Bibliometric analysis of SARS, MERS, and Covid-19 studies from India with focus on sustainable development

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Abstract: India is ranked 5th in the world in terms of Covid-19 publications accounting for 6.7% of the total. About 60% of the Covid-19 publications in the year 2020 are from United States, China, UK, Italy, and India. We present a bibliometrics analysis of the publication trends and citation structure along with identification of major research clusters. By performing network analysis of authors, citations, institutions, keywords, and countries, we explore semantic associations by applying visualization techniques. Our study shows lead taken by United States, China, UK, Italy, India in Covid-19 research may be attributed to the high prevalence of Covid-19 cases in those countries witnessing the first outbreak and also due to access to Covid-19 data, access to labs for experimental trials, immediate funding, and overall support from the govt. agencies. Large number of publications and citations from India are due to co-authored publications with countries like United States, UK, China, and Saudi Arabia. Findings show health sciences with highest the number of publications and citations, while physical sciences and social sciences and humanities counts were low. A large proportion of publications fall into the open access category. With India as focus, by comparing three major pandemics SARS, MERS, Covid-19 from bibliometrics perspective, we observe much broader involvement of authors from multiple countries for Covid-19 studies as compared to SARS and MERS. Finally, by applying bibliometric indicators, we see an increasing number of sustainable development-related studies from the Covid-19 domain, particularly concerning the topic of good health and well-being. This study allows for a deeper understanding on how the scholarly community from a populous country like India pursued research in the midst of a major pandemic which resulted in closure of scientific institutions.

Keywords: COVID-19; Coronavirus; pandemic; bibliometrics; SARS; MERS

1. Introduction
The present Covid-19 pandemic has affected every socioeconomic sector. Globally, everything from manufacturing to entertainment has been affected. Academia is no exception. In fact, most universities globally have suspended on campus activities and have moved online [1]. While teaching practices can to some extent be mitigated by digital interventions and online teaching, research is more complex and often requires campus collaboration and laboratory facilities [2]. While safety norms may require research to be suspended, research is also an essential first step in understanding and fighting this
pandemic. Given that it is a novel virus, research regarding its characteristics is integral to developing mechanisms for fighting it. Similarly, methods of detection, isolation, protection, etc. also need to be developed at a fundamental level. In addition, given the scale of the pandemic, research on its effects on other aspects ranging from the global supply chain to mental health need to be understood and any adverse effects mitigated [3][4]. In light of all these needs, the researchers across the world have continued their work even under these challenging conditions, generating an impressive volume of research during this time [5]. In fact, during the early stages of the Covid-19 pandemic, researchers produced a significant number of publications, and the number started growing exponentially, doubling every two weeks by April 2020 [6]. Furthermore, as of early June 2021, over 167,000 papers on Covid-19 studies have been published despite the restrictions imposed by university closures, social-distancing norms, and disruptions caused by lockdown[7]. Much of the information pertaining to the virus and the pandemic has also been made available in the public domain by the leading research institutions in the world.

Two large outbreaks of this coronavirus family had previously been documented with at least one of them receiving the official designation of “global pandemic” [8]. The first incidence of the Severe Acute Respiratory Syndrome (SARS) disease was recorded on November 16, 2002, in the Guangdong province of Southern China. By 2003, the disease had spread across continents, forcing the World Health Organization to designate it a pandemic. In fact, SARS is dubbed “the First Pandemic of the Twenty-First Century” [9]. On June 13, 2012, the first instance of the Middle Eastern Respiratory Syndrome (MERS) was detected in Jeddah. Until Covid-19 came along, these were the two most significant coronavirus epidemics. Each of these prior epidemics, like Covid-19, had their own literature [10], although on a much lesser scale.

There has in fact been a massive global push for open data sharing during the pandemic. For example, in January 2020, 117 research-related organizations agreed on an open-access data-sharing policy, making any research available to any researcher. The signatories included the likes of Springer and ProMed [8]. UNESCO prompted over 122 countries to implement an open access policy to combat the pandemic and set up an open access platform for the same [9]. The European Union adopted a similar policy by March 2020 [10]. In order to accelerate the speed of publication, a number of preprint services were set up as well. Though they lack the stringency of a detailed peer review process, such approaches have aided in rapid information sharing [11][12]. When compared to other similar infections such as MERS and SARS, Covid-19 has resulted in a mass mobilization of scientific effort, with over 12,000 papers being generated in under five months. The volume of work available at preset on this virus alone is greater than the number of publications generated on all coronaviruses over the last two decades [13]. Clearly, the research community has pulled its weight when it comes to achieving
a deeper understanding more regarding this virus and pandemic, and effectively making the information available to the scientific community.

