A bibliometric and visualization analysis of the aerosol research on glaciers in the Indian Himalayan Region (IHR)

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**Abstract**

This research focuses on a bibliometric analysis of research on aerosols' impact on the glaciers in the Indian Himalayan region (IHR) published in journals from all subject categories based on the Science Citation Index Expanded, collected from the Web of Science and Scopus database between the years 2002 and April 2022. The indexing phrases like "aerosol," "glacier," and "snow" are commonly used terms and have been utilized to collect the related publications for this investigation. The document selections were based on years of publication, authorship, the scientific output of authors, distribution of publication by country, categories of the subjects, and names of journals in which scholarly papers were published. The journal's impact factor trend, citation trend, and the count of keywords used by authors were also included. The number of articles on aerosols accelerating the melting of glaciers shows a notable increase in recent years, along with more glacier melting results from countries involved in climate science research. China (382) was the country with the highest publication output on aerosols accelerating the melting of glaciers. The United States (367) was the most cited country with about 17500 total citations and 80.40 average citations per year from 2002-April 2022. The results reveal that research trends in the glaciers on aerosols' impact on the glaciers have been attractive in recent years, and the number of articles in this field keeps increasing fast.

**Introduction**

The Himalayan glaciers are dynamic and need significant exploration by scientific communities as it is vulnerable to anthropogenic activities and prone to climate change (Babu et al., 2011; Immerzeel et al., 2020; Dimri et al., 2022). The high-altitude mountains in Indian territory are called the Indian Himalayan Region (IHR), the most affected region of these transboundary aerosols due to their climatic and weather conditions (World Bank, 2013; Chen et al., 2020; Kaspari et al., 2020). Modern globalization, urbanization, and other development processes in surrounding regions are the sources of various aerosol pollutants such as black carbon, dust, and pollens (Santra et al., 2019; Zeb et al., 2020; Ningombam et al., 2021; Ramshoo et al., 2021). These atmospheric aerosols play an extensive role in atmospheric dynamics, climate change, and glacier dynamics. Aerosol, such as Black carbon, is an emerging short-lived climate forcer due to its light absorption properties. Aerosols are responsible for the darkening of the snow/ice, the energy/mass balance alterations, and further lead to the rushing up of the glacier melting (Li et al., 2019; Zhang et al., 2020; Kang et al., 2020). Extensive studies showing the potential effects of aerosol on climate change and glacier dynamics have been published over the past decade (Painter et al., 2013; Li et al., 2016; Singh et al., 2016; Singh et al., 2018; Kumar et al., 2021), but researches on the aerosols accelerating the glacier melting are limited need more consideration.

In recent years, a considerable number of in-depth research addressing the mechanistic factors in the generation of aerosols and gaseous substances have been carried out concerning climate change and glacier melting (Kuniyal et al., 2019; Usha et al., 2021; Sharma et al., 2022; Barandun et al., 2022). The purpose of the current study is to shed light on research patterns regarding the characteristics of author distribution, international collaboration, and academic interaction for aerosol-related research on the
glacier. Therefore, bibliometric studies are very important for complete historical information on scientific publications being used widely around the globe (Joshi, 2014). It is a statistical analysis of written articles widely utilized to give a quantitative analysis of academic works of literature in a specific field (Mayr and Scharnhorst, 2014). A bibliometric method is the application of mathematical and statistical tools and other media of communication (Darvish et al., 2015; Darvish, 2019). It involves many stages of development to establish a reproducible study workflow (Wang et al., 2021). Bibliometric analyses were initially applied to logarithmic and calculating techniques and many transmission publications. However, several researchers have argued that this methodology provides additional support for fair and consistent research. This procedure relies on mathematical evaluations of science, scientists, or scientific activity to compile the results of a wide range of studies across various disciplines and investigate research trends in a specific field (Zha et al., 2021; Caputo et al., 2022). In many research areas, bibliometric methods are used to examine the scientific research patterns of authors, journals, countries, and institutes as part of worldwide trends studies of specific topics (Li and Zhao, 2015). It helps graphically present quantitative data about the geographical distribution of authors and the country/institution collaboration network by employing various supplemental ways (Liu et al., 2011). Also, bibliometric analysis indicates the productivity of countries, authors, and organizations and the structure of publications in a particular research area. Therefore, we investigated the academic databases for bibliometric analysis to know about the impact of the aerosols on glaciers and the corresponding consequences of the aerosol and light-absorbing particles deposition on the Indian Himalayan glaciers (Gertler et al., 2016; Chand et al., 2021). Also, we tried to understand aerosols' development and scientific evolution to enhance glacier melting through bibliometric analysis. This study performed a bibliometric analysis on several papers from the Web of Science (WOS) database collection between 2002 to April 2022 in the Indian Himalayan region (IHR). Analyses were conducted on general features such as annual outputs, categories, journal distribution, and productive countries and organizations. In addition, a social network was employed to investigate the cooperative relationship between various nations and organizations. In addition, a co-occurrence analysis of keywords was carried out to uncover the development of recent study themes and evolving research fields.

