Air Quality, Atmosphere & Health (2023) 16:613–628
https://doi.org/10.1007/s11869-022-01290-0

# A bibliometric and scientometric: analysis towards global pattern and trends related to aerosol and precipitation studies from 2002 to 2022

Roshini Praveen Kumar[1] · Brema J.[1] · Cyril Samuel[1] · Sneha Gautam[1]

Received: 22 September 2022 / Accepted: 23 November 2022 / Published online: 30 November 2022


**Abstract**
The recent heavy downpours in specific regions have initiated several studies on the relationship between aerosol and precipitation. The increase in pollution/population and the recent outbreak of diseases and environmental deterioration have been preceded by an increase in aerosol concentration, which would be directly related to precipitation. Considering this background, several studies are being conducted to define a clear relationship between aerosol concentration and precipitation. With the current need to understand aerosol and its characteristics to reduce pollution, research in this domain has significantly increased followed by the demand for control measures and impacts on human health and the environment. A systematic literature review is followed to aid future researchers in mapping the studies and themes related to aerosol and precipitation. Some studies have shown the direct effect of aerosols on the reduction in land surface temperature, by reflection and indirectly enhancing the cloud reflectivity. Even though the research studies conducted in the past have not achieved the perfect correlation of airborne particles and their influence on precipitation around the globe. Our study attempts to show the bibliometric literature review of aerosol and precipitation studies. The mapping stated four conceptual structures of different theme domains: Sampling and retrieval methods, Characterization and effects, Assessment studies, Health and environmental impacts, and Modeling and measures. Lastly, the mapping identified the limitations of the research review, and the scope of future studies to be carried out.

**Keywords** Aerosols · Precipitation · Air pollution · Bibliometric · Scientometric

## Introduction

Aerosols are minute solid particles or liquid droplets scattered in the atmosphere mostly by massive fires, volcanic eruptions, dust storms, and active chemical strains seen in water droplets (Acker et al. 2014; Bisht et al. 2022; Naqvi et al. 2022). Aerosols have become a crucial topic as emerging apprehension on the deterioration of air quality due to pollution concerning climate change as they have been evidently influencing the climate and health (IPCC 2013; Huang 2018; Sweileh et al. 2018; Sun et al. 2020; Han et al. 2021). Aerosols tend to scatter and absorb light, causing a direct effect and a radiative balance; indirect effects influence precipitation during cloud formation (IPCC 2013; Musthaq et al. 2022). Estimating the significance and proportion of radiative forces and effects is a tedious task. Aerosols have been affecting the hydrological cycle, during the condensation process of the clouds, they are also influential during the cloud albedo process, and the potential emitting property of the aerosols which brightens the clouds either for short or long-wave radiation (Graedel et al. 1993; Masih et al. 2019; Nepolian et al. 2021). There may be changes in evaporation when solar radiation and temperature affect the aerosols and impact the hydrological cycle (Ramanathan et al. 2007; Gautam et al. 2021). Aerosol and its interaction with monsoons, convey the natural aerosols as intrinsic elements that derive global climate change and change in land use by external forcing (Li et al. 2016). Cao et al. (2012) found that particulate matter caused during the combustion of fossil fuel which has a detectable impact on health. The optimal yield of rice and wheat is affected by 45% and 75% due to an increase in regional haze pollution in China (Tie

✉ Sneha Gautam
gautamsneha@gmail.com

1 Department of Civil Engineering, Karunya Institute of Technology and Sciences, Coimbatore 641117, India

et al. 2016). Many such examples are spiraling global challenges around aerosol which is one of the prominent reasons that affects human health and global warming. The increase in mortality rates and cardiopulmonary disease is the result of deteriorating air quality due to aerosols (Krewski et al. 2009, Lepeule et al. 2012, Burnett et al. 2014; Gautam et al. 2020; Kumar et al. 2022). Lelieveld et al. (2015) postulated that by the year 2050, the premature mortality deaths caused by the outdoor $PM_{2.5}$ would be around 6.2 million annually with an estimated present-day death of 3.15 million deaths annually. Human activities increase the carbon dioxide in the atmosphere by 30%, because of the radiative forces (Santer et al. 1995). Even research by Liu and Rodriguez, 2005 stated that the average global temperature was found to be increased by 2.15–3.4 °C due to the increased concentration of carbon dioxide. As a result of the anthropogenic influences, the poles at the Artic are affected severely (Gillett et al. 2008). The effect of aerosols and greenhouse gases are also quite contrary to each other. The water vapors, methane, etc., block infrared radiation beyond the atmospheric layer, because of the initial involvement of greenhouse gases, which causes an increase in the surface temperature of the planet (Ehhalt et al. 2001). There are several emerging research to tackle the growing problems in regional and spatial scales, hence understanding aerosol in the area of the Earth system, especially with precipitation can provide sustainable development for our planet (Cao 2017). Few researchers (Trenberth (2020); Aryasree et al. 2020), reported that studies emphasized the importance of the atmospheric aerosols, precipitation, and clouds for the earth's climate including energy and water cycles. The property of aerosol is to form an effective ice nuclei during the formation of convective clouds (Maheskumar et al. 2018). The ice particles are the main cause of warm rain with the cold-rain process during extreme rainfall events (Kumar et al. 2014; Maheskumar et al. 2018). Few updates observed by researchers (Khain et al. 2008; Lee et al. 2008; 2012) highlighted that the precipitation rate is one of the prime factors that influence the climate conditions based on aerosol loading. Li et al. (2011) also recorded that if the concentration of the aerosols is increased, it increases the precipitation content (higher water content) in the clouds with the development of thick and darker clouds. Stevens and Feingold (2009) reported the inadequacy of current tools, which equally contribute to the leading uncertainties in detecting the effects of aerosols on the environment. The studies also state that, the high-water content clouds leading to heavy precipitation in polluted locations are prone to floods in moist areas and droughts in dry areas, through which aerosols are indirectly linked with socioeconomic conditions. Hence, the following review attempts to assemble the different categories, research domains, and hotspots in the field of aerosol in the context of precipitation by using bibliometric software, which provides a pathway for researchers to investigate and solve the growing pollution caused by the emissions of aerosols (primary or secondary aerosols), with new upgradation for the traditional research studies, which are solely the backbone for future methodologies developed by researchers working in this domain.

## Research design and methodology

Bibliometric and text mining pools are systematic processes adapted by researchers to solve research queries (Ranjbari et al. 2022a, b, c, d; Ranjbari et al. 2022a; Ranjbari et al. 2022b; Ranjbari et al. 2022c; Ranjbari et al. 2022d; Ranjbari et al. 2021). In order to analyze the research-based out-turn by the researchers, stakeholders, and policymakers, bibliometric strategies are adopted (Ellegaard and Johan 2015). Considering this, the evaluation and the mapping of the overall potential for the research work carried out in the field integrated with aerosols and precipitation inculcate the answer to the first research question. The research focuses on the publication year, citations, keywords, co-authors, references, and organization of the papers. Bibliographic coupling is carried out where similar bibliographies are clustered based on their references which have been cited; this aggregation is one of the significant parts of the bibliometric analysis. The following procedure was carried out with our datasets for a sample of articles.

On the contrary, in our datasets, there are several occurrences of noun phrases. Therefore, the title and abstracts are text mined to extract these nouns and the phrases used by the authors to identify the main research fields. This was achieved when the data were analyzed (Waltman et al. 2010) based on the links generated during the co-occurrence analysis. The bibliometric and the text mining analyses provide the main research themes, emphasizing the potential research gaps and the future aspects that can be addressed in the coming years. This summarizes that the methodology answers the related research questions. The research framework design is shown in Fig. 1.

### Sampling of the data

Systematic reviews channel the importance of well-structured scientific papers, including the publication years, citations, references, and keywords used by the authors, co-authors, countries, and organizations involved in structuring the literature. (Chowdhury et al. 2021, Zahedi et al. 2016). Based on this ideology, aerosol and precipitation were identified as the two concepts for creating the structure for the review. Secondary keywords like the combination of aerosol with respect to aerosol optical depth (AOD), humidity, temperature, and precipitation were used to extract more