This is despite the limitations imposed by lockdowns across the world. Lockdowns and other preventive measures such as social distancing have varied in intensity from country to country. In fact, the Oxford Covid-19 Government Response Tracker (OxCGRT)[14] defines the Oxford Stringency index, which assesses the severity of lockdown restrictions. Countries such as India, Russia, and Mexico had the most stringent lockdowns globally, with India being the most populous country to impose an extremely strict lockdown (Blavatnik School of Government, n.d.). Other countries such as China, Greenland, and many European countries had a more relaxed lockdown in comparison (Blavatnik School of Government, n.d.). And other countries such as Sweden and Japan continued to remain relatively open while adhering to social-distancing norms. For comparison, lockdown in India involved complete suspension of rail, air and road transport between various states and territories. Furthermore, schools, colleges, and public institutions were completely shut down and people were instructed to stay indoors except for accessing essential services [15]. Public institutions, transport, and educational institutions remained open in Japan with limited restrictions, while Sweden did not impose any major restrictions.

Most of Europe had less stringent policies than India as well [16]. All these approaches had varying degrees of success. Even within India, the success of the response varied from state to state, some faring better than others [17]. However, the overall death rates and per-capita deaths in India have been lower than those of most countries. As of May 31st, 2021, India’s death per million people since the beginning of this pandemic is 252, while that of the United States is 1,841 and that of Germany is 1071 [18]. The limited restrictions in Sweden, with lack of lockdowns, has led to 1,426 deaths per million, almost twice as much as the rest of Scandinavian countries combined. While some error in these numbers is possible due to insufficient testing, it is safe to assume that the lockdown has aided in mitigating the adverse effects of Covid-19 to a significant extent in the country. While this lockdown certainly affected educational institutions from schools to higher research centers, it is interesting to note that India has contributed significantly to research regarding the pandemic. In fact, despite the stringent lockdown and continued travel restrictions, India ranks 5th in number of publications related to Covid-19 worldwide.

This study focuses on academic literature on Covid-19 globally, and the performance of Indian Scientific community in comparison to its counterparts. The study compares how India’s overall scientific output in the year 2020, and research specific to Covid-19 for the same period can be valued relative to global output. This is done by comparing several parameters such as publications, citations, international collaborations, journal
sources, government funding etc. As a starting point, a brief literature summary of research publication growth and sharing is presented in the next section. This will aid in understanding the global collaborations, nature of Covid-19 publications, and how the response of the scientific community with regards to Covid-19 differs from its response to other diseases.

We have structured the paper as follows: Section 2 discusses the study methodology using bibliometrics including the search strategy. Section 3 presents the results in terms of publications, citations, institutions, and countries. Section 4 provides the network analysis with visual representation of bibliographic data while Covid-19 studies connected to Sustainable development are presented in Section 5. And finally section 6 is about conclusions of the study with future directions.

**Study methodology using bibliometrics**

Bibliometrics is a set of methods to measure scholarly impact from research publications. Bibliometrics tools have been used in a variety of analyses [19][20], including those of authors, journal sources, and citation trends [21] or country [22]. Many journals have published bibliometric studies on pandemics such as SARS, MERS, and more recently on Covid-19 [13][23-26].

**Selection of bibliometric software mapping tools and data sources**

The VOSviewer [27] software was used to analyze the co-occurrence network for keywords, co-authorship network [28], citations [29] and bibliographic coupling [30]. The h-index [31] which is widely used in bibliometric studies [32] was also analyzed.

In our study we also considered data sources, [https://www.worldometers.info/coronavirus](https://www.worldometers.info/coronavirus) for data on Covid-19 deaths and cases, as well as [www.scimagojr.com](http://www.scimagojr.com) for Scimago Journal Rankings (SJR). Average of the daily score of the Oxford Stringency index was taken from ([https://COVIDtracker.bsg.ox.ac.uk/](https://COVIDtracker.bsg.ox.ac.uk/)) for the period on the 31st of December 2020. A minimum threshold of daily score of 30 was set to account for varying dates of lockdown measures.

**Search strategy**

For our bibliometric analysis we chose Scopus which is a large abstract and citation database with over 74 million records from 23500 peer-reviewed publications in the fields of science, technology, medicine, social sciences, and arts and humanities [33][34].

Publications were retrieved via a topic search (title/ abstract/ key words) from Scopus database for year 2020 as on 1st January 2021. The following search queries were created with the goal of reducing the amount of data overlap across the SARS, MERS, and
Covid-19 datasets [35]. In order to eliminate overlap, relevant phrases from various literatures were joined with the Boolean operator “AND NOT” in each search. The time period for each search was determined by considering the year in which each virus epidemic occurred.

**SARS:** (TITLE-ABS-KEY ((("Severe acute respiratory syndrome" OR "SARS") AND (coronavirus*)) OR ("SARS virus" OR "SARS disease" OR "Severe acute respiratory syndrome disease" OR "Severe acute respiratory syndrome virus" OR "SARS-Cov")) AND NOT TITLE-ABS-KEY ((("covid" OR "nCov" OR "Covid-19" OR "covid19" OR "SARS-Cov-2" OR "Severe acute respiratory syndrome-2" OR "MERS" OR "middle east respiratory syndrome"))) AND PUBYEAR > 2001.