**Methods And Data**

**Data source**

Bibliometric analysis is a quantitative tool used to access many scientific databases in a targeted and candid way (Cobo et al., 2011; Donthu et al., 2021). This research study used the WoS database, and a review was conducted by following the PRISMA framework (Gilardoni et al., 2022). This study includes published documents such as research articles, review articles, data papers, and proceedings. The main keywords used for searching the articles from WoS databases functioned in three different combinations as (ALL = (aerosol*)) AND ALL = (glacier*) as first, ALL = (“aerosol”) AND (ALL = (“ snow*”)) AND ALL = (“radiative forcing”) as second, and ALL = (“glacier melt*”) AND ALL = (“black carbon*)”) AND ALL = (“dust*”) as third. These three combinations of keywords were searched separately on the same day. The
criteria for searching the keywords were as we include all fields of WoS that include these keywords in the title, abstract, and author keywords as well as the keyword plus from the WoS database. The asterisk mark was used to search query articles with keywords that include research related to aerosol and glaciers. Furthermore, each keyword was marked in quotation to enhance the accuracy of the search (Sweileh et al., 2016). The web of science filter was used to refine the search. The refining filter was used for the previously published research articles and papers indexed in Scopus, Science Citation Index Expanded (SCI-EXPANDED), and Web of Science categories. In addition, some research articles were filtered by reading the title, abstract, and full text. A total of 11,400 articles were found during the search, out of which 1,055 were included in this study for details analysis, showing PRISMA closely related to the researched keywords. Figure 1 outlines the PRISMA framework with significant steps in identifying, screening, and including articles (Matandirotya, 2021; Mauro et al., 2021). The publishers included in the database were Elsevier, Springer Nature, MDPI, and Copernicus. The research area and subject categories were Environmental Sciences/Studies, Meteorology, Atmospheric Sciences, Geosciences Multidisciplinary, and Environmental Remote Sensing. All included studies were available in various languages, and English was the dominant language during the database search. The author itself had done the database search by taking care of all the inclusion and exclusion criteria.

The analysis, such as coupling and clustering for this study, has been done by "Biblioshiny" (Aria et al., 2017), which is a bibliometric package for R language 'Biblioshiny' and VOS viewer (Waltman et al., 2010). The methodology adopted for this work has shown in the research methodology framework (Fig. 2). Here we used different methods and analytical software to get better results. During the analysis, we considered all the inclusion and exclusion criteria limited to the study period (2002-April 2022) and location.

Dataset For Visualization Analysis

The clusters and authors' collaboration from VOS-viewer software represents the coupling of the most studied keywords and authors and how they are related to each other (Callon et al., 1991). Also, we have tried to find the author's keywords coupling and co-occurrences for the research paper published by the authors from 2002 to April 2022. "Biblioshiny" of R package 'Bibliometrix' used for advanced citation-based analysis. We used Bradford's law, Lotka's law, Factorial analysis, thematic mapping, and centrality for better scientific investigation, and various other analysis methods applied during the study to visualize better the scientific production of academic documents by author, institution, and country. We limit the investigation to the Indian Himalayan region (IHR) only to get a closer view of how the aerosols affect the glacier of this region in various ways. In this study, contributions by different types of documents have been used, such as articles, review papers, proceeding papers, and data papers in all available languages (Fig. 3).