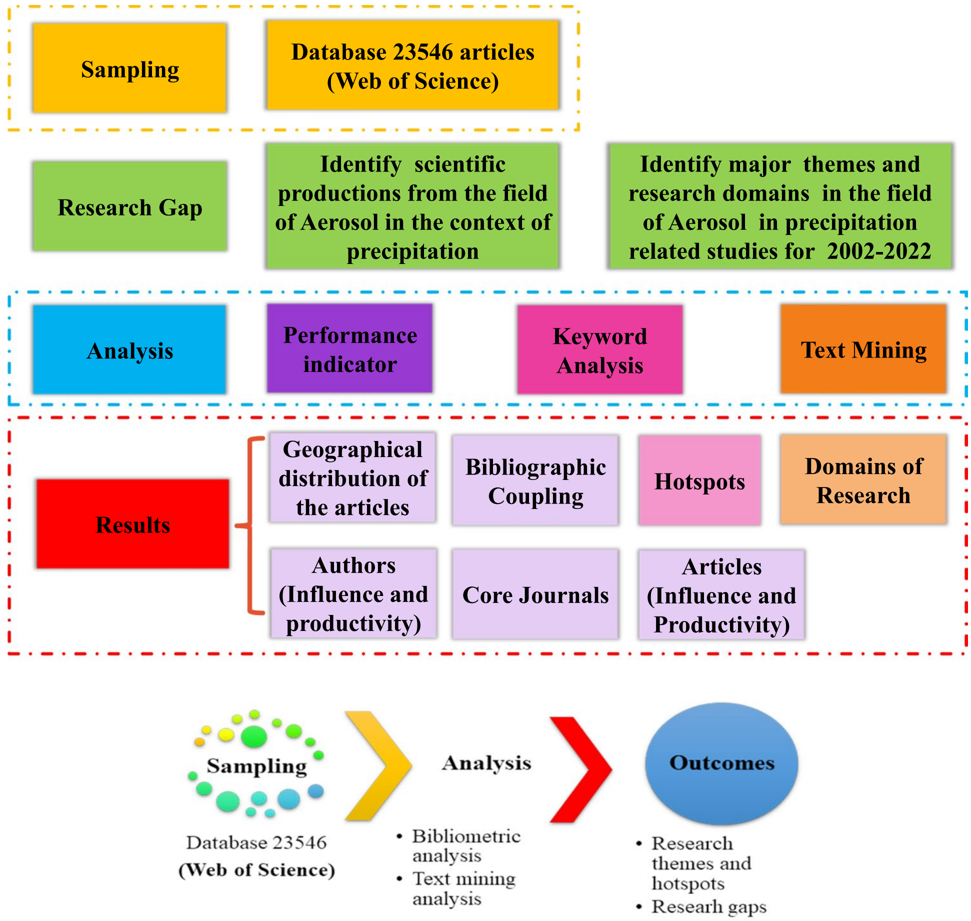


**Fig. 1** The framework of research

relevant articles from the Web of Science databases. The research seeks to cover all the streams related to aerosols, hence the search was not limited, the articles covered all the areas that have ever been on the Web of Science. The search string with keywords was extracted by title and abstracts of the articles in the Web of Science database. The download articles were 23,546 including all reviews and articles published during 2002 to 2022, non-English materials were not included. Table 1 summarizes the collection process of the data.

## Analysing the sampled data

Scientific mapping is an extensive area of study where statistical tools evaluate performance broadly, and bibliometric analysis is one of the statistically prominent tools.

**Table 1** Process of data sampling for VOSviewer

| | |
|---|---|
| Search string<br>Secondary keywords<br>Used for data extraction | "Aerosol" OR "Precipitation" OR "AOD" "Aerosol and Precipitation" OR "Aerosol and Relative Humidity" OR "Aerosol and precipitation" OR "Relative Humidity and Precipitation" OR "Aerosol and AOD" OR "AOD and Aerosol" OR "AOD and precipitation" OR "AOD and temperature" OR "AOD and relative humidity", "Aeronet" |
| Fields mined | Documents, Author keywords, and keyword plus, Organization, Countries |
| Database | Web of Science |
| Search date | February 22, 2022 |
| Language | Only in English materials |
| Inclusion Criteria | Peer-reviewed journal articles, limited to 2002–2022 |
| Final samples | 23,546 articles |

Potential and effective scrutiny of links based on the journals, keywords, citations, and co-citations networks (Feng et al. 2017), provides insight to the scientists and researchers to come across current trends and future aspects of research. The software used for this research is VOSviewer. VOSviewer is a software tool to analyze and visualize bibliometric data in order to understand the trends, domains, hotspots, and themes of a particular study; VOS means 'visualization of similarities' (Van Eck and Waltman 2010). VOSviewer inherits the smart local moving algorithm introduced by Waltman and Van Eck (2013). The limitation of VOSviewer observed in our datasets is the complex functionality that is restricted to manage large datasets and is less interactive.

## Results and discussion

The section below gives the results from the text mining and the bibliometric analysis. This fills the first and second research questions.

### Bibliometric indicators

#### Spatial and geographical distribution of the articles

The distribution of articles is based on the activities of the published articles that are geographically situated across the countries. These spatial distributions of the articles are in the research context, including aerosol and precipitation from 2002 to 2022. Our analysis accounts for 144 countries that have researched in the following field of aerosol and precipitation and 100 countries which are in a collective network for co-authorships. Figure 2 provides a pictorial representation of the co-authorship network based on the research that includes aerosol and precipitation. The nodes and the size of nodes signify the number of articles, a country publishes. The thickness of the link illustrates the potential co-authorship between each country. Table 2 lists the top 10 countries with the number of articles published. The number of links indicates the collaborating countries and the total link strength indicates the entire number of the co-authored with the citations of their articles.

Table 2 has categorized values of the collaborations, co-authorships, citations, and published documents from the top 10 countries working in aerosols in the context of precipitation. The USA ranks first in all four categories with 8486 articles, 323,157 citations, 94 collaborating links with other counties, and 7714 co-authorships. China has been marked second in the categories with published articles with 6087, total citations of 130,378, and 6087 co-authorships. England has secured second place with 85 co-author countries. Germany ranks third in all four categories with 2342 articles, 85,291 citations with 4180 co-authorships, and 82 co-author collaboration links. India, France, Canada, Japan, South Korea, Italy, and Switzerland also appear in the top countries contributing to the following field. These link strengths interpret the collaborations among each country. Figure 2 displays that the USA has the most collaborations with 94 co-authorship countries, it has the most collaboration with China (1447 co-authorship), Germany (691 co-authorship), and

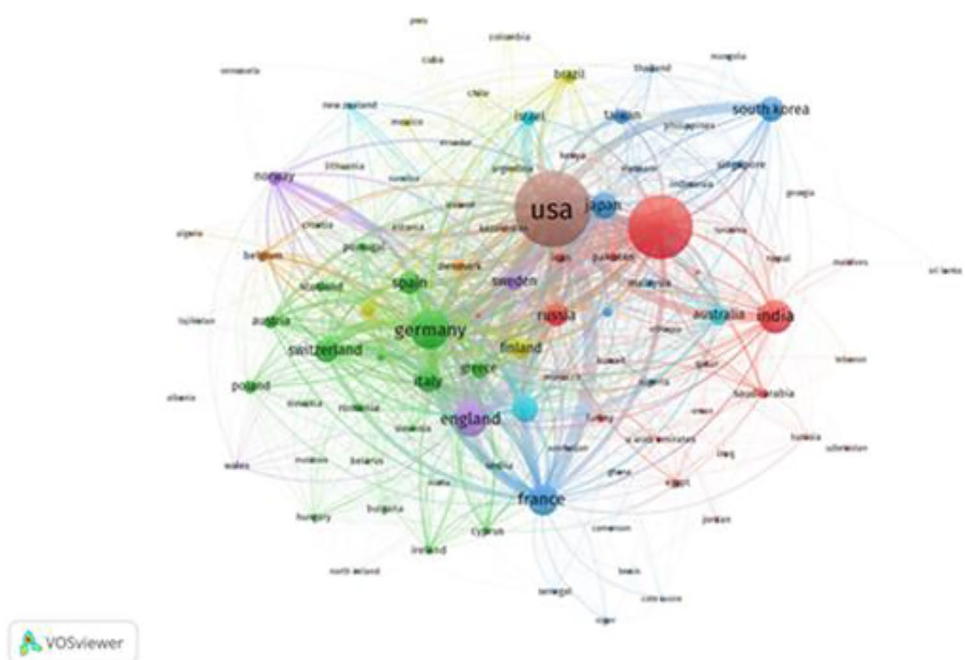


**Fig. 2** The co-authorship network is based on countries for research related to aerosol and precipitation

**Table 2** The top 10 countries with number of co-authorships, co-author countries and the total number of citations of their research articles

| *Rank* | *Published articles (total documents)* | | *Total no of citations* | | *Co-author countries* | | *Co-authorships* | |
|---|---|---|---|---|---|---|---|---|
| 1 | USA | 8486 | USA | 323,157 | USA | 94 | USA | 7714 |
| 2 | China | 6087 | China | 130,378 | England | 85 | China | 6087 |
| 3 | Germany | 2342 | Germany | 85,291 | Germany | 82 | Germany | 4180 |
| 4 | England | 1874 | England | 69,828 | France | 77 | England | 3452 |
| 5 | India | 1727 | France | 50,220 | China | 75 | France | 2933 |
| 6 | France | 1514 | Canada | 42,676 | Switzerland | 71 | Switzerland | 2000 |
| 7 | Canada | 1084 | Switzerland | 35,447 | Canada | 67 | Canada | 1678 |
| 8 | Japan | 1062 | India | 32,453 | Japan | 65 | Japan | 1468 |
| 9 | South Korea | 961 | Japan | 28,434 | India | 64 | India | 1009 |
| 10 | Switzerland | 885 | Italy | 26,366 | South Korea | 51 | South Korea | 750 |

**Table 3** Top 10 highly productive authors contributed in the domain of aerosols and precipitation

| Authors | Documents | Co-authors | Total co-authors |
|---|---|---|---|
| Li, Zhanqing | 117 | 126 | 386 |
| Che, Huizhen | 103 | 114 | 556 |
| Zang, Xiaoye | 94 | 103 | 555 |
| Gua, Jianping | 85 | 91 | 311 |
| Wang, Yuesi | 81 | 98 | 216 |
| Wang, Jun | 79 | 93 | 358 |
| Sun, Yele | 75 | 142 | 487 |
| Xue, Yong | 75 | 29 | 328 |
| Gong, Wei | 74 | 49 | 267 |
| Reid, Jonathanas | 74 | 21 | 81 |

**Table 4** Top 10 highly influential authors in the domain of aerosol and precipitation

| Authors | Citations | Co-authors | Total co-authors |
|---|---|---|---|
| Li, Zhanqing | 5604 | 126 | 386 |
| Rosenfeld, David | 4303 | 74 | 150 |
| Poeschl, Ulrich | 3980 | 79 | 216 |
| Zhang, Qiang | 3787 | 33 | 51 |
| Hsu, N.C | 3552 | 19 | 58 |
| Liu, Yang | 3453 | 37 | 78 |
| Zhang, Qiang | 3263 | 33 | 81 |
| Guo, Jianping | 3170 | 98 | 311 |
| Remer, I. A | 3162 | 22 | 36 |
| Feingold, Graham | 3137 | 34 | 56 |

England (620 co-authorship). These countries also have the strongest links in the networks among themselves and other countries.