**MERS:** (TITLE-ABS-KEY ((("Middle east respiratory syndrome" OR "MERS") AND (coronavirus)) OR ("MERS-Cov" OR "MERS virus" OR "MERS disease" OR "Middle east respiratory syndrome virus" OR "Middle east respiratory syndrome disease")) AND NOT TITLE-ABS-KEY ((("nCov” OR "Covid-19" OR "covid19" OR "SARS-Cov" OR "SARS-Cov-2" OR "SARS" OR "Severe acute respiratory syndrome"))) AND PUBYEAR > 2011.

**Covid-19:** TITLE-ABS-KEY ("covid-19" OR "covid19" OR "coronavirus disease 2019" OR "2019-nCov" OR "Novel Coronavirus" OR "Novel Corona virus" OR "SARS-Cov-2") AND PUBYEAR > 2018.

Results on Publications, Citations, Institutions and Countries

Publication and citation trends

A total of 93,485 Covid-19-related publications, between Jan 1st, 2020, and Dec 31st, 2020, are indexed in Scopus as of Jan 1st, 2021, based on our search strategy. Out of this total, 58,643 (60.2%) were from United States, China, UK, Italy, and India with United States having the highest total of 23,608 (25.4%) publications. Publications in English were 87,529 (94.1%) with 7,723 (5.9%) in Spanish, German, Chinese, French. This information is summarized in Table 1.

| Country     | Number of Publications | % Publications | Citations | Citations/Publication | Cases/1M population | Deaths/1M population | Oxford Stringency Index |
|-------------|------------------------|----------------|-----------|-----------------------|---------------------|----------------------|------------------------|
| United States | 23608                  | 25.4%          | 194117    | 8.2                   | 60900               | 1057                 | 68.1                   |
| China       | 10356                  | 11.1%          | 273493    | 26.4                  | 60*                 | 3*                   | 70.5                   |
| UK          | 10002                  | 10.7%          | 90474     | 9.0                   | 37347               | 1089                 | 69.6                   |
| Italy       | 8454                   | 9.0%           | 74527     | 8.8                   | 35245               | 1235                 | 65.2                   |
United States had both the highest number of cases and deaths per million population while Australia had the lowest score in the stringency index. India has the highest score 78.7, which may provide a possible explanation of low number of cases and deaths per million population. China had the highest number of citations per publication possibly due to the effect of the first outbreak of the Covid-19 virus and easy availability of data among Chinese authors to write papers and cite each other’s work. A total of 6,223 publications, with affiliation as India for at least one author, were found for the year 2020. These publications were written by 12,417 authors and published in 1,370 sources. Out of this, 2,513 (40.3%) publications had at least one citation in Scopus, providing a total of 20,816 citations. This resulted in an average citations per paper of 3.3 and citations per author of 1.7.

It is seen that Indian authors have collaborated with researchers in 147 countries, with 4,667 (74.9%) publications having international co-authorships. This indicates a healthy international collaboration during the pandemic. The largest number of collaborations were with the United States, followed by China, UK, Saudi Arabia, Japan, Italy, Columbia, and South Korea, as seen in Table 2. These seven collaborating countries accounted for 1,866 (30.1 %) publications. For publications from India, the number of citations is highest for publications from United States followed by those from China, UK, and Italy. The number of citations per publication varies from 22.7 for Nepal to 7.1 for United States. However, given that a larger number of publications are generated in Italy, China, US, and UK, researchers have diverse options for citing work from these countries, thereby moderating the number of citations per publication. With a very limited number of publications from Nepal and Japan (58 and 70 papers each), leads to larger number of citations on the ones available. The quality of research work can therefore not be assessed based on same metric.

Table 2. Top collaborating countries with India for Covid-19 studies

| Country  | Number of Citations | Number of Publications | Citations/Publications |
|----------|---------------------|------------------------|------------------------|
| India    | 6223                | 20816                  | 7404                   | 107        | 78.7       |
| Spain    | 3834                | 23603                  | 41415                  | 1087       | 67.2       |
| Canada   | 3841                | 31004                  | 15371                  | 412        | 66.5       |
| Germany  | 3531                | 41895                  | 20924                  | 410        | 60.6       |
| France   | 3526                | 36776                  | 39796                  | 985        | 63.9       |
| Australia| 3437                | 29772                  | 1108                   | 35         | 65.8       |

*Data about cases and deaths from China were not updated at the source of information for Table 1 but given the early outbreak of Covid-19 in China, we chose to include it in our study.*
| Country          | Publications | Citations | Impact Factor |
|------------------|--------------|-----------|---------------|
| United States    | 4233         | 595       | 7.1           |
| China            | 2528         | 212       | 11.9          |
| UK               | 2420         | 335       | 7.2           |
| Saudi Arabia     | 1545         | 175       | 8.8           |
| Japan            | 1517         | 70        | 21.7          |
| Italy            | 1367         | 160       | 8.5           |
| Colombia         | 1322         | 87        | 15.2          |
| South Korea      | 1321         | 106       | 12.5          |
| Nepal            | 1319         | 58        | 22.7          |
| Spain            | 1126         | 66        | 17.1          |
| France           | 1038         | 57        | 18.2          |
| Brazil           | 1011         | 82        | 12.3          |

Although the number of publications and citations related to SARS and MERS increased since the respective outbreaks took place, Indian authors took more interest in them only in the year 2020 when Covid-19 happened, as shown in the Table 3. The surge in coronavirus research triggered by the Covid-19 outbreak, on the other hand, appears to be on a scale that is unprecedented in the history of coronavirus research, and probably perhaps in the history of science.