Result And Discussion
Keywords Distribution Analysis

We have used various methods for analyzing the keywords and how they co-occurred by the network with density distribution, overlay visualization, and clusters with other authors’ keywords. During the keyword co-occurrence (Callon et al., 1991) analysis most frequently used keywords in the different papers were identified. These keywords indicate the most studied topics through VOS viewer software. About 4480 significant keywords have been detected, out of which 2716 were plus keywords while 1764 were the authors’ keywords used for co-occurrence, network, and cluster analysis. The circle’s size represented the overall frequency of keywords used during the study period by the authors (Van Eck and Waltman, 2014). Therefore, the larger size represented a higher frequency of the keyword used with bulky circles, while the line represented strong links and associations between other keywords. The keyword black carbon shows a maximum occurrence about 86 times in 27 articles (Fig. 4) in all published documents during the study period. Black carbon, Tibetan plateau, climate change, and radiative forcing were the keywords showing the highest link strength with other keywords, this represented that these were studied more together compared to other keywords and given more importance during the study period. While aerosols, deposition, glaciers, Himalayas, and glacier melt were having fewer link strengths. So, the studies related to aerosol deposition at the glacier region studied limited and need more exploration from the scientific community in a combination of these keywords having fewer link strength.

The sequence of frequency of occurrences of the primary ten keywords was as follows: black carbon (86) > Tibetan Plateau (60) > snow (44) > climate change (40) > dust (40) > glacier (38) > radiative forcing (36) > ice core (34) > albedo (28) > Himalayas (21) > arctic (19) > air pollution (19) > mineral dust (18) presented in Table 1 with top 20 keywords showing their frequency of occurrences. We have also analyzed the author's keywords coupling and cluster analysis from 2002 to April 2022. The black carbon and Tibetan plateau were widely correlated and studied, while black carbon and aerosols were the most widely used keywords during the study period. This resulted in the black carbon fraction of aerosol at the Tibetan plateau being studied more frequently during the study period while comparing the other terms. Aerosol at the Himalayan glacier region (IHR) needs focus as this region is an import water source at downstream countries such as India, Nepal, Bhutan, Bangladesh, etc.
Table 1

Keywords and their frequency of occurrence in the searched document during the study period.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Terms</th>
<th>Frequency</th>
<th>No. of Articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Black Carbon</td>
<td>86</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>Tibetan Plateau</td>
<td>60</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>Snow</td>
<td>44</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>Climate Change</td>
<td>40</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>Dust</td>
<td>40</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>Glacier</td>
<td>38</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>Radiative Forcing</td>
<td>36</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>Ice Core</td>
<td>34</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>Albedo</td>
<td>28</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>Aerosol</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td>Antarctica</td>
<td>22</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>Himalayas</td>
<td>22</td>
<td>4</td>
</tr>
<tr>
<td>13</td>
<td>Arctic</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>14</td>
<td>Air Pollution</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>15</td>
<td>Mineral Dust</td>
<td>19</td>
<td>3</td>
</tr>
<tr>
<td>16</td>
<td>Aerosols</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>17</td>
<td>Glaciers</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>18</td>
<td>Snow Albedo</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>19</td>
<td>Cryosphere</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>20</td>
<td>Remote Sensing</td>
<td>14</td>
<td>3</td>
</tr>
</tbody>
</table>

The density distribution in the network of the author's keywords was observed. The more co-occurred and frequently used term has higher density distribution with its more cluster-forming capacity. Black carbon > mineral dust > radiative forcing > climate change > snow albedo > optical properties were the sequence for decreasing distribution of density of authors' keywords during the study in searched articles (Fig. 5). In the cluster analysis of keywords, the size of the circle and text represent the higher cluster-forming capacity with other keywords. Keywords cluster analysis demonstrated that black carbon (red color)
formed a cluster with 19 key terms followed by snow (blue color) 13 keywords, albedo (green color) 7 keywords, climate change (purple color) 4 keywords, and aerosol (orange color) 2 keywords (Fig. 6).