### The most productive and influential authors

Researchers, especially in the academic field, have a prior role in development (Guo et al. 2021). The author with the highest number of articles is identified as the most productive author by the software, similarly, the author who has the most citations in our dataset is termed the most influential author. From our dataset, there are 638,887 contributing authors to the field of aerosol and precipitations, among them 4954 authors have contributed at least 5 articles. Table 3 and Table 4 list the authors with the most articles and citations respectively, doing so we interpret the author's productivity and influence with the total number of co-authors and co-authorship. According to our data, Zhanqing Li is the most productive and influential author with 117 articles and 5604 citations.

### The influential and productive core journal

Two thousand six hundred fifty-four articles have been published in 570 journals related to aerosols and precipitation. To scrutinize our dataset, we have considered only those journals that had at least 5 articles published. Figure 3 and Fig. 4 represent the top journals based on the number of articles published and citations to their articles. From these figures, the *Journal of Atmospheric Chemistry and Physics* ranks first with the most published articles, i.e., 2415, and the most cited articles with 93,689 citations. The *Journal of Geophysical Research* (1633 published articles, 73,242 citations) and the atmospheric environment (1633 published articles, and 47,224 citations), hold the second and third productive and influential journals. There is a significant gap between the remaining journals based on their published articles and citations. Based on the retrieved data from 2002 to 2022, it is evident that these are considered to be the most influential and productive journals, as they contributed to publishing research related to aerosols and precipitations.

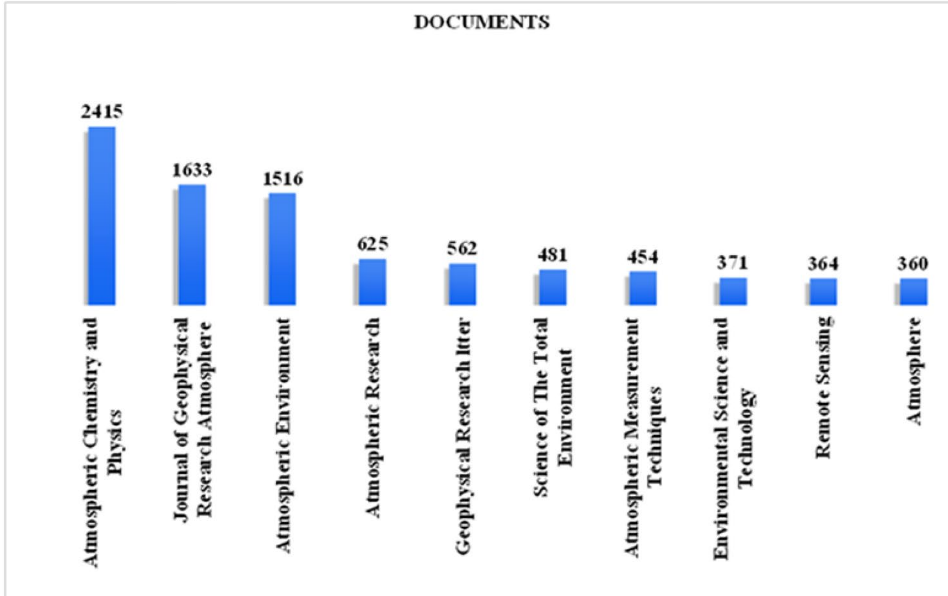


**Fig. 3** The top 10 most productive journals in reference to the articles published

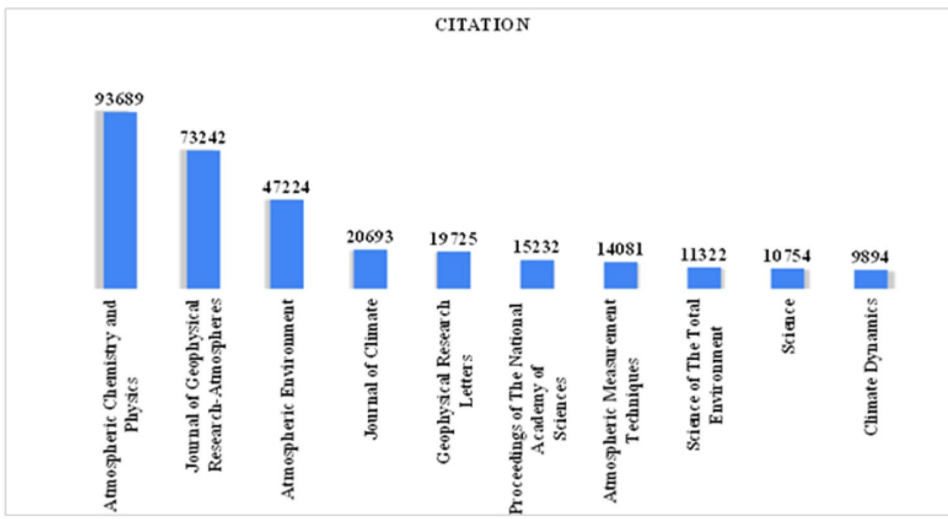


**Fig. 4** The top 10 most influential journals in reference to the articles cited

## Articles

This section delivers two main analyses. Based on article citations and their bibliographic coupling.

**Influential articles in the research area of aerosol and precipitation** Among various approaches, evaluating the numerous times an article has been cited related to a particular domain of research would result in interpreting the influence of an article (Merigó et al. 2015). Likewise, Table 5 lists the top 10 most cited articles on the research of aerosol and precipitation. The most influential article in our dataset is with citation of 2160, research conducted by Ramanathan and Carmichael (2008) that has focused on the regional distribution based on the high absorption combination aligned with the solar irradiance and the intermixing of the aerosols with the emitted black carbons article causing the melting of glaciers and snowpacks which can eventually affect the hydrological cycle. Similarly, the second most influential article with 1372 citations is based on the importance of aerosol interference in public health, climate, and the biosphere. The research mostly studies the quantification and the identification of biological particles and carbonaceous compounds by fine particles in the ambient air, and how these airborne solid and liquid particles would affect the hydrological cycle and atmospheric circulation Pöschl (2005). These articles mainly focus on how the climate and health would be affected when these aerosols interact with pollutants, especially fine particulate matter. The third article with 1109 citations by Levy et al. (2013), was based on introducing the algorithm that would use MODIS-observed Spectral reflectance to retrieve aerosol optical depth and aerosol size parameters, reduction

**Table 5** The top 10 highly cited research in the domain of aerosol and precipitation

| Rank | Author | Year | Title | Journal | Citation |
|---|---|---|---|---|---|
| 1 | Ramanathan, V | 2008 | Global and regional climate changes due to black carbon | Natural Geo Science | 2160 |
| 2 | Poschl, U | 2005 | Atmospheric aerosol: composition, transformation, climate and health effects | Angewandte Chemie-International Edition | 1372 |
| 3 | Levy, R.C | 2013 | The collection 6 Modis aerosol products over land and ocean | Atmospheric Measurement Techniques | 109 |
| 4 | Hansen, J | 2005 | Efficacy of climate forcings | Journal Of Geophysical Research-Atmospheres | 864 |
| 5 | Levy, R.C | 2010 | Global evaluation of the collection 5 Modis dark-target aerosol products over land | Atmospheric Chemistry and Physics | 801 |
| 6 | Ervens | 2011 | Secondary organic aerosol formation in cloud droplets and aqueous particles(aqsoa): a review of laboratory, field and model studies | Atmospheric Chemistry and Physics | 726 |
| 7 | Donner, Leo J | 2011 | The dynamical core, physical parameterizations, and basic simulation characteristics of the atmospheric component am3 of the gfdl global coupled model cm3 | Journal of Climate | 696 |
| 8 | Despres, Viviane R | 2012 | Primary biological aerosol particles in the atmosphere: a review | Tellus Series B-Chemical and Physical Meteorology | 674 |
| 9 | Stevens | 2009 | Untangling aerosol effects on clouds and precipitation in a buffered system | Nature | 673 |
| 10 | Stier | 2005 | The aerosol-climate model echam5-ham | Atmospheric Chemistry and Physics | 652 |

of the gap coverage, and location-specific (Land and Sea) for better visualizations. The retrieval methods would enhance the studies that require information regarding clouds and aerosols at 3 km resolution. The studies comparing climate-forcing agents responsible for climate change use a global climate model to analyze the effectiveness. Hansen et al. (2005) research provides insights on anthropogenic tropospheric O3 and Black Carbon (BC) snow albedo effect cause instant warming and sea ice loss in the Arctic, the study also evidences the interference of the greenhouse that could increase the Hadley circulation in the models that could cause increase rainfalls in the intertropical convergence zones and Easter parts of the continents, and other model simulations are discussed in this research article. Other articles that secure a fifth (801 citations), sixth (726 citations), seventh (696 citations), and tenth rank (652 citations) contribute to retrievals (levy et al. 2010), modeling studies based on simulation (Ervens et al. 2011), and parameterizations of aerosols-cloud properties based on their characteristics like the global coupled model (Donner et al. 2011). Introducing aerosol-climate modeling system ECHAM5-HAM, for malleable microphysical approach for wide studies related to climate regimes (Stier et al. 2005). The research related to understanding the effects of aerosols on clouds and atmospheres and health impacts made the articles by Després et al. (2012) and Stevens and Feingold (2009) rank the eighth and ninth most influential articles with 674 and 673 citations in our datasets. The *Journal of Atmospheric Chemistry and Physics* has three articles that appear influential in arena of precipitation and aerosols.