Table 3. Comparison of Publications and Citations for SARS, MERS, and Covid-19

| Outbreaks | SARS | MERS | Covid-19 |
|-----------|------|------|----------|
| Publications | 167  | 558  | 6223     |
| Citations   | 2207 | 7109 | 20816    |

Structure of publications

Analyzing the total number of Covid-19 related publications globally, it is seen that 50,865 (54%) are research ‘Articles’ as shown in Table 4. Trend is similar in India with 3,186 (51%) publications. Furthermore, in India, Letters and Reviews add up to 2,392 (38%), while the share of such publications is only 25,203 (27%) globally. Other publications take up 10% of overall share in India and 19% globally. It should be noted that such a high share of non-article publications is abnormal, and generally 71% of all publications in India are articles in year 2020. This higher fraction of non-articles related to
Covid-19 may be attributed to the time required for peer review process as softer letters and reviews do not have to pass that hurdle.

**Table 4. Covid-19 publications by type**

| Publication Type | India | World |
|------------------|-------|-------|
| Article          | 3186  | 50865 |
| Letters, Review  | 2392  | 25203 |
| Others           | 645   | 17417 |

**Top contributing institutions**

Globally, Harvard Medical School (USA) published the largest number of Covid-19 related publications followed by Huazhong University of Science and Technology and Tongji Medical College from China, as can be observed in Table 5. Both private and public institutions are represented well in the top-10 in the world for institutions with most Covid-19 publications.

**Table 5. Top contributing institutions in the world for Covid-19 studies**

| Institution Name                                | Number of Publications | Country        | Ownership | Discipline     |
|-------------------------------------------------|------------------------|----------------|-----------|----------------|
| Harvard Medical School                          | 1552                   | United States  | Private   | Medical        |
| Huazhong University of Science and Technology    | 1203                   | China          | Public    | Multidisciplinary |
| Tongji Medical College                          | 1143                   | China          | Private   | Medical        |
| Inserm                                          | 1050                   | France         | Public    | Medical        |
| University of Toronto                           | 999                    | Canada         | Public    | Multidisciplinary |
| Università degli Studi di Milano                | 851                    | Italy          | Public    | Multidisciplinary |
| University of Oxford                            | 838                    | United Kingdom | Private   | Multidisciplinary |
| Università degli Studi di Roma La Sapienza       | 797                    | Italy          | Public    | Multidisciplinary |
| University College London                       | 774                    | United Kingdom | Private   | Multidisciplinary |
| Massachusetts General Hospital                   | 735                    | United States  | Private   | Medical        |

When comparing the publications and citations achieved by public and private institutions in India, the former has a clear upper hand, as shown in Table 6. A much larger number of publications were produced by public medical institutions such as AIIMS,
and PGI Chandigarh. The private medical institute with the highest number of publications is Saveetha, where the medical and dental departments together roughly match the number of publications by PGI Chandigarh. However, in terms of number of citations, public medical institutes are far ahead of private institutes. IVRI (Veterinary) has 15 citations per publication while ICAR New Delhi has 14.4 citations per paper. Tata Memorial has a citation per publication score of 6.2. However, among private sector institutes, the highest citation per publication is 3.7 for CMC Vellore. Clearly, public medical institutes have exceeded their private counterparts in academic excellence in this area. This is partly due to government funding and ease of access enjoyed by these institutes with regards to viral samples and data for clinical studies.

Table 6. Top contributing institutions in India for Covid-19 studies

| Institution Name          | Number of Publications | Number of Citations | Citations/ Publication | Ownership | Discipline      |
|---------------------------|------------------------|---------------------|------------------------|-----------|-----------------|
| AIIMS New Delhi           | 427                    | 942                 | 2.2                    | Public    | Medical         |
| PGI Chandigarh            | 309                    | 1248                | 4.0                    | Public    | Medical         |
| Saveetha (Medical)        | 171                    | 24                  | 0.1                    | Private   | Medical         |
| Saveetha (Dental)         | 162                    | 40                  | 0.2                    | Private   | Dental          |
| Datta Meghe Wardha        | 138                    | 77                  | 0.6                    | Private   | Medical         |
| DY Patil Pune             | 132                    | 293                 | 2.2                    | Private   | Medical         |
| ICMR New Delhi            | 109                    | 515                 | 4.7                    | Public    | Medical         |
| Manipal, MAHE             | 107                    | 439                 | 4.1                    | Private   | Multidisciplinary|
| NIMHANS Bengaluru        | 100                    | 446                 | 4.5                    | Public    | Medical         |
| SG PGI Lucknow            | 97                     | 346                 | 3.6                    | Public    | Medical         |
| AIIMS Jodhpur             | 93                     | 146                 | 1.6                    | Public    | Medical         |
| Tata Memorial             | 91                     | 564                 | 6.2                    | Public    | Medical         |
| ICAR New Delhi            | 90                     | 1295                | 14.4                   | Public    | Agriculture     |
| King George Lucknow       | 86                     | 484                 | 5.6                    | Public    | Medical         |
| IVRI (Veterinary)         | 87                     | 1309                | 15.0                   | Public    | Medical         |
| University of Delhi       | 82                     | 248                 | 3.0                    | Public    | Multidisciplinary|
| AIIMS Rishikesh           | 81                     | 127                 | 1.6                    | Public    | Medical         |
| Homi Bhabha Mumbai        | 72                     | 374                 | 5.2                    | Public    | Multidisciplinary|
| Amity University          | 66                     | 89                  | 1.3                    | Private   | Multidisciplinary|
When we compare the three outbreaks, we observe that the research interest from Indian institutions in conducting coronavirus studies has increased by a factor of three from 160 in SARS to 249 in MERS to 523 institutions for Covid-19. This interest is also reflected in the very large number of publications and citations related to Covid-19 studies.