A total of 5 groups of clusters have been observed for the authors' keywords. The highly cited documents by authors through keywords were shown in different sets with similar research fields. The size varied according to the frequency of citation of keywords (Fig. 6). A similar bibliometric approach was applied in various past studies (Ahmad et al., 2021, Mattos et al., 2020, Donthu et al., 2020, Bartolacci et al., 2020, Zurita et al., 2020, Laengle et al., 2021). The cluster analysis and the density distribution of keywords indicate that black carbon and mineral dust were widely correlated and studied keywords. Therefore, the black carbon fraction of aerosol was the most studied term throughout the literature on the Himalayan glaciers (Becagli et al., 2016; Sen et al., 2018; Kang et al., 2022; Li et al., 2022). This fraction of the aerosol concerning the glacier in different perspectives like melting, radioactive forcing, snow darkening, albedo, transport towards the Himalayas, and a glowing light-absorbing particle (Sandeep et al., 2021; Bond et al., 2013; Li et al., 2021; Thornhill et al., 2021). Glaciers were studied under various dynamics, but aerosol accelerating the glacier melting studies were limited. The density distribution and cluster analysis resulted that the aerosols need more extensive study in the IHR region for understanding the impact of these aerosols at the glacier region in different aspects such as radiative forcing, reduced albedo, snow darkening, melt, rising temperature, and climate change.

**Authors Distribution**

Coupling by cluster has been done through VOS viewer software for authors who contributed to writing the document alone or in collaboration during the study period. During the author-coupling analysis (Meng et al., 2020) in the study period from 2002 to April 2022, about 4238 authors contributed to writing the articles related to this study. The circle size and color showed the number of occurrences of the most popular author. Lines represent the strongest correlation for co-occurrences. There were few single-author articles (13), and most articles had been co-authored. The co-author's contribution per document was 7.49%, the document per author was about 0.24%, and the author per document was 4.24%, respectively. The size of the circle represents the percentage of contribution, the circle's color shows the year in which it is coupled most with others, and the lines represent the coupling with other authors. Still, the most related author means the highest yearly collaboration with other authors. The collaboration between authors enhanced rapidly after 2019 (Figure S1). Kang was the coupled author with other authors and had a higher H-index (30) on 116 articles.

In comparison, Flanner was the author having the highest total citation (5560) on 16 published articles with 12 H-index during the study period (Table S1). This H-index value represents the authors' contribution, and most of the authors related to this study have H-index (~ 14). The top 15 authors' production over time represented the article production efficiency based on the total number of articles published and cited per year. The dark blue color represented the number of articles produced by the author over time, while the light blue color represented the total citation of the articles. S. Kang and M.
Schwikowski were the top productive author with the highest total citations over time, and the highest citation was in the year 2019 (Figure S2). We analyzed the citation basis co-occurrences of the top contributed institutions. S. Kang published 15 articles and had 160 total citations in 2019. Most concerning authors regarding the research on the impact of aerosol on glaciers belong to the Chinese Academy of Science and co-occurred with the Institute of Tibetan Plateau Research, Lanzhou University, and the University of California among the top 10 institutions network (Fig. 7). Coupling of authors and authors' countries with their used keywords in the form of three field-plot was to understand how one author collaborated with the other (Figure S3). These different dynamics of the author distribution on basis of citations, publication production per year, the institutional collaboration of authors with other authors, and coupling of authors on basis of production and citations represented the result that the scientific study had more potential results in collaboration.

