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

Khalid Mehmood1,2,3 · Sana Mushtaq4 · Yansong Bao1,2 · Saifullah5 · Sadia Bibi5 · Muhammad Yaseen6 · Muhammad Ajmal Khan7 · Muhammad Mohsin Abrar8,9 · Zaid Ulhassan10 · Shah Fahad11,12 · George P. Petropoulos13

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
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 (PM2.5 and PM10, respectively), ozone (O3), nitric oxide (NO2), 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, PM2.5 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 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 NO2 by ~64.8%, ~77.9%, 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 PM2.5, CO2, and NO2 concentration levels (Pansini and Fornacca 2020). Long-term exposure to air pollutants (PM10, PM2.5, NO2, and O3) 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 PM2.5 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 PM2.5 concentration increased the COVID-19 death rate by 15%. In terms of climatic factors, a study conducted by Mehmood et al. (2021b) indicated that PM2.5 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 conceptualization of bibliometric analysis refers to the objective assessment of scientific knowledge, highlighting the hotspots 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 “PM2.5” 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.
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-authored documents, and multi-authored 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 Stacked 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     |
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 “NO$_2$” (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 (IF$_{2020}$ 7.96) published the highest documents ($n=176$, 8.78%), followed by Aerosol and Air Quality Research ($n=72$, 3.59%; IF$_{2020}$ 3.13) and International Journal of Environmental Research and Public Health ($n=71$, 3.54%; IF$_{2020}$ 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
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 IF 2020 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 sub-institutes 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

| 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       |
of the researcher and help us to understand the implication of the research work on this theme. Maximum local citations were received by Zhang HL (439), followed by Xie JG (267) and Zhu YJ (267). We employed a highly impactful manuscript to understand the implication of a particular area of interest. The highly impactful manuscript enumerates a high level of a document on a particular subject (Ho and Hartley 2016).

Table 5 reflects the highly impactful articles based on total citations and average citations during 2020–2021 related to the impact of the COVID-19 pandemic on air pollution. The most highly impactful work was published by Le Quéré et al. (2020) in Nature Climate Change, with 355 and 177.5 total citations average and citations per year, respectively. A paper published by Le Quere and their co-authors found that daily global CO₂ emissions decreased by 17% at the start of April 2020 as compared with the average 2019 levels by only applying restrictions in surface transport.

We have used the authors’ co-citation network using density visualization (Fig. 6a.) Sankey three-field plot (Fig. 6b) was employed to estimate the association between top authors, references, and co-citation web and author keywords. We used co-citation analysis with cited references applying the full counting method. Maximum citation (541) was grabbed by World Health Organization (WHO) with 8523 total link strengths and 440 links with one cluster. For index analysis, the top g-index (8), h-index (6), and m-index (3) were recorded for Wang Q, followed by Ciasis P (g-index = 7; h-index = 5; and m-index = 2.5) and Coccia M (g-index = 5; h-index = 5; and m-index = 2.5) (Table 6). Gathering the results of various factors described in this heading, research conducted by Bourouiba (2020), Le Quéré et al. (2020), and Sharma et al. (2020) was substantially greater than that of other authors.

**Impact of COVID-19 pandemic on air pollution**

The lockdowns to slow down the severity of COVID-19, though temporary, has resulted in better air quality; however, it contributed a little to resolve the issues related to air pollution on a long-term basis. Population residing in poor air quality (with high airborne PM) areas may be more vulnerable to COVID-19. However, countries now have an opportunity to develop a cleaner future. In this study, we have selected specific studies from our collected data on
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 µgm$^{-3}$ (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 NOx during the different courses of five-week lockdown periods in Canada. In a similar vein, Tobias 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
of NO$_2$ (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

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
### 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 CO2 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 (NO2) 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 μgm$^{-3}$. 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 μgm$^{-3}$, 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
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 scientists 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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References

Adams MD (2020) Air pollution in Ontario, Canada during the COVID-19 State of Emergency. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.140516

Bao R, Zhang A (2020) Does lockdown reduce air pollution? Evidence from 44 cities in northern China. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.139052

BBC (2016) Polluted air causes 5.5 million deaths a year new research says

Bao Y, Mehmood K, Saifullah et al (2021) Global research on the air quality status in response to the electrification of vehicles. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2021.148861

Bourouiba L (2020) Turbulent gas clouds and respiratory pathogen emissions: potential implications for reducing transmission of COVID-19. JAMA - J. Am. Med. Assoc

Broomandi P, Karaca F, Nikfal A et al (2020) Impact of COVID-19 event on the air quality in Iran. Aerosol Air Q Res. https://doi.org/10.4209/aqr.2020.05.0205

Chakraborty P, Jayachandran S, Padalkar P et al (2020) Exposure to nitrogen dioxide (NO2) from vehicular emission could increase the COVID-19 pandemic fatality in India: a perspective. Bull Environ Contam Toxicol. https://doi.org/10.1007/s00120-020-02937-3