**Most influential journals**

A list of journal sources with number of publications, citations, Scimago Journal Rankings (SJR) and h-index are listed in Table 7. The highest citation per publication is achieved by the Journal Science of the Total Environment which is a Q1 journal with a high h-index of 224. Similarly, the Journal Diabetes Research and Clinical practice, another Q1 journal with a high h-index of 107 has over 23 citations per publication. The Journal of Biomolecular Structure and Dynamics, a Q2 journal, with a relatively moderate h-index of 32 has the highest number of Covid-19 related publications while Nature Medicine and The Lancet, the most reputed journals in the field have a very limited number of Covid-19 related publications (4 each), likely owing to the highly stringent review process and high article processing charges.

### Table 7. Most influential journals

| Journal title                                           | Number of Publications | Number of Citations | Citations /Publication | SJR (Q1-Q4) | h-index |
|---------------------------------------------------------|------------------------|---------------------|------------------------|-------------|---------|
| Journal of Biomolecular Structure and Dynamics          | 274                    | 2868                | 10.5                   | Q2          | 32      |
| Indian Journal of Medical Research                      | 186                    | 856                 | 4.6                    | Q2          | 81      |
| Asian Journal of Psychiatry                             | 93                     | 517                 | 5.6                    | Q2          | 29      |
| PLOS ONE                                                | 54                     | 118                 | 2.2                    | Q1          | 300     |
| Chaos Solitons and Fractals                             | 47                     | 381                 | 8.1                    | Q1          | 132     |
| Diabetes Research and Clinical Practice                 | 42                     | 970                 | 23.1                   | Q1          | 107     |
| Life Sciences                                           | 41                     | 387                 | 9.4                    | Q1          | 156     |
When we observe the data on studies about SARS, MERS and Covid-19 published in journals, we see a large surge in the number of different journals where Covid-19 studies were published. While SARS studies were limited to 124 journals, MERS had 310 while Covid-19 studies were published in over 1370 journals.

**Top performing subject areas**

A majority of publications related to Covid-19 are from health sciences (76,657, 82.1%), with medicine alone accounting for (64,505, 69.3%) globally. The proportion is slightly lower for India, with 4,165 (67.2%) publications coming from health sciences, as indicated in Table 8. Of these, 3,790 (91.4%) are from medicine. However, life sciences also contributed a healthy 43% of the total share of Covid-19-related articles, while physical sciences and social sciences made up the rest at 29% and 15% respectively. It is also interesting to note that within physical sciences, computer science and engineering which are technology oriented constitute a higher share than that of pure sciences such as chemistry or physics. Within social sciences, art and humanities contribute the least while pure social science contributes the highest share.