**Evolution Of Scientific Production**

Analysis of scientific productions annually is an essential part of the research process to develop knowledge, scientific quality, and impact on the academic world (Basualdo et al., 2016; Lv et al., 2021). The annual scientific production represents how many journal articles have been published. Here we calculated the annual scientific production of the articles through the study period (2002- April 2022); the year 2020 was the only year with the average highest number of published articles; after that, a slight decline was observed (Figure S4). In contrast, the frequency distribution of scientific productivity represents the percentage of authors who frequently contributed to writing articles in a defined period. The percentage of authors' contributions more significant would be the frequency distribution of scientific production, which has been calculated by using Lotka law. The publishing frequency of authors for this study field was represented in a dotted line (Figure S5) through Lotka law, indicating a higher publishing frequency for one or two articles by authors was more prominent than others. About 3158 authors contributed ~ 0.745% with single publications, and 513 contributed 0.121% by double author publications in the total searched articles (Table S2). This indicated that the research is not much more profound in this field and has an emerging future scope. The word growth and source growth for the current study evolution has been observed based on occurrences of annual keywords in word growth per year used in articles for the study's inclusion criteria (Figure S6). In recent years climate change, aerosol dust, Tibetan plateau, black carbon, light-absorbing particles, and albedo were key terms representing the maximum global production. Here we compare the top 15 author's production during the study. The author's year-wise production could be used to estimate the significance of the research topic. The productivity of documents published by the author could be verified by the total and the average number of citations by scholars and how frequently the author publishes the paper with their impact factor. The country-wise literary production for 2002- April 2022 has been presented in Table 2. USA (382) and China (367) were the most productive countries during the study period, while USA and Netherlands had the most average citation per year with 81.40 and 78.50, respectively. The production frequency of the articles was highest for the USA (1207) and lowest for the Netherlands (189). The contribution and production through different publishers were mentioned in the table (Table S3). Among the publishers, Elsevier was the
highest (27.87% with 294 articles) contributing publisher during the study period, followed by Copernicus and AGU with 27.87% and 16.78% proportions and 294 and 177 articles, respectively. This type of scientific production provides extensive details of literature that help the researcher to get a general idea about the research field and finds the gap between the studies for future research, that needs more focus for the betterment of the world.

Table 2
Authors’ corresponding countries’ contribution, total citations, and total citations per year.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Country</th>
<th>No. of articles</th>
<th>Contribution (%)</th>
<th>Total Citations</th>
<th>Average Citations</th>
<th>Production Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>USA</td>
<td>382</td>
<td>36.21</td>
<td>17500</td>
<td>81.40</td>
<td>1207</td>
</tr>
<tr>
<td>2</td>
<td>Peoples R China</td>
<td>367</td>
<td>34.79</td>
<td>157</td>
<td>78.45</td>
<td>1176</td>
</tr>
<tr>
<td>3</td>
<td>Germany</td>
<td>107</td>
<td>10.14</td>
<td>2006</td>
<td>59.00</td>
<td>187</td>
</tr>
<tr>
<td>4</td>
<td>France</td>
<td>106</td>
<td>10.05</td>
<td>1214</td>
<td>33.72</td>
<td>167</td>
</tr>
<tr>
<td>5</td>
<td>Japan</td>
<td>102</td>
<td>9.67</td>
<td>1374</td>
<td>26.94</td>
<td>270</td>
</tr>
<tr>
<td>6</td>
<td>Switzerland</td>
<td>99</td>
<td>9.38</td>
<td>814</td>
<td>20.87</td>
<td>235</td>
</tr>
<tr>
<td>7</td>
<td>United Kingdom</td>
<td>91</td>
<td>8.63</td>
<td>1999</td>
<td>44.42</td>
<td>204</td>
</tr>
<tr>
<td>8</td>
<td>India</td>
<td>88</td>
<td>8.34</td>
<td>905</td>
<td>14.84</td>
<td>186</td>
</tr>
<tr>
<td>9</td>
<td>Italy</td>
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<td>8.06</td>
<td>1136</td>
<td>29.13</td>
<td>198</td>
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<tr>
<td>10</td>
<td>Netherlands</td>
<td>14</td>
<td>1.33</td>
<td>157</td>
<td>78.50</td>
<td>189</td>
</tr>
</tbody>
</table>

Trends Of Topics

The software "biblioshiny" was used to analyze the trends in topics or words by comparing the topic frequency in the study period. This trending topic-based analysis and frequency of co-occurrence of words provide the evolution of study topics/phrases that can be easily detected through developing areas and evolving scientific research trends. Here, annual trends of the topics represented the co-occurred frequency of the subject, the bigger the size of the dot, the more frequent the term. The terms arctic, mineral dust, cryosphere, snow albedo, black carbon, radiative forcing, Tibetan plateau, optical properties of aerosols, and aerosols were some significant terms used more frequently in the study period (Cong et al., 2013; Gautam et al., 2013; Guleria et al., 2013; Xu et al., 2016; Kang et al., 2019; Chand et al., 2021). The line represents the trend distribution of the topics to the current period. Cryosphere (80 times) and
radiative forcing (60 times), and black carbon (40) were the most frequent terms used in the study period by different authors. While aerosols, Himalayas, and glaciers show trending nature as terms representing the longest trend line (between 2011–2020) in the study period 2002-April 2022 (Figure S7). The most frequent and trending keywords have been mineral dust, cryosphere, snow albedo, black carbon, and radioactive forcing. At the same time, aerosols and Himalayan glaciers were less frequently used keywords in the entire searched literature during the study period. The thematic evolution of different topics and their trend in two-time slices are mentioned in (Fig. 8). The radioactive forcing due to black carbon at glacier/ice is studied most, while aerosols impacting the melting of glacier region is still a partial studied field (Kaspari et al., 2013; Jacobi et al., 2015; Alexandra Bancheva, 2016; Qin et al., 2021). Himalayan glaciers affected by aerosols are a less explored or might be a limited studied research area, which suggests the scope of future research in the Himalayas.