Ching J, Kajino M (2020) Rethinking air quality and climate change after covid-19. Int J Environ Res Public Health. https://doi.org/10.3390/ijerph17145167

Coccia M (2021) The impact of first and second wave of the COVID-19 pandemic in society; comparative analysis to support control measures to cope with negative effects of future infectious diseases. Environ Res. https://doi.org/10.1016/j.envres.2021.111099

Cohen AL, Brauer M, Burnett R et al (2017) Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. Lancet. https://doi.org/10.1016/S0140-6736(17)30505-6

Cole MA, Ozgen C, Strobl E (2020) Air pollution exposure and COVID-19 in Dutch municipalities. Environ Resour Econ. https://doi.org/10.1016/j.s0160-6441.2020.00491-4

Comunian S, Dongo D, Milani C, Palestini P (2020) Air pollution and COVID-19: the role of particulate matter in the spread and increase of COVID-19’s morbidity and mortality. Int J Environ Res Public Health

Conticini E, Frediani B, Caro D (2020) Can atmospheric pollution be considered a co-factor in extremely high level of SARS-CoV-2 lethality in Northern Italy? Environ Pollut

Cui Y, Zhang Z-F, Froines J et al (2003) Air pollution and case fatality of SARS in the People’s Republic of China: an ecologic study. Environ Heal. https://doi.org/10.1186/1476-069x-2-15

Egghe L (2006) Theory and practise of the g-index. Scientometrics. https://doi.org/10.1007/s11192-006-0144-7

Fattorini D, Regoli F (2020) Role of the chronic air pollution levels in the Covid-19 outbreak risk in Italy. Environ Pollut

GISAID (2021) hCov19 Variants

Guan W, Ni Z, Hu Y et al (2020) Clinical characteristics of coronavirus disease 2019 in China. N Engr J Med. https://doi.org/10.1056/nejmoa2002032

Gupta A, Bherwani H, Gautam S et al (2021) Air pollution aggravating COVID-19 lethality? Exploration in Asian cities using statistical models. Environ Dev Sustain. https://doi.org/10.1007/s10640-020-00878-9

Hirsch JE (2005) An index to quantify an individual's scientific statistical models. Environ Dev Sustain. https://doi.org/10.1007/s10668-008-789-8

Hirschi JM (2005) An index to quantify an individual’s scientific research output. Proc Natl Acad Sci U S A. https://doi.org/10.1073/pnas.0507655102

Ho YS, Hartley J (2016) Classic articles published by American scientists (1900-2014): a bibliometric analysis. Curr Sci. https://doi.org/10.15820/css/v111/i7/11156-1165

IQAir (2019) World air quality report. 2019 World Air Qual Rep

Le Quéré C, Jackson RB, Jones MW et al (2020) Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. Nat Clim Chang. https://doi.org/10.1038/s41558-020-0797-x

Liu N, Chee ML, Niuc C et al (2020) Coronavirus disease 2019 (COVID-19): an evidence map of medical literature. BMC Med Res Methodol. https://doi.org/10.1186/s12874-020-01059-y

Luo CH, Morris CP, Sachithanandam J, et al (2021) Infection with the SARS-CoV-2 delta variant is associated with higher recovery of infectious virus compared to the alpha variant in both unvaccinated and vaccinated individuals. Clin Infect Dis ciab986. https://doi.org/10.1093/cid/ciab986
Ma Y, Zhao Y, Liu J, He X, Wang B, Fu S et al (2020) Effects of temperature variation and humidity on the death of COVID-19 in Wuhan, China. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.138226

Ma CJ, Kang GU (2020) Air quality variation in Wuhan, Daegu, and Tokyo during the explosive outbreak of COVID-19 and its health effects. Int J Environ Res Public Health. https://doi.org/10.3390/ijerph17114119

Mahato S, Pal S, Ghosh KG (2020) Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.139086

Mehmood K, Saiuffullah, Abrar MM, et al (2020a) Can PM2.5 pollution worsen the death rate due to COVID-19 in India and Pakistan? Sci Total Environ. 742:142935. https://doi.org/10.1016/j.scitotenv.2020.140557

Mehmood K, Saiuffullah, Abrar MM, et al (2020b) Can PM2.5 pollution worsen the death rate due to COVID-19 in India and Pakistan? Sci Total Environ

Mehmood K, Saiuffullah, Iqbal M, Abrar MM (2020c) Can exposure to PM2.5 particles increase the incidence of coronavirus disease 2019 (COVID-19)? Sci Total Environ 741:. https://doi.org/10.1016/j.scitotenv.2020.140441

Mehmood K, Bao Y, Abrar MM et al (2021a) Spatiotemporal variability of COVID-19 pandemic in relation to air pollution, climate and socioeconomic factors in Pakistan. Chemosphere. https://doi.org/10.1016/j.chemosphere.2021.129584