**Table 8. Top performing subject areas in India**

| Subject Area                                    | Publications | Impact Factor | Journal Rank | Top Publications |
|-------------------------------------------------|--------------|---------------|--------------|------------------|
| Dermatologic Therapy                            | 41           | 179           | 4.4          | Q2               |
| Diabetes and Metabolic Syndrome                 | 38           | 232           | 6.1          | Q2               |
| Science of the Total Environment                | 37           | 964           | 26.1         | Q1               |
| Indian Journal of Paediatrics                   | 27           | 578           | 21.4         | NA               |
| Virus Research                                  | 23           | 262           | 11.4         | Q2               |
| JCO Global Oncology                             | 15           | 288           | 19.2         | NA               |
| Journal of Medical Virology                     | 13           | 211           | 16.2         | Q2               |
| The Lancet                                      | 12           | 170           | 14.2         | Q1               |
| Aging and Disease                               | 11           | 571           | 51.9         | Q1               |
| Brain Behavior and Immunity                     | 10           | 282           | 28.2         | Q1               |
| Travel Medicine and Infectious disease          | 8            | 614           | 76.8         | Q1               |
| Kidney International                            | 5            | 180           | 36           | Q1               |
| Nature Medicine                                 | 4            | 80            | 20           | Q1               |
| The Lancet Infectious Diseases                  | 4            | 50            | 12.5         | Q1               |
| Subject Area         | Subject Area Classifications                              | Number of Publications |
|----------------------|----------------------------------------------------------|------------------------|
| **Health Sciences (67%)** | Medicine                                                  | 3825                   |
|                      | Dentistry                                                 | 138                    |
|                      | Health Professions                                        | 85                     |
|                      | Nursing                                                   | 77                     |
|                      | Veterinary                                                 | 40                     |
| **Life Sciences (43%)** | Biochemistry, Genetics and Molecular Biology               | 1098                   |
|                      | Pharmacology, Toxicology and Pharmaceutics                 | 724                    |
|                      | Immunology and Microbiology                                | 459                    |
|                      | Agricultural and Biological Sciences                       | 208                    |
|                      | Neuroscience                                               | 190                    |
| **Physical Sciences (29%)** | Computer Science                                          | 341                    |
|                      | Engineering                                                | 296                    |
|                      | Environmental Science                                      | 284                    |
|                      | Mathematics                                                | 198                    |
|                      | Chemistry                                                  | 141                    |
|                      | Physics and Astronomy                                      | 118                    |
|                      | Chemical Engineering                                       | 116                    |
|                      | Energy                                                     | 103                    |
|                      | Materials Science                                          | 90                     |
|                      | Earth and Planetary Sciences                               | 70                     |
|                      | Decision Sciences                                          | 64                     |
| **Social Sciences (15%)** | Social Sciences                                            | 452                    |
|                      | Economics, Econometrics and Finance                        | 175                    |
|                      | Psychology                                                 | 150                    |
|                      | Business, Management and Accounting                        | 94                     |
|                      | Arts and Humanities                                        | 59                     |
Open Access publications

Overall, there is a rise in the number of open-access publications, especially with those related to Covid-19. This indicates an interest from the academics in increasing the availability of their work to a wider audience without the barriers of restricted access. In fact, with regards to publications related to Covid-19, worldwide 75,242 (80.4%) are in open access, and in India, the trend is similar with 4,841 (77.7%) in open access. This is especially relevant in India, given that only 26% of all publications from India are in open access for the entire year 2020. Essentially, a large portion of Covid-19 publications fall into the open access category. The fraction of Open Access medical publications is especially high, with 83.8% and 82.9% of Covid-19 related medical papers being open access globally and in India, respectively.

It is important to note that although authors have been publishing in open access for several years only in the last few years, several of the established journals have started publishing in full open access mode. This is reflected in the very high number of Open Access articles for Covid-19 studies (4841) compared with 431 for MERS and 113 for SARS.

Major funding sources

From all the Covid-19 related publications studied, 20,134 (22.5%) reported the funding sources involved. Led by United States, National Institutes of Health, National Science Foundation and National Institute of Allergy and Infectious Diseases funded largest number of 2,776 (13.7%) Covid-19 studies. The National Natural Science Foundation from China was second with 2,111 (10.4%) funded studies followed by UK’s National Institute for Health Research with 459 (2.2%) and European Commission with 236 (1.1%) funded studies. When it comes to funding by private sources, the following number of studies were funded: Wellcome Trust, 388; Pfizer, 255; Bill & Melinda Gates Foundation, 243.

Government funding was relatively lower in India with agencies Science & Engineering Review Board (SERB), Indian Council of Medical Research (ICMR), Department of Science & Technology (DST), Department of Bio-Technology (DBT) and University Grants Commission (UGC) accounting for 129 (0.5%) studies. However, countries hit earlier by Covid-19 such as United States and China are more likely to have allocated more funding to research at that stage.
Network analysis: Co-authorship, Co-occurrence, and Bibliographic couplings

Co-authorship network and publications

In order to study the collaboration networks of authors, we used co-authorship network analysis which is a widely accepted practice in bibliometric studies [36].

In a network graph, each author is represented by a bubble and the bubble size is proportional to the number of publications attributed to the author. Two authors who have collaborated on any paper are linked by a line, with each line representing collaboration on a single paper. Colors indicate clusters of authors that are relatively strongly connected by co-authorship links and authors with a high degree of collaboration are located close to each other.

We investigated the co-authorship network in India, with authors having at least 15 Covid-19 related publications. This resulted in 7 major collaboration clusters with a total of 132 authors, as can be observed in Fig. 1.

Fig. 1 Co-authorship network and publications in India

The important clusters in the co-authorship network of authors shown in the following colors: red corresponds to authors "kumar a", "kumar s", "sharma p"; green color to author "gupta n"; yellow to author "das s" and finally blue to "dharma k". As indicated by the size of the bubble, those are leading authors who produced highest number of papers in collaboration with others.
Co-citation network of authors

Similarly, we investigated the co-citation network of Indian authors with at least 5 citations. Note that co-citations indicate formats that contain ideas, experiments, or methods that have received peer recognition, as evidenced by their co-occurrence of citations [37].