Additionally, the *Journal Atmospheric Chemistry and Physics* is considered a pre-eminent journal with three of its articles in the top 10 spots securing its status as the most productive and most influential journal.

**Bibliographic coupling of articles** The bibliographic coupling is exercised to categorize relevant themes under aerosol and precipitations based on their shared references. To understand the entire research from our data set we set at least one common reference from 23,546 articles (research and reviews) which gave us 20,469 published articles to scrutinize the themes. Figure 5 gives the pictorial representation of the articles clubbed in 4 specific clusters. The clusters are differentiated by the colors that symbolize different themes. Each cluster has similar references which makes one know a similar type of research is found in that particular cluster. The size of each bubble interprets as the total number of citations of the corresponding articles, and the links between each bubble define the article's co-occurrences. The top 10 most cited articles of each category are listed in Tables 6, 7, 8, 9.

The articles under red clusters majorly focus on the retrieval of aerosol optical depth (AOD) using sensors (Moderate-resolution Imaging Spectroradiometer), based on spectral reflectance over different surface types for better visualization and to provide advanced information on clouds and

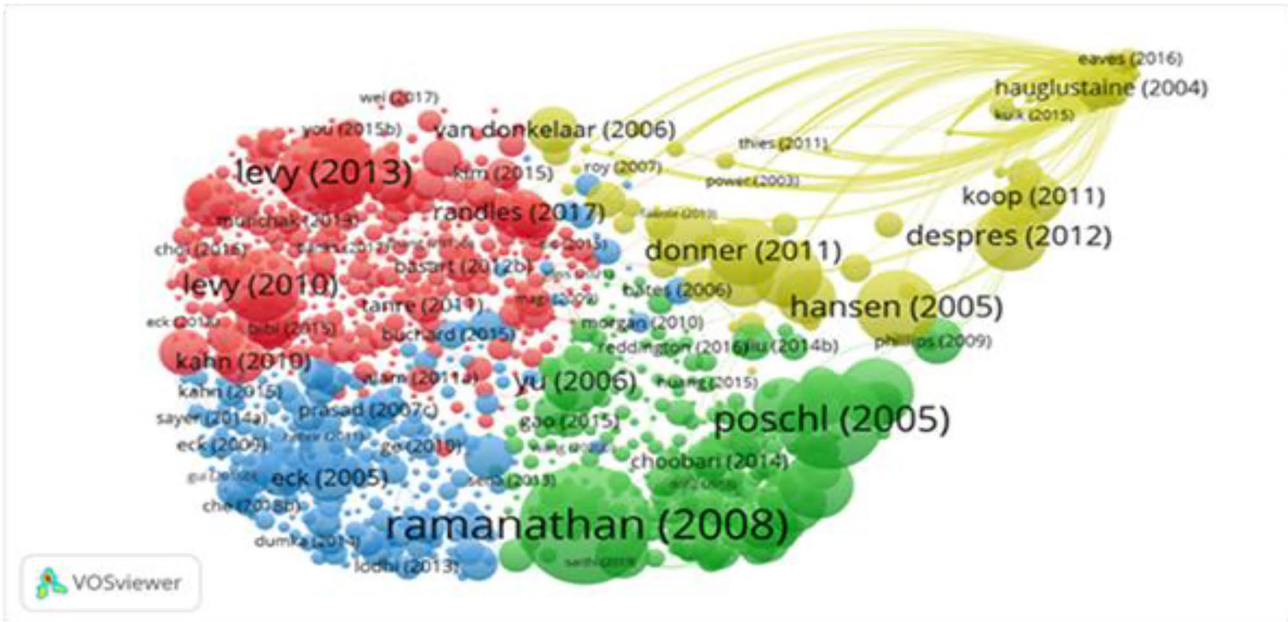


**Fig. 5** Distribution of the group of clusters based on their category

**Table 6** Highly cited articles from the Red clusters

| Retrieval, sampling, and analyses (remote sensing and sensors) (RED) | | |
|---|---|---|
| Reference | Article citation | Title |
| Levy et al. (2013) | 1092 | The collection 6 MODIS aerosol products over land and ocean |
| Levy et al. (2010) | 801 | Global evaluation of the collection 5 MODIS dark-target aerosol products over land |
| Remer et al. (2008) | 515 | Global aerosol climatology from the MODIS satellite sensors |
| Randles et al. (2017) | 374 | The MERRA-2 aerosol Reanalysis, 1980 Onward. Part 1: System Description and Data Assimilation evaluation |
| Sayer et al. (2014) | 369 | MODIS collection 6 aerosol products: Comparison between aqua's Deep blue target and merged data sets and usage recommendations |

**Table 7** Highly cited articles from the BLUE clusters

| Physical–chemical characteristics and transportation of aerosol particles in the atmosphere (BLUE) | | |
|---|---|---|
| Reference | Article citation | Title |
| Eck et al. (2005) | 333 | Columnar aerosol optical properties at AERONET sites in central eastern Asia and aerosol transport to the tropical mid-pacific |
| Singh et al. (2004) | 301 | Variability of aerosol parameters over Kanpur, northern India |
| Ramanathan et al. (2007) | 301 | Atmospheric brown clouds: Hemispherical and regional variations in long range transport, absorption and radioactive forcing |
| Dey et al. (2004) | 282 | Influence of dust storms on the aerosol optical properties over the Indo-Gangetic basin |
| Che et al. (2014) | 210 | Column aerosol optical properties and aerosol radiative forcing during a serious haze-fog month over north China plain in 2013 based on ground-based sun photometer |

the interactions with the aerosols (Levy et al. 2013; Remer et al. 2008). Further research in this category is based on advancements in comparative studies, categorical analysis using Modern-Era Retrospective Analysis for Research and Application-version 2, Goddard Earth Observing System-version 5, Aerosol Robotic Network, etc., to assimilate the

**Table 8** Highly citied articles from the green cluster

| Impacts of aerosols on climate and health (GREEN) | | |
|---|---|---|
| Reference | Article citation | Title |
| Ramanathan and Carmichael (2008) | 2160 | Global and regional climate changes due to black carbon |
| Pöschl (2005) | 1372 | Atmospheric aerosol: composition, Transformation, climate and health effects |
| Yu et al. (2006) | 555 | A review of measurement- based assessments of the aerosol direct radiative effect and forcing |
| Stevens and Feingold (2009) | 673 | Untangling aerosol effects on clouds and precipitation in a buffered system |
| Ervens et al. (2011) | 726 | Secondary organic aerosol formation in cloud droplets and aqueous particles(aqSOA): a review of laboratory, field and model studies |

**Table 9** Highly citied articles from the yellow clusters

| Stimulation models, predictive models and climate models (YELLOW) | | |
|---|---|---|
| Reference | Article citation | Title |
| Hansen et al. (2005) | 864 | Efficacy of climate forcings |
| Stier et al. (2005) | 652 | The aerosol-Climate model ECHAM5-HAM |
| Donner et al. (2011) | 696 | The dynamical core, physical Parameterizations, and basic simulation characteristics of the atmospheric component AM3 of the GFDL Global Coupled Model CM3 |
| Després et al. (2012) | 674 | Primary biological aerosol particles in the atmosphere: a review |
| Hunees et al. (2011) | 573 | Global dust model intercomparison in AeroCom phase 1 |

AOD from location-specific platforms like the ground or remote sensing for initial evaluation of the AOD fields, study the aerosol emissions (Levy et al. 2010, Sayer et al. 2014, Randles et al. 2017). Table 6 listed the highly cited article from the red clusters.

The blue category has been categorized as the studies related to aerosol characteristics, based on physical and chemical characteristics, reactivity, and mobility analysis for various climatological parameters and regional conditions (Eck et al. 2005; Singh et al. 2004; Ramanathan et al. 2007; Dey et al. 2004; Che et al. 2014). Green clusters have a combination of impacts and analysis studies, which involve depositions of black carbons, anthropogenic pollutants, and particulate matters that would affect the hydrological cycle, the interference of solar radiance involving absorption, and cause heating at high elevations. The contribution of the biogenic, greenhouse and reactive trace gases would cause environmental and health effects when they are exposed to aerosols of a particular size, structure, concentrations, and chemical compositions (Pöschl 2005, Ramanathan and Carmichael 2008, Yu et al. 2006, Stevens and Feingold 2009, Ervens et al. 2011). The fourth category is the group of yellow clusters; their main focus is on the effectiveness of the climate models when exposed to biomass burnings, particulate organic matter, mineral dust, and other global aerosol compounds (Stier et al. 2005). General circulation models (CM3), ECHAM5-HAM (aerosol-climate modeling system), atmospheric models and other such models are developed to understand the aerosols (types of aerosols, i.e., biological aerosol particles etc.) clouds interaction and climate variabilities caused by emerging issues of pollutions and global warming (Després et al. 2012, Donner et al. 2011, Hunees et al. 2011) are some related and highly cited works from this category.

## Keyword analysis to derive hotspots from the research domain

A keyword analysis is considered to understand research domains, i.e., research tendencies and the most active hotspots from the collected data. The initial analysis extracted 46,012 keywords; of which 28,212 keywords were scrutinized after data cleaning. The relevant keywords, i.e., 6107 have been retrieved by selecting keywords with at least 5 occurrences, and visualized in the heat map, as seen in Fig. 6. The following area is where the current focus draws aerosol as the most frequently used keyword with 2059 frequencies. Particulate matter and Aerosol Optical Depth are ranked as the second and the third most occurred keywords, whereas precipitation keywords ranked fifth on the list with 382 frequencies. In order to ease the identification of the most occurred author keyword with 230 occurrences, they are listed in Tables 10 and 11.

