016/j.scitotenv.2020.138704	258	129	117	141
Indirect effects of COVID-19 on the environment	Zambrano-monserrate et al. (2020)	Science of the total environment	2020	10.1016/j.scitotenv.2020.138813	254	127	95	159
Effects of temperature variation and humidity on the death of COVID-19 in Wuhan, China	Ma et al. (2020)	Science of the total environment	2020	10.1016/j.scitotenv.2020.138226	254	127	132	122

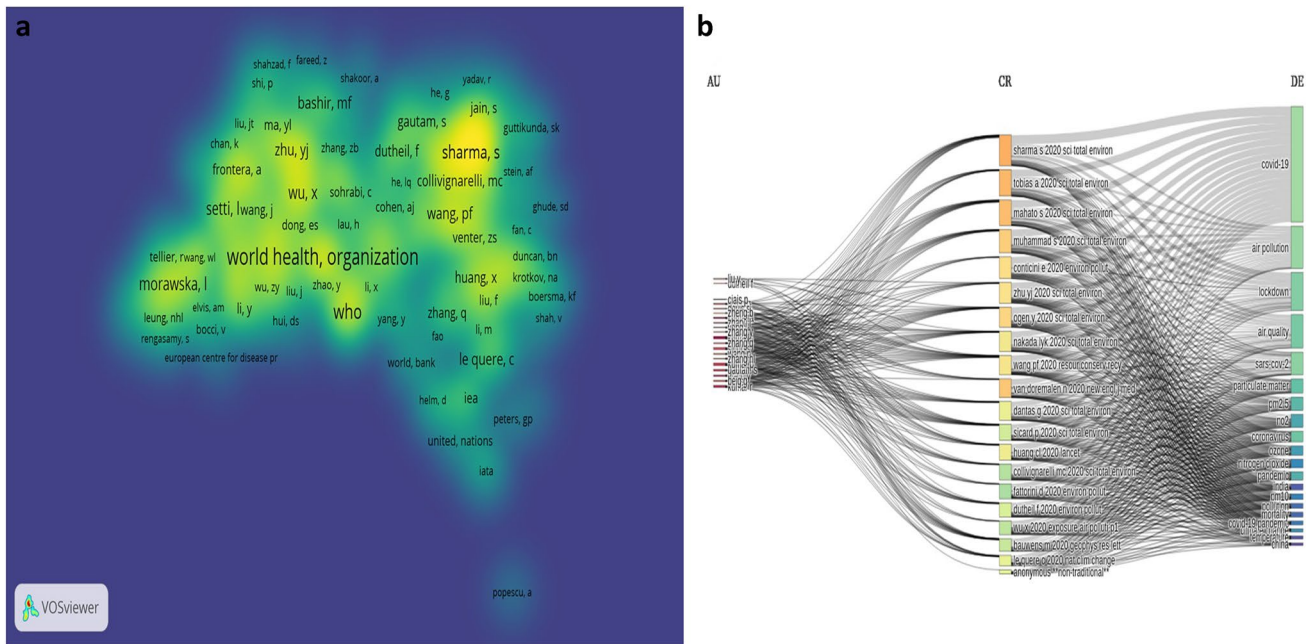


Fig. 6 Authors co-citation network using density visualization (a). Sankey three-field plot exploring the relationship among productive authors, references, and keywords (b)

Table 6 Author index analysis (h-index, g-index, and m-index) with total citation (TC) and number of publications (NP) during 2020–2021