This network analysis resulted in 6 clusters, where 124 out of the 12,417 authors had at least 5 citations, as shown in Fig. 2. Each author is represented by a node whose size is proportional to the number of citations. The important clusters of citations appear in the following colors: red corresponds to author “dharma k”; green to author “chakrabarti s”; yellow to author “gupta n” and finally color to “sharma s”. As indicated by the size of the bubble, those are leading authors with the highest number of citations.

![Fig. 2 Co-authorship network and citations in India](image)

Co-occurrence network of keywords

When searching for scientific publications, a key word search is usually the easiest way to access relevant information. Therefore, appropriate key words that provide a reasonable description of the work allows the study to reach a wider audience. To carry out a keyword-based analysis, keywords described by at least 5 publications were chosen and a co-occurrence network constructed. The unit of analysis has also been set to all keywords (this includes both author and index keywords) and the method of counting was set to full counting.
These results are shown in Fig. 3, where it can be seen that works published by Indian authors have employed a wide range of key words, ranging from those related to virology and epidemiology to those associated with mental health, air pollution, and lockdown. This indicates that the work generated in India spans multiple disciplines and covers a diverse gamut of topics related to the pandemic.

With respect to each of the three epidemics, distinct clusters of keywords were identifiable but there were commonalities among them. All three epidemics had a cluster with terms such as pandemic, infection control, viral, epidemic, virus transmission associated with general public health and disease outbreak. Another cluster had terms that are generally associated with virology studies like virus protein, virus entry, chemistry, amino acid sequence, virus genome, protein binding, etc.

Fig. 3 (bottom) shows that the Covid-19 studies resulted in four clusters which are described below:
Cluster 1 (red) shows high-frequency key words related to epidemiological and public-health studies on Covid-19, such as:

- Pandemic, coronavirus disease 2019, public health, health care personnel, infection control, mental health, quarantine, disease transmission

Cluster 2 (green) includes terms associated with virus and drug treatments, including:

- Sars-cov-2, virology, immunology, drug positioning, antivirus agent, virus genome, drug design, drug repositioning

Cluster 3 (blue) involves high-frequency key words associated to clinical studies, signs, and symptoms of the disease, as well as pharmacological and nonpharmacological interventions for Covid-19, for instance:

- Hydroxychloroquine, remdesivir, azithromycin, cytokine storm, chloroquine, angiotensin enzyme, dyspnea, respiratory failure, comorbidity, fever, fatigue

Cluster 4 (yellow) includes terms relevant to measures of disease control and spread prevention such as:

- Covid-19, coronavirus, lockdown, air pollution, China, WHO

**Fig. 3** keyword co-occurrences associated with the Covid-19 studies

**Bibliographic couplings among countries**

Bibliographic couplings are described by [38] which proposes that two papers that refer to a third paper are highly related, so they should be grouped into a cluster solution.

Fig. 4 presents the bibliographic coupling among countries, where any country with a minimum of 5 publications with an Indian collaboration was considered. When the three maps of co-authorships are compared, a pattern of author engagement emerges...
from the area where each virus outbreak began. In all three epidemics, studies produced by scholars linked with Indian institutions are well represented. However, the figure also illustrates frequent coupling among other countries such as England, Germany and Netherlands for Covid-19 studies with United States, United Kingdom, Saudi Arabia, Japan, Italy, Columbia, and South Korea as top collaborators.

Overall, the number of collaborating countries has increased from 28 for SARS to 81 for MERS and, reached a total of 154 for Covid-19.

Fig. 4 Bibliographic coupling of countries associated with SARS studies

Fig. 4 Bibliographic coupling of countries associated with MERS studies
Similarly, we studied the bibliographic couplings of journal sources for all three pandemics. We observe that the journal sources have increased dramatically from 124 journals for SARS to 310 journals for MERS, up to a large 1,370 journals for Covid-19. Journal of Biomolecular structure and Indian Journal of Medical Research is found common for all three pandemics, as seen in Fig. 5. We also notice that MERS studies were published in specialty journals like Journal of Virology, Human Vaccines & Immunotherapy and Frontiers in Microbiology.
When it comes to Covid-19 studies, we evaluated the journals with a minimum of ten publications from total of 1,370 journal sources that Indian authors had published. This resulted in 97 items divided into 7 clusters, as shown in Figure 5 (bottom). As expected, most of the highly cited papers appeared in high-impact factor journals indicating their higher research quality. Most publishers followed an accelerated review process, online-first policy and provided open access to such publications.