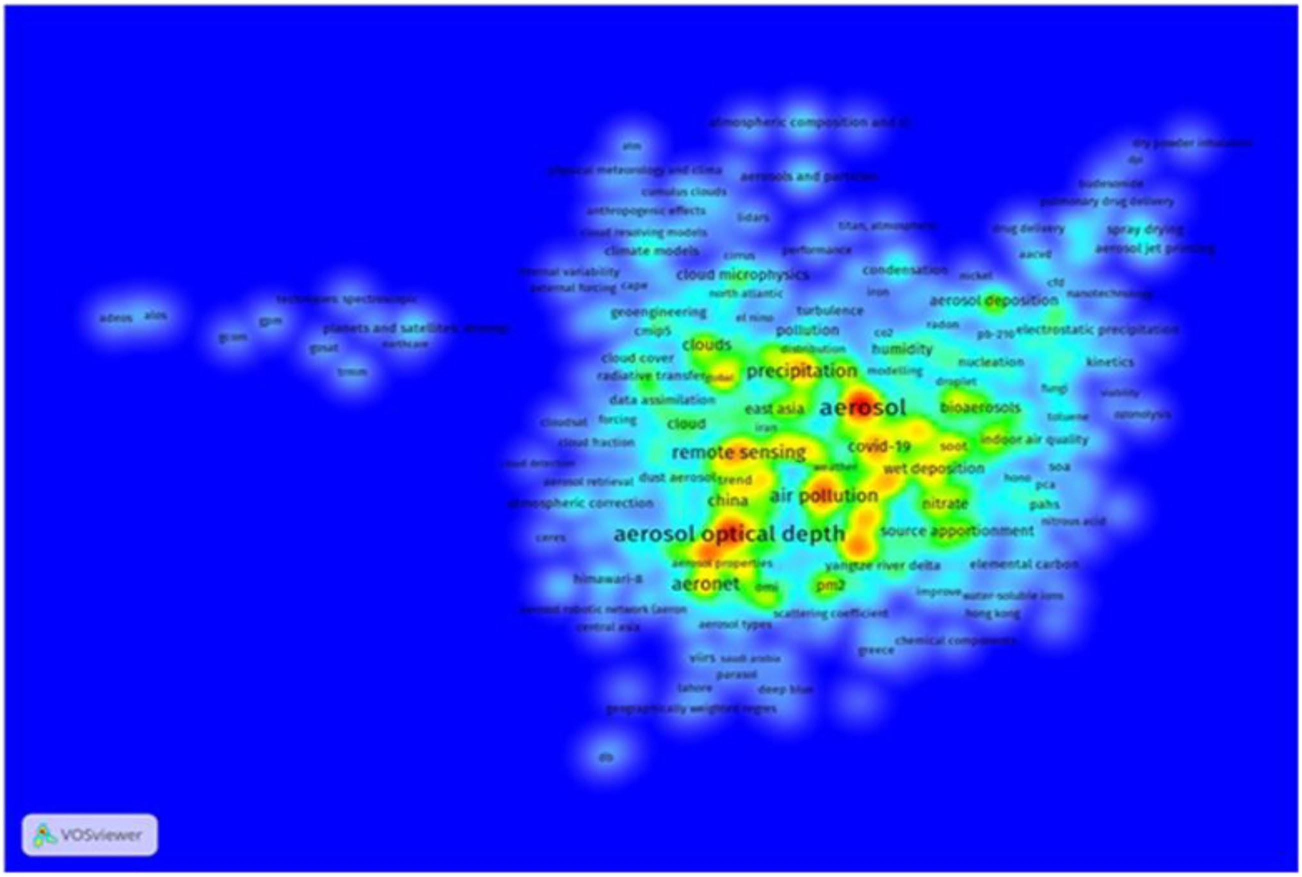


**Fig. 6** The density visualization map of author keywords from our dataset in the domain of aerosol and precipitation

**Table 10** The most frequently used author keywords in the research area of aerosol and precipitation

| Rank | Keyword | Frequency |
|---|---|---|
| 1 | Aerosol | 2059 |
| 2 | Particulate matter | 1172 |
| 3 | Aerosol optical depth | 1101 |
| 4 | Modis | 695 |
| 5 | Precipitation | 382 |
| 6 | Remote sensing | 376 |
| 7 | Air pollution | 375 |
| 8 | AERONET | 326 |
| 9 | Climate change | 307 |
| 10 | LiDAR | 269 |

**Table 11** The most frequent pairs from the author keywords taken in account Aerosol as the pivotal keyword

| Keyword 1 | Keyword 2 | Frequency |
|---|---|---|
| aerosol | MODIS | 124 |
| aerosol | LiDAR | 109 |
| aerosol | Remote sensing | 102 |
| aerosol | Precipitation | 95 |
| aerosol | Particulate matter | 90 |
| aerosol | AOD | 87 |
| aerosol | AERONET | 66 |
| aerosol | Air pollution | 46 |
| aerosol | Black carbon | 44 |

Compared to the rest of the keywords, "Aerosol" has a higher frequency of 2059 occurrences and has the most co-occurrences with other keywords. As formulated in Table 8, Aerosol has a strong focus and collaborates with MODIS, LiDAR, Remote sensing, and Precipitation in author keyword lists of 124,109,102, and 95 articles, respectively. A clearer visual is obtained when the most frequently occurring pairs ignore the keyword "Aerosol". Table 6 provides the most occurring pairs excluding the keyword "aerosol". Aerosol Optical Depth and MODIS, and also, Aerosol Optical Depth and Particulate matter are the most frequently occurring pairs with 410 and 280 occurrences. AERONET and Aerosol Optical Depth is ranked the third most frequently occurred pair of keywords, followed by other top ten pairs (Table 12).

**Table 12** The most frequent pairs from the author's keywords excluding Aerosol

| Keyword 1 | Keyword 2 | Frequency |
|---|---|---|
| Aerosol Optical Depth | MODIS | 410 |
| Aerosol Optical Depth | Particulate matter | 280 |
| AERONET | Aerosol Optical Depth | 194 |
| AERONET | MODIS | 132 |
| MODIS | Particulate matter | 115 |
| Air pollution | Particulate matter | 106 |
| Air quality | Particulate matter | 60 |
| Aerosol Optical Depth | Air pollution | 58 |
| Aerosol Optical Depth | Remote sensing | 56 |
| MODIS | Remote sensing | 45 |

## Text mining analyses: sectoral conceptualization

Text mining analyses are done only with abstracts and the title of the articles, Fig. 7 is extracted without cleaning the repetition and pronouns whereas, Fig. 8 clearly clusters the major themes. The first cluster represents the retrieval of aerosols considering the Aerosol Optical Depth using remote sensing, the following cluster also reflects the mechanism, sampling studies, and spectroscopy absorption and reflectance studies related to aerosols. The major studies contributing to this cluster is the use of Moderate-resolution Imaging Spectroradiometer (MODIS) sensors. The Collection 6 (C6) algorithm is introduced to retrieve the aerosol size parameters and aerosol optical depth over various surface types. Based on this characterization studies on the residual biases that are observed like geometry, surface properties, and comparative studies related to the validation of approaches either by assumptions or certainty (Levy et al. 2010, Levy et al. 2013). This research theme also has reviews and research articles under comparison studies on several reanalysis systems based on their upgradation, i.e., Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2), Goddard Earth Observing System, version 5 (GEOS-5), Integrated Earth System Analysis (IESA), prognostic model coupled to GOCART aerosol module. With the above references and observations, we understand that there is a need for precise evaluation, validation and simulation to understand the assimilation of