Element	h_index	g_index	m_index	TC	NP	PY_start
Wang Q	6	8	3	315	8	2020
Ciais P	5	7	2.5	151	7	2020
Coccia M	5	5	2.5	190	5	2020
Davis SJ	5	8	2.5	209	8	2020
Ghosh S	5	5	2.5	34	6	2020
Gupta A	5	6	2.5	100	6	2020
Miani A	5	6	2.5	333	6	2020
Piscitelli P	5	6	2.5	333	6	2020
Shahzad U	5	5	2.5	122	5	2020
Wang YF	5	5	2.5	177	5	2020
Yang I	5	7	2.5	79	7	2020
Zheng B	5	7	2.5	232	7	2020
Barbieri P	4	4	2	323	4	2020
Bera B	2	2	2	24	2	2021
Bherwani H	4	5	2	94	5	2020
Chevallier F	4	6	2	118	6	2020
Conte M	2	2	2	19	2	2021
Creutzig F	2	2	2	5	2	2021
Cui KP	4	4	2	133	4	2020
Dancer SJ	2	2	2	58	2	2021
DE Gennaro G	4	4	2	323	4	2020
Domingo JI	4	4	2	106	4	2020
Eskes H	4	5	2	222	5	2020
Fu QY	4	5	2	158	5	2020

pandemic; however, these studies' analyses are characterized to provide health benefits from air pollution reductions by means of decreasing human and industrial activities.

Current and future perspectives

According to a recent study, half of the premature deaths that occur each year are in China and India as a result of indoor air pollution (BBC, 2016). It has been demonstrated that better air quality and a cleaner environment can be achieved during a lockdown (Usman et al., 2021; Ching and Kajino, 2020). Globally, ambient air pollution causes 4.2 million deaths each year. The World Health Organization estimates that air pollution is responsible for 26% of deaths caused by respiratory disorders, 25% of deaths from chronic obstructive pulmonary disease, and 17% of deaths from heart attacks and strokes (WHO 2016). Another aspect related to the impact of air pollution on the COVID-19 pandemic has been discussed in several studies. This study has selected and discussed some specific studies here which are related to the impact of air pollution on COVID-19 during 2020–2021. A study conducted by Gupta et al. (2021) found a correlation between $PM_{2.5}$, PM_{10} , and COVID-19 deaths at a regional level. Their findings suggest that air pollution could worsen the death rate globally. On the basis of univariate analysis, Setti et al. (2020) observed that the SARS-CoV-2 infection rate was higher in northern Italy, especially where PM_{10} concentrations were $> 50 \mu\text{g m}^{-3}$. Similar to Gupta et al. (2021), Cole et al. (2020) also studied in-depth by collecting data from certain municipalities in the Netherlands. Their outcomes proposed that with $1 \mu\text{g m}^{-3}$, increased of $PM_{2.5}$ aggravates 9.4 times more COVID-19 cases and 2.3 times more mortalities. Yao et al. (2020) concluded that exposure to NO_2 emissions increased the COVID-19 infection rate. Their results found a positive association between NO_2 pollution levels and transmission rates (R_0) for COVID-19 in Chinese cities. Chakraborty et al. (2020) found that exposure to NO_2 emissions through vehicles increased the COVID-19 cases in India. Ogen (2020) assessed that about nearly 80% of the COVID-19 deaths were linked with high levels of NO_2 pollution in European countries. Research on COVID in response to air pollution from European and Asian countries suggested that COVID-19 deaths occur mostly in polluted environmental conditions (Comunian et al. 2020; Conticini et al. 2020). All these studies are clearly indicating that those areas or regions whose experiencing heavy air pollution are likely to affect higher by the COVID-19 pandemic compared to the less polluted region. Therefore, measures of air pollution reduction during on COVID-19 pandemic are in dire need of time to save human life.

Figure 7 explains the impact of air pollution on the COVID-19 pandemic and future combat strategies. Furthermore, in the light of the above in-depth analysis, the

potential impact of air pollution on COVID-19 pandemic studies can play a key role in exploring the new horizons and future research directions. Recent evidence suggests that the impact of air pollution may have significant effects on the global COVID-19 pandemic and more efforts should be focused on the following key issues.