Covid-19 studies connected to sustainable development

We also evaluated the connections between Covid-19 studies and sustainable development. In this regard we used 17 United Nations Sustainable Development Goals (SDG), adopted in 2015, as proxy for sustainable development. It is clear that the Covid-19 pandemic has had an important impact across all the SDGs, for instance through reduced CO₂ emissions because of the lockdowns [39], with clear implications on SDG 13 (on climate action). However, a number of studies [40, 41] suggest that the situation...
may progressively return to the pre-pandemic levels, in the context for instance of avia-
tion and its impact on the environment. Several studies suggest that the symptoms
associated to Covid-19 may be exacerbated due to increase pollution levels [42], a fact
that closely connects SDGs 3 (on health) and 11 (on sustainable cities). Another im-
portant aspect regarding the management of the Covid-19 has to do with the digital-
contact-tracing apps, which aimed at achieving a better control of the pandemic, with
positive impact on SDG 3, but could potentially exhibit challenges [43][44][45] in the
context of SDGs 10 (on reduced inequalities) and 16 (on strong institutions). The con-
nections reported above have a clear relation with the results presented in Table 9,
where the number of Indian Covid-19 articles and their citations related to each of the
17 SDGs are reported. There are clearly very strong connections with SDGs 3 and 11, as
well as 13 (with the clear implications on pollution levels) and 16. When it comes to the
latter, we would like to highlight the strong polarization in our societies, exacerbated
by the algorithms used by news outlets and social media [46]; the problems associated
to this polarization have become particularly dire due to the Covid-19 pandemic, cre-
ating a data crisis [47]. It is also important to note the significant number of studies doc-
umenting connections between Covid-19 and SDGs 8 (on economic growth) and 4 (on
quality education), which reflect the negative impact of the Covid-19 restrictions on two
very important areas of our societies. Perhaps two areas that have not received suffi-
cient attention according to Table 9 are the negative effects on SDGs 1 (on no poverty)
and 5 (on gender equality), which have undoubtedly experienced quite negative effects
from Covid-19.

Table 9: Number of publications and citations corresponding to Covid-19 studies from India with impact on each of the 17 SDGs.

| SDG                          | Publications | Citations |
|------------------------------|--------------|-----------|
| 3 Good Health and Well Being | 2230         | 14066     |
| 8 Decent Work and Economic Growth | 163         | 256       |
| 11 Sustainable Cities and Communities | 151         | 1354      |
| 4 Quality Education         | 148          | 553       |
| 16 Peace, Justice and Strong Institutions | 108         | 247       |
| 13 Climate Action           | 71           | 118       |
| 7 Affordable and Clean Energy | 66           | 103       |
| 2 Zero Hunger               | 54           | 160       |
| 10 Reduced Inequalities     | 38           | 97        |
| 6 Clean Water and Sanitation | 34           | 222       |
| 12 Responsible Consumption and Production | 29         | 248       |
| 1 No Poverty                | 11           | 49        |
| 15 Life on Land             | 6            | 15        |
| 5 Gender Equality           | 3            | 8         |
| 9 Industry, Innovation, and Infrastructure | 2          | 0         |
6. Conclusions

In the present study the authors performed a bibliometric analysis on Covid-19 publications in India and at multiple places compared with worldwide data. United States is the country with the highest number of Covid-19 publications in the year 2020. This might reflect the fact that journal databases and referencing system usually refer to US standards. Many journals, with a wide range of impact factors, exhibit publications by Indian authors. The publications are the result of collaboration both within India and in the international scene. As also reported [48], who studied bibliometric features on the Covid-19 worldwide, our results indicate that the studies on Covid-19 are published by institutions worldwide. There are many publications in India, with a rapid increasing rate of publication after disease emerged in the country, in a pattern similar to that reported by [49]. This study also shows that there are many publications from both governmental and non-governmental institutes. A worldwide collaboration network can be clearly identified, and this agrees with the report by [50]. Collaboration in excellent way to increase visibility of the work and generalization of the knowledge. During the early stage of disease emergence, studies in the form of short report or viewpoints were common and become publications with high numbers of citations [51]. Such collaboration, and an active data-sharing policy, are essential aspects to fight this pandemic and other future crises [52][53][54]. The high number of studies on Covid-19 indicates that it will be necessary to conduct active research with the emergence of new variant of the diseases [55][56][57][58][60].

We also identified important connections between Covid-19 studies at the 17 SDGs of the UN. In particular, there are clear implications on SDGs 3 (on health), 11 (on sustainable cities) and 13 (on climate action), the two latter due to the reduced emissions following the Covid-19 restrictions. Digital contact tracing must be conducted in a decentralized way in order to avoid negative effects on SDGs 10 (on reduced inequalities) and 16 (on strong institutions). Despite the obvious negative effects of Covid-19 on SDGs 8 (on economic growth) and 4 (on quality education), we would like to highlight the very important consequences on SDGs 1 (on no poverty) and 5 (on gender equality), which are not as prominently represented in the literature.

A detailed assessment of the scientific work published in reaction to the three most notable coronavirus outbreaks, namely SARS, MERS, and Covid-19, reveals striking parallelisms. Public-health and emergency-management studies are the first to appear, followed by virology studies. The volume and rate of scholarly study on Covid-19, on the other hand, remains an outlier, potentially unparalleled in the history of scientific literature.

Although India had reasonably large number of reported Covid-19 cases, the number of publications at the time of the study still follow countries where the
disease occurred earlier. But in the recent weeks, the situation has abruptly changed for the worse with India reporting very high number of daily cases mainly attributed to the double-mutant strain. Many states have again implemented lockdowns resulting in closure of campuses. It remains to be seen how the academic community will adapt to this new situation.

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