Mehmood K, Bao Y, Petropoulos GP et al (2021b) Investigating connections between COVID-19 pandemic, air pollution and community interventions for Pakistan employing geoinformation technologies. Chemosphere. https://doi.org/10.1016/j.chemosphere.2021.129909

Muhammad S, Long X, Salman M (2020) COVID-19 pandemic and environmental pollution: a blessing in disguise? Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.138820

Nakada LYK, Urban RC (2020) COVID-19 pandemic: impacts on the air quality during the partial lockdown in São Paulo state, Brazil. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.139087

Ogen Y (2020) Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.138605

Pansini R, Fornacca D (2020) Initial evidence of higher morbidity and mortality to SARS-CoV-2 in regions with lower air quality. medRxiv

Pei L, Wang X, Guo B et al (2021) Do air pollutants affect as well as meteorological factors impact coronavirus disease 2019 (COVID-19)? Evidence from China based on the geographical perspective. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-021-12934-6

Rodríguez-Urrego D, Rodríguez-Urrego L (2020) Air quality during the COVID-19: PM2.5 analysis in the 50 most polluted capital cities in the world. Environ Pollut

Rogers G, Szomszor M, Adams J (2020) Sample size in bibliometric analysis. Scientometrics. https://doi.org/10.1007/s11192-020-03647-7

Saadat S, Rawtani D, Hussain CM (2020) Environmental perspective of COVID-19. Sci Total Environ

Setti L, Passarini F, De Gennaro G et al (2020) SARS-Cov-2RNA found on particulate matter of Bergamo in Northern Italy: first evidence. Environ Res. https://doi.org/10.1016/j.envres.2020.109754

Sharma S, Zhang M, Anshika et al (2020) Effect of restricted emissions during COVID-19 on air quality in India. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.138878

Tao L, Wang R, Han N et al (2021) Acceptance of a COVID-19 vaccine and associated factors among pregnant women in China: a multi-center cross-sectional study based on health belief model. Hum Vaccin Immunother. https://doi.org/10.1080/21645515.2021.1892432

Tobías A, Carnero C, Reche C et al (2020) Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.138540

Usman M, Ho YS (2020a) A bibliometric study of the Fenton oxidation for soil and water remediation. J Environ Manage. https://doi.org/10.1016/j.jenvman.2020.110886

Usman M, Ho YS (2020b) A bibliometric study of the Fenton oxidation for soil and water remediation. J Environ Manage 270:110886. https://doi.org/10.1016/j.jenvman.2020.110886

Usman M, Husnain M, Riaz A, Riaz A, Ali Y (2021) Climate change during the COVID-19 outbreak: scoping future perspectives. Environ Sci Pollut Res 28(35):49302–49313

Valérie D, Pierre AG (2010) Bibliometric idicators: quality measurements of scientific publication. Radiology van Eck NJ, Waltman L (2014) Visualizing bibliometric networks. In: Measuring Scholarly Impact
Authors and Affiliations

Khalid Mehmood1,2,3 · Sana Mushtaq4 · Yansong Bao1,2 · Saifullah5 · Sadia Bibi5 · Muhammad Yaseen6 · Muhammad Ajmal Khan7 · Muhammad Mohsin Abrar8,9 · Zaid Ulhassan10 · Shah Fahad11,12 · George P. Petropoulos13

1 Key Laboratory of Meteorological Disaster, Ministry of Education (KLME), Joint International Research Laboratory of Climate and Environment Change (ILCEC)/Collaborative Innovation Center On Forecast and Evaluation of Meteorological Disasters (CIC-FEMD)/CMA Key Laboratory for Aerosol-Cloud-Precipitation, Nanjing University of Information Science & Technology, Nanjing 210044, China
2 School of Atmospheric Physics, Nanjing University of Information Science & Technology, Nanjing 210044, China
3 School of Environmental Science and Engineering, Nanjing University of Information Science and Technology, Nanjing 210044, China
4 Nishtar Medical University, Multan, Pakistan
5 Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad, Faisalabad 38040, Pakistan
6 Faculty of Sciences, Department of Mathematics and Statistics, University of Agriculture Faisalabad, Faisalabad 38040, Pakistan
7 Deanship of Library Affairs, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia
8 College of Resources and Environment, Zhongkai University of Agriculture and Engineering, 510225, Guangzhou, China
9 Engineering and Technology Research Center for Agricultural Land Pollution and Integrated Prevention, Guangzhou, China
10 Institute of Crop Sciences, Ministry of Agriculture and Rural Affairs, Laboratory of Spectroscopy Sensing, Zhejiang University, Hangzhou 310058, China
11 Hainan Key Laboratory for Sustainable Utilization of Tropical Bioresource, College of Tropical Crops, Hainan University, Haikou 570228, Hainan, China
12 Department of Agronomy, University of Haripur, Haripur, Khyber Pakhtunkhwa, Pakistan
13 Department of Geography, Harokopio University of Athens, El. Venizelou 70, 17671 Kallithea, Athens, Greece