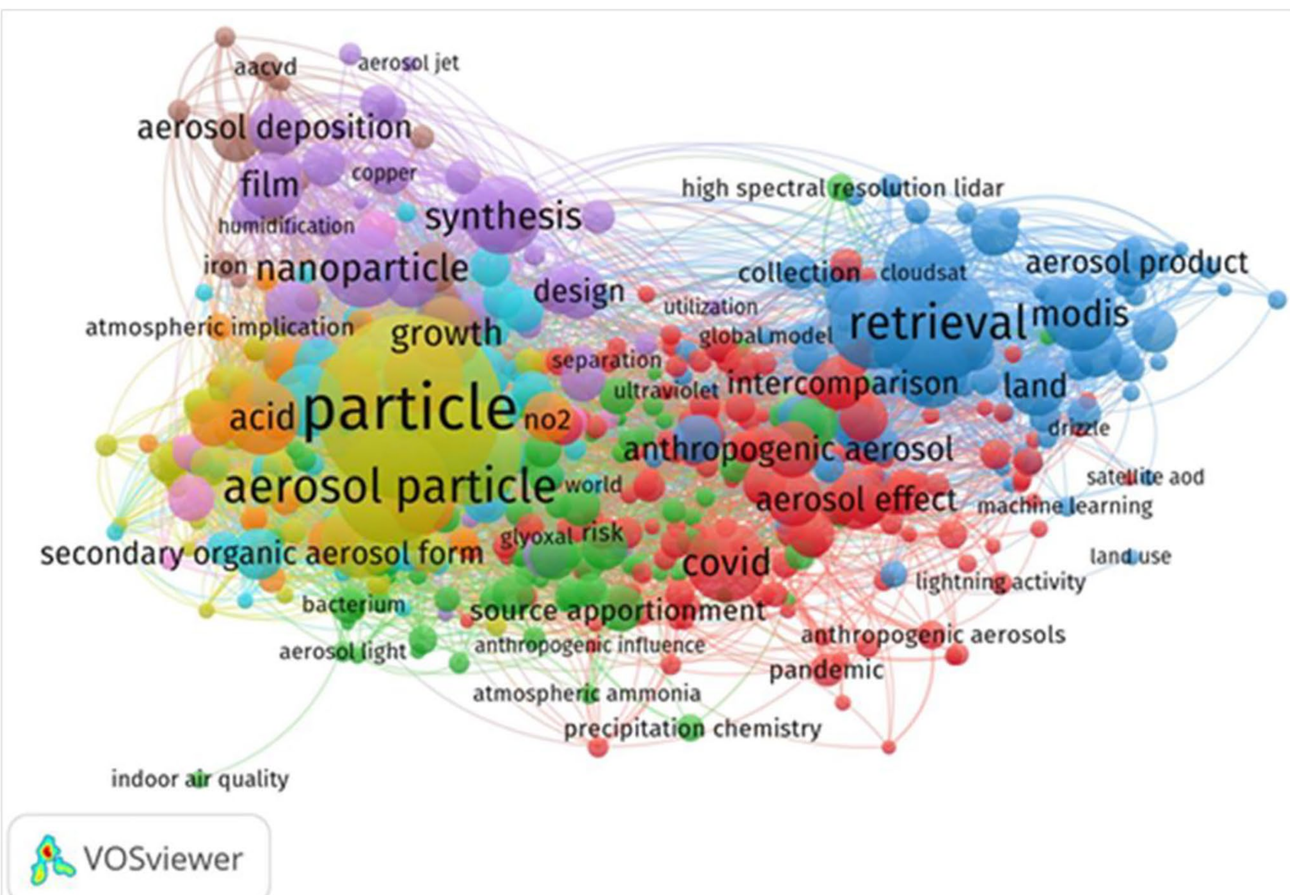


**Fig. 7** Major research themes before data cleaning

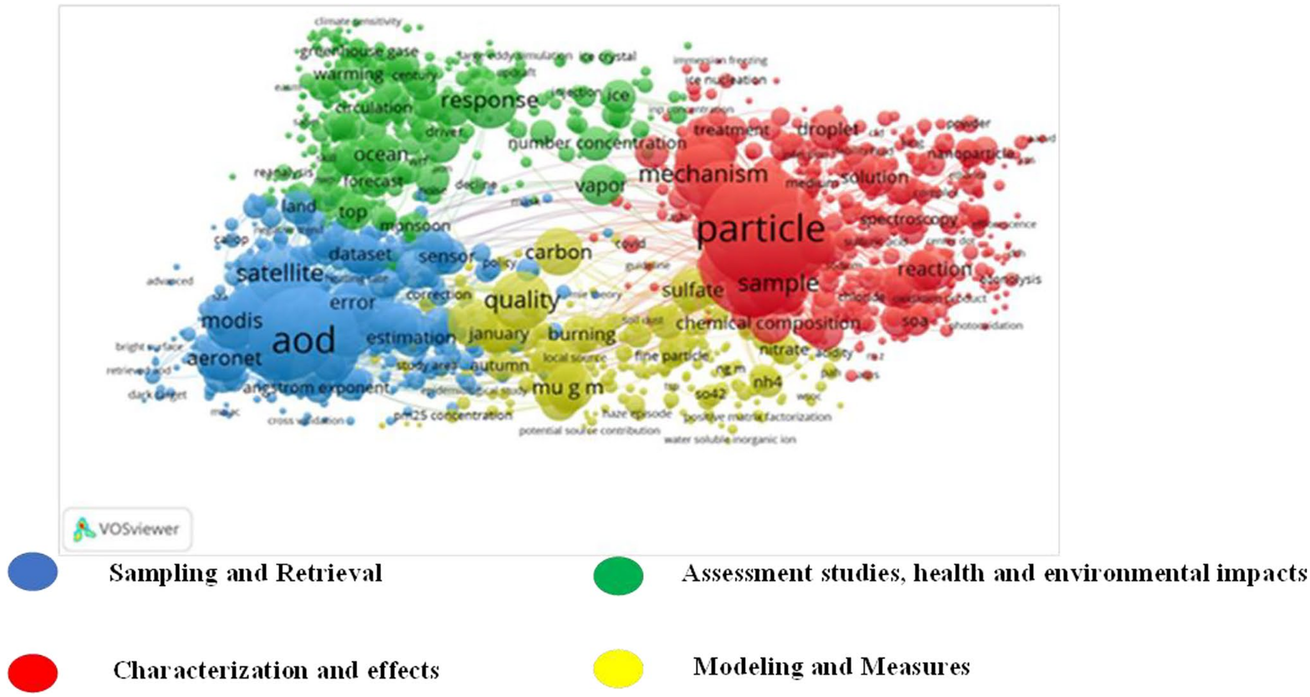


**Fig. 8** Major research themes in the field of Aerosol and precipitation

the aerosol emission and their interaction with the climate (Randles et al. 2017), as retrieval methods are yet to find the accurate precision for sampling. Many studies are emerging daily, and the retrieval of aerosols using remote sensing is currently necessary to understand the aerosol sources, interactions, and effects on human health and climate.

Cluster 2 focuses on the research themes that involve the study of the characterization, effects of these aerosols by climatic variations, and, later on, human health and the environment. The pollution accumulation during dry seasons, polluted oceanic regions, brown clouds, i.e., the scattered anthropogenic aerosols that absorb the solar radiations (Ramanathan et al. 2007) are the most researched area in this cluster. Seasonal and inter-annual variability influence the aerosol optical properties in various regions, especially in urban-industrial sites. Singh et al. (2004) stated in their study that aerosol properties over Kanpur showed influential links with seasonal effects with maximum variations, i.e., during the monsoon seasons. Dust is the detrimental factor to the optical depth during premonsoons and later gets dominated by the urban aerosols during the winter and post-monsoon times.

Dust storms are the most common natural hazards affecting various levels of health. Jing and Singh (2020) studied that the concentration of particulate matter less than 10 µm was found to be increased by almost 150 µg $m^{-3}$ after every dust event. With the population's rapid growth and the activities involved in fossil fuel combustions, global climatic factors are affected due to those aerosol emissions. The latest studies included in the research theme are to study the aerosol interaction on both direct and indirect radiative force effects on droplet properties and cloud dynamics. Recent studies involve satellite remote sensing techniques that provide the global information of the aerosol optical depth in a nominal manner; the complete information on absorption and the properties are tedious to attain; hence, the requirement of precision and proper assessment of the emitted aerosols and their characterization has attracted the scientist to work in this research theme.

Cluster 3 has the overall research related to reviews based on assessments, health and environmental effects of exposure to aerosols which is in line with the previous research theme. The assessment studies are involved in the comparison studies based on the latest observational capabilities and uncertainties for the direct forcing of aerosols based on either ground-based measurements or remote sensing. There is a lack of measurement of aerosol due to the surface reflections and to overcome uncertainties, etc. Several articles have been published in this cluster, out of which Yu et al. (2006) has the most cited article in this domain. Also, there are many research that derives the importance of atmospheric chemistry, physics climate, and health. Related research is based on particulate matter and its influence on the hydrological cycle and energy balance of the Earth. Ramanathan and Carmichael (2008) and Pöschl (2005) have the most cited articles in this research area, which is based on health effects and environmental degradation caused by the composition of atmospheric aerosols; and anthropogenic sources that emit black carbon. Additionally, Li et al. (2008) and Shiraiwa et al. (2017) have experimented based on the absorption of the aerosols and secondary organic aerosols and their scattering ability, transportation, and impacts on the medium of contact causing oxidation, biodegradation, etc. These are merely some examples from the research theme in cluster 3 related to aerosol and precipitation.

Cluster 4 documents the research area that involves the modeling and comparison studies based on global climate models, Geophysical Fluid Dynamics Laboratory models, General circulation models, and many more, that are modeled for atmosphere, ocean, sea ice, etc. Modeling aspects of these research are mainly focused recently as they primarily work on the basic simulation of these models that address the aerosol and the cloud interactions either based on chemical or physical interactions present in the stratosphere and troposphere. These studies also highlight the climate conditions and the predictive future of the global climate and consequences. Studies by Donner et al. (2011) and Hansen et al. (2005) have been the most citied and followed research in this domain. According to the thematic structure as mentioned in previous sections through bibliometric and text mining evaluations, the research questions were addressed.

## Research gap and future direction

The outcome was to identify the research gaps for future direction in the research area of aerosol and precipitation. As highlighted by Yu et al. (2006), precise characterization and aerosol absorption remain a challenging task, and only a few articles address this kind of research, making this domain lesser addressed. Research strategies have to be well developed in terms of integration and measuring satellite observations, as this is an emerging domain for retrieval. There is a need to find verifications for a direct relationship between aerosol and precipitation since research in this hotspot is based on probabilities and scenarios. Several studies on exposure due to aerosol leading to adverse health and climate conditions are available, but all the findings remain anticipated. Lastly, aerosol and precipitation are challenging research areas that involve high-level scientific cooperation and upgraded knowledge of machine learning and remote sensing techniques.

Hence, the need to have a proper characterization for the type of aerosol since preventive measures can be taken prior to the exposure of these air pollutants. Also, the involvement of control and management studies especially for less developed countries on exposure to anthropogenic aerosols either due to municipal waste, air pollution, water pollution, and soil pollution, on human health deserves investigation in future research.

## Conclusion

The study attempted to provide a comprehensive outline of aerosol in the context of precipitation by performing bibliometric and text mining analyses of 23,546 peer-reviewed journal articles from the Web of Science citation database. The outcome of the conducted analysis has led to the quantum of scientific production from the field of aerosol in the context of precipitation. The analysis has been carried out based on various indicators that mark the performance like geographical distribution of the articles, the most productive and influential authors, the most contributing journals and publications, with author keyword–based evaluation which has unravelled the research hotspots. The bibliometric coupling is performed in order to provide the 4 main clusters of research in the field of aerosol in context to precipitation which are identified as (a) Retrieval, Sample Analyses (Remote sensing and sensors), (b) Physical–Chemical Characteristics and Transportation of aerosol particles in the atmosphere, (c) Impacts of aerosols on climate and health, and (d) Simulation models, predictive models and climate models. Followed by the research domains namely, 1. Sampling and Retrieval methods, 2. Characterization and Effects 3. Assessment studies, health and environmental impacts, and 4. Modeling and Measures based on text mining on titles and abstracts of the target literature.