1. The global impact of air pollution on chronic lung and heart disease is sufficient enough to encourage aggressive mitigation strategies. The current world including WHO and US-EPA guidelines for $PM_{2.5}$ and NO_2 does not protect human adequately and are essential to be dropped. Strategies that protect the inhabitants from the worse effects of air pollution are probably to protect as well as to curb COVID-19 fatalities attributed to air pollution.
2. Air pollution is responsible for several chronic diseases such as lung cancer, chronic obstructive pulmonary disease (COPD), asthma, diabetes, and heart diseases. Several of these ailments influence COVID-19 hospitalizations, intensive care unit (ICU) admissions, and mortalities. Due to this reason, there is major apprehension about the adverse impact of air pollution on the COVID-19 pandemic. More in-depth studies are required to quantify the scale of this ancillary effect of air pollution on the COVID-19 pandemic.
3. Recent studies have indicated that people residing in highly polluted cities are likely to be infected by SARS-CoV-2 and more frequently develop COVID-19 symptoms after eruptions of the disease occur. Most of the research have been investigating at the cumulative level of cities and regions. However, COVID-19 as well as air pollution are interrelated to population density and other spatial factors. Research at the discrete level is immediately required in order to examine the progress of the COVID-19 situation at large and well-characterized cohorts in different continents across the world.
4. COVID-19 pandemic and air pollution are occurring coherently, and the lockdown measures have been lifted in most of the countries. Both air pollution and COVID-19 have probably disturbed the underprivileged populations more badly due to higher exposure rates. Thus, measures to reduce the negative impact of both COVID-19 and air pollution should be focused on underprivileged groups specifically, where the need is urgent.

Implications of this work

Findings of this work attributed to several major implications for the analysis of the scientific productivity on the impact of COVID-19 on severe air pollution. These analyses highlighted a series of key information and data which enable researchers and policy-makers to gain an