**Documents Basis Dynamics**

In this study, we have done the source impact citation index for all the searched articles for whole study period. The top 15 documents were compared for better visualization of the most cited document, and to check the source growth, we analyzed the top 5 sources throughout the study period. The total citation (TC) index by local source (Lv et al., 2021) represents the citation of articles in a specific journal. There were 232 journals related to this study, of which we used the top 15 journals/sources to check their production efficiency. The most cited documents were from the Journal of Geophysical Research-Atmospheres with the H index (27) and Atmospheric Chemistry and Physics with the H index (37) (Table 3).
Table 3
Source impact and contribution throughout the study.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Journal</th>
<th>No. of Articles</th>
<th>Contribution (%)</th>
<th>H index</th>
<th>G index</th>
<th>M index</th>
<th>Total Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Atmospheric Chemistry and Physics</td>
<td>107</td>
<td>10.14</td>
<td>37</td>
<td>72</td>
<td>2.17</td>
<td>5436</td>
</tr>
<tr>
<td>2</td>
<td>Journal of Geophysical Research Atmospheres</td>
<td>87</td>
<td>8.25</td>
<td>27</td>
<td>72</td>
<td>1.68</td>
<td>6758</td>
</tr>
<tr>
<td>3</td>
<td>Atmospheric Environment</td>
<td>57</td>
<td>5.40</td>
<td>19</td>
<td>38</td>
<td>1.18</td>
<td>1532</td>
</tr>
<tr>
<td>4</td>
<td>Science of The Total Environment</td>
<td>54</td>
<td>5.12</td>
<td>17</td>
<td>24</td>
<td>1.7</td>
<td>725</td>
</tr>
<tr>
<td>5</td>
<td>Cryosphere</td>
<td>41</td>
<td>3.89</td>
<td>20</td>
<td>30</td>
<td>2</td>
<td>973</td>
</tr>
<tr>
<td>6</td>
<td>Environmental Science Technology</td>
<td>31</td>
<td>2.94</td>
<td>19</td>
<td>28</td>
<td>1.26</td>
<td>878</td>
</tr>
<tr>
<td>7</td>
<td>Geophysical Research Letters</td>
<td>30</td>
<td>2.84</td>
<td>18</td>
<td>28</td>
<td>1.12</td>
<td>1240</td>
</tr>
<tr>
<td>8</td>
<td>Journal of Glaciology</td>
<td>27</td>
<td>2.56</td>
<td>15</td>
<td>23</td>
<td>0.93</td>
<td>596</td>
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<tr>
<td>9</td>
<td>Atmospheric Research</td>
<td>22</td>
<td>2.09</td>
<td>13</td>
<td>21</td>
<td>0.81</td>
<td>699</td>
</tr>
<tr>
<td>10</td>
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Average citations per document were 37.78, and the average citation per year per document was 4.57. Cumulative occurrences of source growth started blooming in the past five years rapidly. Atmospheric
Chemistry and Physics, Journal of Geophysical Research and Atmospheres, and Atmospheric Environment contributed more significantly with ~10.14%, 8.25%, and 5.40%, respectively. Bradford's law was used to rank the top 10 articles in which Atmospheric Chemistry and Physics journal was ranked first, Science of the Total Environment was ranked second, and Atmospheric Environment ranked third with the frequency values of 106, 79, 53, and cumulative frequency values of 106, 185, 238 respectively (Figure S8).