The insights obtained by our research would support future research to understand the research domains better and present a more precise visualization and direction for their further contribution in this field. Though there is much literature on the latest approaches, still there is a need for better bifurcation and characterization of the aerosols, their precise retrieval methods for obtaining an intelligible relationship between the aerosol and precipitation.

There are some drawbacks to this research:

1. We have taken the sample data from the Web of Science database, the incorporation of other databases like Scopus would have extended more reliable information on the present and future findings.
2. We have included only those documents in English; this would have caused some potentially specific studies involving aerosol and precipitation to be missing at the micro-level.
3. Our search only considered the articles published from 2002 to February 2022; there would be more extensive research articles and authors prior to 2002 and after February 2022.

**Acknowledgements** SG is thankful to Karunya Institute of Technology and Sciences Coimbatore for providing the required funding and support.

**Data availability** On request.

## Declarations

**Competing interests** The authors declare no competing interests.

## References


Acker J, Williams PR, Chiu L, Ardanuy P, Miller SW et al (2014) Remote sensing from satellites, reference module in earth systems and environmental sciences, Elsevier,2014,ISBN 9780124095489,https://doi.org/10.1016/B978-0-12-409548-9.09440-9

Aryasree S, Nair PR, Hegde P (2020) Radiative characteristics of near-surface aerosols at a tropical site: an estimation based on concurrent measurements of their physico-chemical characteristics. J Earth Syst Sci 129:185. https://doi.org/10.1007/s12040-020-01444-7

Bisht DS, Srivastava AK, Singh V, Tiwari S, Gautam AS, Gautam S, Santosh M, Kumar S (2022) High-altitude air pollutants monitored from rainwater chemistry in the Central Himalaya. Water Air Soil Pollut. https://doi.org/10.1007/s11270-022-05855-8

Burnett RT, Pope 3rd, Ezzati M, Olives C, Lim SS et al (2014) An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. Environ Health Perspect. 122(4):397–403. https://doi.org/10.1289/ehp.1307049

Cao J (2017) The importance of aerosols in the earth system: science and engineering perspectives. Aerosol Sci Eng 1.https://doi.org/10.1007/s41810-017-0005-1

Cao J, Wang Q, Chow JC, Watson JG, Tie X, Shen Z, Wang P, An Z (2012) Impacts of aerosol compositions on visibility impairment in Xi'an, China. Atmos Environ 59:559–566

Che H, Xia X, Zhu J, Li Z, Dubovik O et al (2014) Column aerosol optical properties and aerosol radiative forcing during a serious haze-fog month over North China Plain in 2013 based on ground-based sunphotometer measurements. Atmos Chem Phys 14:2125–2138. https://doi.org/10.5194/acp-14-2125-2014

Chowdhury H, Chowdhury T, Sait SM (2021) Estimating marine plastic pollution from COVID-19 face masks in coastal regions, Marine Pollution Bulletin, Volume 168,2021,112419,ISSN 0025–326X,https://doi.org/10.1016/j.marpolbul.2021.112419.

Després V, Huffman AJ, Burrows SM, Hoose C, Safatov A et al (2012) Primary biological aerosol particles in the atmosphere: a review. Tellus B: Chem phys Metrol 64:1. https://doi.org/10.3402/tellusb.v64i0.15598

Dey S, Tripathi SN, Singh RP, Holben BN (2004) Influence of dust storms on the aerosol optical properties over the Indo-Gangetic basin. J Geophys Res 109:D20211. https://doi.org/10.1029/2004JD004924

Donner L, Wyman BL, Hemier RS, Horowitz LW, Ming Y et al (2011) The dynamical core, physical parameterizations, and basic simulation characteristics of the atmospheric component AM3 of the GFDL global coupled model CM3. J Clim 24:3484–3519. https://doi.org/10.1175/2011JCLI3955.1

Eck TF, Holben B, Dubovik O, Smirnov A, Goloub P et al (2005) Columnar aerosol optical properties at AERONET sites in central eastern Asia and aerosol transport to the tropical mid-Pacific. J Geophys Res 110:D06202. https://doi.org/10.1029/2004JD005274

Ehhalt D, Prather M, Dentener F (2001) Atmospheric Chemistry and Greenhouse Gases. United States. https://www.osti.gov/servlets/purl/901482

Ellegaard O, Johan AW (2015) The bibliometric analysis of scholarly production: how great is the impact? Scientometrics 105(3):1809–1831. https://doi.org/10.1007/s11192-015-1645-z

Ervens B, Turpin BJ, Weber RJ (2011) Secondary organic aerosol formation in cloud droplets and aqueous particles (aqSOA): a review of laboratory, field and model studies. Atmos Chem Phys 11:11069–11102. https://doi.org/10.5194/acp-11-11069-2011

Feng, Y., Zhu, Q., Lai, K. (2017). Corporate social responsibility for supply chain management: a literature review and bibliometric analysis. J Clean Prod Volume 158,2017,Pages 296–307,ISSN 0959–6526,https://doi.org/10.1016/j.jclepro.2017.05.018.

Gautam S, Gautam AS, Singh K, James EJ, Brema J (2021) Investigations on the relationship among lightning, aerosol concentration, and meteorological parameters with specific reference to the wet and hot humid tropical zone of the southern parts of India. Environ Technol Innov. https://doi.org/10.1016/j.eti.2021.101414

Gautam S, Elizabeth J, Gautam AS, Singh K, Abhilash P (2022) Impact assessment of aerosol optical depth on rainfall in Indian rural areas. Aerosol Sci Eng (Accepted - https://doi.org/10.1007/s41810-022-00134-9).

Gautam S, Tataliya A, Patel M, Chabhadiya K, Pathak P (2020) Personal exposure to air pollutants from winter season bonfires in rural areas of Gujarat, India. Expo Health 12:89–97

Gillett NP, Stone DA, Stott PA, Nozawa T, Karpechko et al (2008) Attribution of polar warming to human influence. Nature Geo Sci 1(11):750–754. https://doi.org/10.1038/ngeo338

Graedel TE, Bates TS, Bouwman AF, Cunnold D, Dignon J et al (1993) A compilation of inventories of emissions to the atmosphere. Glob Biogeochem Cycles 7(1):1–26. https://doi.org/10.1029/92GB02793

Guo YM, Huang ZL, Guo J, Guo XR, Li H et al (2021) A bibliometric analysis and visualization of blockchain, Future Generation ComputerSystems,Volume116,2021,Pages316332,ISSN0167739X,https://doi.org/10.1016/j.future.2020.10.023.

Hansen J, Sato M, Ruedy R, Nazarenko L, Lacis A et al (2005) Efficacy of climate forcings. J Geophys Res 110:D18104. https://doi.org/10.1029/2005JD005776

Han M, Yang F, Sun H (2021) A bibliometric and visualized analysis of research progress and frontiers on health effects caused by PM2.5. Environ Sci Pollut Res 28:30595–30612

Huang H (2018) More on the t-interval method and mean-unbiased estimator for measurement uncertainty estimation. Cal Lab Int J Metrol 25(2):24–33

Hunees N, Schulz M, Balkanski Y, Griesfeller J, Prospero J et al (2011) Global dust model intercomparison in AeroCom phase I. Atmos Chem Phys 11:7781–7816. https://doi.org/10.5194/acp-11-7781-2011

IPCC (2013) AR5 Climate Change 2013: The Physical Science Basis — IPCC (https://www.ipcc.ch/report/ar5/wg1/. Last Assess: Sept 11, 2022)

Jing F, Singh RP (2020) Optical properties of dust and crop burning emissions over India using ground and satellite data. Sci Total Enviro. 718:134476. https://doi.org/10.1016/j.scitotenv.2019.134476

Khain AP, BenMoshe N, Pokrovsky A (2008) Factors determining the impact of aerosols on surface precipitation from clouds: an attempt at classification. J Atmos Sci 65:1721–1748

Krewski D, Jerrett M, Burnett RT, Ma R, Huges E et al (2009) Extended follow-up and spatial analysis of the American Cancer