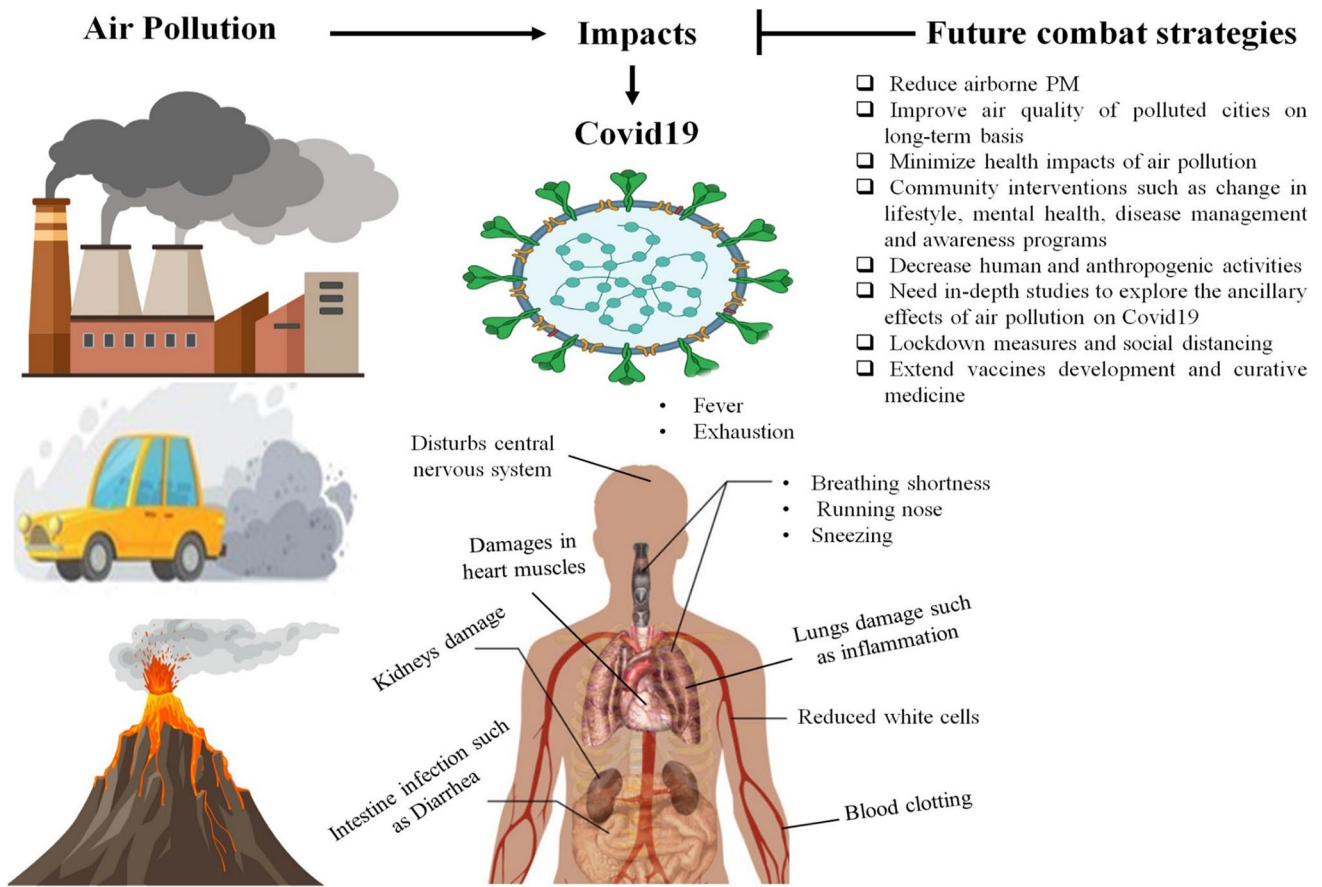


Fig. 7 Impact of air pollution on COVID-19 pandemic and future combat strategies

understanding on the role of countries, authors, institutions, and specific research hotspots on the theme of air pollution with respect to COVID-19. This study clearly illustrated the contribution of each country’s research productivity, research intuitions, and renowned scientist related to famous institutions at a global level. The cutting-edge research and research hotspot collected from literature offers detailed information on the current and future perspectives on this theme. We have conducted extensive analysis, both quantitative and qualitative which provides in-depth information for each parameter being used in this study. For instance, in terms of country, scientific country productivity implies the research status of a particular country in the future. Similarly, a highly impactful article indicated the significance of the research for a specific topic of interest. These can be referred to other bibliometric parameters such as collaborations and no. of citation. The demarcation of tentative changes in the research domain and trend compared to the existing literature is an auxiliary key implication of this analysis. Furthermore, COVID-19 research is at an emergent stage, and the situation is changing rapidly over time due to new expected COVID-19 waves or new variants in the world in response to external factors such

as temperature and humidity (Mehmood et al. 2021b). So, this type of study is maybe beneficial for environmentalists and epidemiologists to gain an in-depth understanding of current and future research.

Conclusions

This quantitative descriptive study has integrated and elucidated the knowledge on the publications based on the impact of COVID19 pandemic on air pollution pandemic which is accessible from the WoS database. Several bibliometric analyses that included both quantitative and qualitative in relation to the countries scientific productivity, keywords analysis, institutions, sources, and authors were studied. Most of the articles were issued in journals like Science of the Total Environment (8.78%), Aerosol and Air Quality Research (3.59%), and International Journal of Environmental Research and Public Health (3.54%). This study also explored the leading institutions working on this research topic to expedite collaborations and other activities such as workshops and training. In terms of qualitative aspect, the most highly impactful based on cited work was published

by Le Quéré et al. (2020) in *Nature Climate Change* with 355 total citations and 177.5 average citations per year. This study utilized index analysis (h-index, m-index, and g-index analysis for both journals and authors to measure the productivity of each). This study also comprehensively analyzed the current status of the impact of air pollution amid COVID and future perspectives. Hence, the findings of this study provide knowledge to experts with a reliable and unbiased structure of the major present scientific work combining specifically to the impact of COVID-19 pandemic on air pollution.

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Declarations

Ethics approval Not applicable.

Consent to participate All authors agreed to contribute to this study.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.


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