**Thematic Mapping**

Here, we have used the thematic map of “biblioshiny” to understand better development degree/density with their centrality (relevance degree) of the topic. A quadrate with the X and Y axis in thematic map visualization was used (Donthu et al., 2021; Ahmad et al., 2022). The thematic map was created based on author keywords and was designed into four themes: niche themes, motor themes, emerging or declining themes, and basic themes, as shown in Fig. 9. The centrality on the X-axis shows the degree of collaboration of a cluster in contrast with other clusters, while the density on the Y-axis shows the internal strength of a cluster (Lau et al., 2010). The motor themes were advanced and essential for constructing the research field. The highly focused domains in niche themes were black carbon (BC) and atmospheric dust, the minor developed themes during the study. Basic themes were the most developed and formed three clusters of authors' keywords. The domains of concern in basic themes were the Tibetan plateau, black carbon and glaciers, climate, and snow albedo. Further aerosol at glaciers has scope for future studies to explore different perspectives of aerosol through which it disturbs the Himalayan glacier’s ecosystem. This will provide future insight to the scientific community regarding the newly emerging research field and which topic need to focus on in the future.

These themes formed three clusters, first with black carbon, Tibetan plateau, and glaciers, second with snow, albedo, and dust, and third with climate change, arctic, and air pollution. The basic themes were well-developed and showed high relevance degree. The emerging or declining themes were mainly focused on deposition, precipitation chemistry, and atmospheric dust, reflecting most development degrees. The dendrogram was used for hierarchical cluster analysis (De Sausa, 2021) for the keyword's evolution, an emerging field in the past few years. This dendrogram has five themes; green represents the most widely used topics with two clusters over the period, while the red one represents the topics less used but in a short span (Fig. 10). This dendrogram resulted in the dust at the glacier region not being explored much as these terms were studied in the limit, and even at IHR glaciers so the scientific community must explore it to find how much aerosol is responsible for the melting of glaciers at IHR.

We also analyzed the conceptual structural mapping by multiple component analysis (MCA) with factorial analysis for authors' keywords. There were five clusters, out of which the pink-colored cluster most dominated during the study period with primary keywords black carbon, glacier, Himalayas, aerosol, Tibetan plateau, and albedo (Fig. 11). Aerosols were significant factors influencing the glacier due to their dynamic behavior, such as radioactive forcing, snow darkening effect, and reduced albedo (Skiles et al.,
These were major emerging research areas with a future vision for the scientific community (Yang et al., 2015; Sharma et al., 2022). For this study, aerosol and glaciers were the significant components that were focused on, but Indian Himalayan Region still has limited study compared to Tibetan Plateau and other cryosphere. The region might be the scientific community more focused on the hydrological, glacier melts, and glacier dynamics, climate change factors in this region, but the result showed that in recent years, aerosols getting more attention at IHR glaciers due to their unique optical properties. It further has future scope for exploring the aerosol at the IHR glacier.

Geographical Collaboration

This study developed a country contribution map that represented country-wise academic research evolution and collaboration to understand the acceleration of glacier melting and other alterations due to different types of aerosols. The network of relationships/collaboration between keywords with geographical locations presented on the map, and the thickness of the curved red line represented the collaboration frequency between the countries (Figure S9). The USA and the Republic of China were the countries that collaborated largely. Also, most of the corresponding authors belong to these two countries. China was the country that published the highest number of documents with the second-highest total citation. At the same time, the USA and Netherlands were the most average country per year during the study period. India ranked eighth based on the corresponding author's country with 186 frequency of collaboration articles and 905 total 14.84 average citations. To know about multi-country publications (MCP) and single-country publications (SCP), collaboration based on geographical location was also performed (Fig. 12). This collaboration between different geographical locations helps the scientific community to give a better understanding of the issues at a global scale.