Society study linking particulate air pollution and mortality. Res Rep Health Eff Inst 140:5–114 (**discussion 115-36**)
Kumar S, Hazra A, Goswami BN (2014) Role of interaction between dynamics, thermodynamics and cloud microphysics on summer monsoon precipitating clouds over the Myanmar Coast and the Western Ghats. Clim Dyn 43:911–924. https://doi.org/10.1007/s00382-013-1909-3
Kumar RP, Perumpully SJ, Samuel C, Gautam S (2022) Exposure and health: a progress update by evaluation and scientometric analysis. Stoch Env Res Risk Assess. https://doi.org/10.1007/s00477-022-02313-z
Lee SS, Donner LJ, Phillips VTJ, Ming Y (2008) The dependence of aerosol effects on clouds and precipitation on cloud-system organization, shear and stability. J Geophys Res 113:D16202
Lee SS, Feingold G, Chuang PY (2012) Effect of aerosol on cloud-environment interactions in trade cumulus. J Atmos Sci 69:3607–3632
Lelieveld J, Evans JS, Fnais M, Giannadaki D, Pozzer A (2015) The contribution of outdoor air pollution sources to premature mortality on a global scale. Nat 525(7569):367–371. https://doi.org/10.1038/nature15371
Lepeule J, Laden F, Dockery D, Schwartz J (2012) Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities study from 1974 to 2009. Environ Health Perspect 120(7):965–70. https://doi.org/10.1289/ehp.1104660
Levy H, Horowitz LW, Schwarzkopf MD, Ming Y, Golaz J-C, Naik V, Ramaswamy V (2013) The roles of aerosol direct and indirect effects in past and future climate change. J Geophys Res Atmos 118:4521–4532. https://doi.org/10.1002/jgrd.50192
Levy RC, Mattoo S, Munchak LA, Remer LA, Sayer AM et al (2013) The Collection 6 MODIS aerosol products over land and ocean. Atmos Meas Tech 6:2989–3034. https://doi.org/10.5194/amt-6-2989-2013
Levy RC, Remer LA, Kleidman RG, Mattoo S, Ichoku C et al (2010) Global evaluation of the Collection 5 MODIS dark-target aerosol products over land. Atmos Chem Phys 10:10399–10420. https://doi.org/10.5194/acp-10-10399-2010
Li B, Cantino DP, Olmstead RG, Bramley GLC, Xiang CL et al (2016) A large-scale chloroplast phylogeny of the lamiaceae sheds new light on its subfamilial classification. Sci Rep 6:34343. https://doi.org/10.1038/srep34343
Li G, Wang Y, Zhang R (2008) Implementation of a two-moment bulk microphysics scheme to the WRF model to investigate aerosol-cloud interaction. J Geophys Res 113:D15211. https://doi.org/10.1029/2007JD009361
Li Z, Niu F, Fan J, Liu Y, Rosenfeld D, Ding Y (2011) Long-term impacts of aerosols on the vertical development of clouds and precipitation. Nat Geosci 4:888–894
Liu H, Gabriel R (2005) Human activities and global warming: a cointegration analysis. Environ Model Softw 20:761–773. https://doi.org/10.1016/j.envsoft.2004.03.017
Maheskumar RS, Padmakumari B, Konwar M, Morwal SB, Deshpande CG (2018) Characterization of hydrometeors and precipitation over the Indian monsoon region using aircraft measurements, AtmosRes 205: 147-154,ISSN 0169-8095,https://doi.org/10.1016/j.atmosres
Masih J, Gautam S, Nair A, Singhal RK, Venkatesh M, Basu H, Dyavarchetty S, Uzgare A, Tiwari R, Taneja A (2019) Chemical characterization of sub-micron particles in indoor and outdoor air at two different microenvironments in the western part of India. SN Appl Sci 1:165. https://doi.org/10.1007/s42452-019-0164-6
Merigó, J., Mas-Tur, A., Roig-Tierno, N., Ribeiro-Soriano, D. (2015) A bibliometric overview of the Journal of Business Research between 1973 and 2014. J Bus Res 2015;68(12) 26452653 ISSN01482963,https://doi.org/10.1016/j.jbusres.2015.04.006.
Musthaq J, Sharma M, Bangotra P, Gautam AS, Gautam S (2022) Atmospheric aerosols: some highlights and highlighters, past to recent years. Aerosol Sci Eng. https://doi.org/10.1007/s41810-022-00133-w
Naqvi HR, Mutreja G, Shakeel A, Singh K, Abbas K, Fatma D, Chaudhary AA, Siddiqui MA, Gautam AS, Gautam S, Naqvi AR (2022) Wildfire-induced pollution and its short-term impact on COVID-19 cases and mortality in California. Gondwana Res. https://doi.org/10.1016/j.gr.2022.04.016
Nepolian JV, Siingh D, Singh RP, Gautam AS, Gautam S (2021) Analysis of positive and negative atmospheric air ions during new particle formation (NPF) events over urban city of India. Aerosol Sci Eng. https://doi.org/10.1007/s41810-021-00115-4
Pöschl U (2005) Atmospheric aerosols: composition, transformation, climate and health effects. Angew Chem Int Ed 44:7520–7540. https://doi.org/10.1002/anie.200501122
Ramanathan V, Carmichael GR (2008) Global and regional climate changes due to black carbon. Nat Geosci 1.https://doi.org/10.1038/ngeo156
Ramanathan V, Li F, Ramana MV, Praveen PS, Kim D et al (2007) Atmospheric brown clouds: hemispherical and regional variations in long-range transport, absorption, and radiative forcing. J Geophys Res 112:D22S21. https://doi.org/10.1029/2006JD008124
Randles CA, Silva AMD, Buchard V, Colarco PR, Darmenov A et al (2017) The MERRA-2 aerosol reanalysis, 1980 - onward, Part I: system description and data assimilation evaluation. J Clim 30(17):6823–6850. https://doi.org/10.1175/JCLI-D-16-0609.1
Ranjbari M, Saidani M, Shams Esfandabadi Z et al (2021) Two decades of research on waste management in the circular economy: insights from bibliometric, text mining, and content analyses. J Clean Prod 314:128009
Ranjbari M, Shams Esfandabadi Z, Ferraris A, Quatraro F, Rehan M et al (2022a) Biofuel supply chain management in the circular economy transition: an inclusive knowledge map of the field, J Chemosphere 296,2022a,133968, 0045–6535 https://doi.org/10.1016/j.chemosphere.2022.133968
Ranjbari M, Shams Esfandabadi Z, Gautam S, Ferraris A, Domenico Scagnelli S (2022b) Waste management beyond the COVID-19 pandemic: bibliometric and text mining analyses. Gondwana Res 1342–937X.https://doi.org/10.1016/j.gr.2021.12.015
Ranjbari M, Shams Esfandabadi Z, Quatraro F, Vatanparast H, Shiung Lam S et al (2022) Biomass and organic waste potentials towards implementing circular bioeconomy platforms: a systematic bibliometric analysis. J Fuel 318(123585):0016–2361. https://doi.org/10.1016/j.fuel.2022.123585
Ranjbari M, Shams Esfandabadi Z, Shevchenko T et al (2022) Mapping healthcare waste management research: past evolution, current challenges, and future perspectives towards a circular economy transition. J Hazard Mater 422:126724
Remer L, Kleidman R, Levy RC, Kaufman YJ, Tanre D et al (2008) Global aerosol climatology from MODIS satellite sensors. J Geophys Res 113.https://doi.org/10.1029/2007JD009661
Santer BD, Taylor KE, Penner J (1995) A search for human influences on the thermal structure of the atmosphere. Nat 382.https://doi.org/10.2172/116649
Sayer AM, Munchak LA, Hsu NC, Levy RC, Bettenhausen C, Jeong M-J (2014) MODIS Collection 6 aerosol products: Comparison between Aqua's e-Deep Blue, Dark Target, and “merged” data sets, and usage recommendations. J Geophys Res Atmos 119(24) 13-965. https://doi.org/10.1002/2014JD022453
Shiraiwa M, Li Y, Tsimpidi AP, Karydis VA, Berkemeier T et al (2017) Global distribution of particle phase state in atmospheric secondary organic aerosols. Nat Commun 8:15002. https://doi.org/10.1038/ncomms15002
Singh RP, Dey S, Tripathi SN, Tare V, Holben B (2004) Variability of aerosol parameters over Kanpur, northern India. J Geophys Res 109:D23206. https://doi.org/10.1029/2004JD004966

Stevens B, Feingold G (2009) Untangling aerosol effects on clouds and precipitation in a buffered system. Nat 461:607–613. https://doi.org/10.1038/nature08281

Stier P, Feichter J, Kinne S, Kloster S, Vignati E et al (2005) The aerosol-climate model ECHAM5-HAM. Atmos Chem Phys 5:1125–1156. https://doi.org/10.5194/acp-5-1125-2005

Sun J, Zhou Z, Huang J, Li G (2020) A bibliometric analysis of the impacts of air pollution on children. Int J Environ Res Public Health 17:1277

Sweileh WM, Al-Jabi SW, Zyoud SH et al (2018) Outdoor air pollution and respiratory health: a bibliometric analysis of publications in peer-reviewed journals (1900–2017). Multidiscip Respir Med 13:15

Tie J, Wang Y, Tomasetti C, Li L, Springer S et al (2016) Circulating tumor DNA analysis detects minimal residual disease and predicts recurrence in patients with stage II colon cancer. Sci Transl Med 8(346):346ra92. https://doi.org/10.1126/scitranslmed.aaf6219

Trenberth K (2020) Understanding climate change through Earth's energy flows. J R Soc N Z 50(2):331–347. https://doi.org/10.1080/03036758.2020.1741404

Van Eck NJ, Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84(2):523–538

Waltman L, Van Eck NJ (2013) A smart local moving algorithm for large-scale modularity-based community detection. Eur Phys J B 86:471

Waltman L, Eck NJV, Noyons E (2010) A unified approach to mapping and clustering of bibliometric networks. J Informetr 4:629–635. https://doi.org/10.1016/j.joi.2010.07.002

Yu H, Kaufman YJ, Chin M, Feingold G, Remer LA et al (2006) A review of measurement-based assessments of the aerosol direct radiative effect and forcing. Atmos Chem Phys 6:613–666. https://doi.org/10.5194/acp-6-613-2006

Zahedi M, Shahin M, Babar MA (2016) A systematic review of knowledge sharing challenges and practices in global software development, Int J Inf Manage 2016;36(6 Part A) 995–1019,ISSN 0268 4012,https://doi.org/10.1016/j.ijinfomgt.2016.06.007.

Zhang R, Khalizov AF, Pagels J, Zhang D, Xue H et al (2008) Variability in morphology, hygroscopicity, and optical properties of soot aerosols during atmospheric processing. Proc Natl Acad Sci U S A 105(30):10291–6. https://doi.org/10.1073/pnas.0804860105