Future Scope And Limitations

At the bibliometric analysis, we observed that black carbon and mineral dust-induced radiative forcing had been studied most in the glacier region. However, the study of aerosols in the Indian Himalayas and also at the Tibetan Plateau has limitations. Therefore, it indicates the future scope for scientists to explore the research field related to the aerosols in the glacier region to increase the database for a better understanding of the complex role of aerosols in the glacier ecosystem. This would help understand the climate alteration on the glaciers. The reason behind the field landscape in its current shape might be the climate change-related issues growing in the past few years the scientific community is more aware of these climate change issues in recent years. There were numerous studies focusing on climate and the climate directly linked to the increasing temperature, the cryosphere is the most prone area to this rising temperature. It starts melting as the global temperature rises. Aerosol has unique optical properties of absorbing and scattering solar radiation. These absorption properties of aerosol affect the heat budget of the earth. Aerosol primarily the light-absorbing particles (LAIs) disturb the radiative forcing and affects the albedo, which causes a change in the radiation budget which leads to a change in the climate. This change in climate is the source of various kinds of natural calamities and therefore, this might be the
reason for this kind of shape of the study landscape. The scientific community must more focus on the research area like how much aerosol affects the albedo and radioactive forcing, snow darkening, and LAIs at glaciers. And how these phenomena are associated with the melting of glaciers. The studies related to the cryosphere are generally expansive therefore, developed countries should have to collaborate with other countries, to support the scientific community so that better policies can be made for a better world and attain sustainable goals such as clean water and air, etc.

The limitation of the study was that we only had access to the web of science database. We were bound to the study time to 2002- April 2022, as this topic has evolved recently, and most articles were published within the past five years. It has excellent future scope for scholars and academicians to explore different dimensions of aerosol through which they accelerate the melting and affect the glacier ice/snow in IHR and other cryosphere regions.

**Conclusion**

A systematic analysis of the aerosol research evolution in the Indian Himalayan region (IHR) has been conducted. Undoubtedly, under the changing climate and increasing environmental risks, there is a need for academic research to be ahead of the times. The need for quick and direct responses to new threats of climate change raises the question of planning and directing academic research toward the aerosol. The core concepts of bibliometric visualization of the aerosol research on glaciers in the Indian Himalayan Region (IHR) have been drawn based on the keywords and authors appearing in the articles of WoS from 2002-April 2022. However, the research theme has progressed speedily in the past five years, with 51% of the research being published by the SCI-WoS. The most cited documents were from the Journal of Geophysical Research-Atmospheres with the H index (27) and Atmospheric Chemistry and Physics with the H index (37), with average citations per document of 37.78 and an average citation per year per document of 4.57. Atmospheric Chemistry and Physics, Journal of Geophysical Research and Atmospheres, and Atmospheric Environment contributed more significantly with ~ 10.14%, 8.25%, and 5.40%, respectively. Under Bradford's law ranking process, Atmospheric Chemistry and Physics journal got the first rank, Science of the Total Environment second rank, and Atmospheric Environment third rank with the frequency values of 106, 79, 53 and cumulative frequency values of 106, 185, 238 respectively. Current events such as climate change, positive radiative forcing, enhanced snow darkening, and glacier melt, increasing concentration of aerosols over IHR influence this field. This study has found the evolution of scientific literature in this field and the emerging impacts of different studies related to aerosol on glaciers and literary production. The results showed that the research theme has full-edged in the 5 clusters shown through a conceptual structural map derived through multiple component analysis. Moreover, depth analyses by visualizing maps of the top active countries, authors, and top-cited documents on the citation, coupling, clustering, co-occurrence, and thematic mapping have discovered quite a lot of essential information in this research area. The results further reveal that research on the aerosol effects on the glaciers of the Indian Himalayan region (IHR) has evolved in recent years. The number of articles in this field keeps increasing fast as the USA and China play the most crucial role in related research. This field of study has great potential for continued growth, showing a progressive
increase in research topics. The USA (36.21%) and China (34.79%) were the most productive countries throughout the study period. This field has future scope for scholars to understand better how aerosols affect glaciers from a different perspective.

**Declarations**

**Acknowledgment**

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**Authors Contribution**

Prity Singh Pippal: Conceptualization, Original draft preparation, and Methodology. Ramesh Kumar: Methodology, Visualization, Investigation, and Editing. Atar Singh: Software, Data curation, and Validation. Rajesh Kumar: Conceptualization, Supervision, and Reviewing.

Ethical Approval- The ethical approval requirement is not applicable.

Consent to Participate- All authors have significantly contributed to this work.

Consent to Publish- All authors agreed to publish.

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Competing Interest- Not applicable.

Availability of Data and Materials- Data available at request due to privacy and other restrictions.

**References**


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Represents the single-country and multi-country publication of the article published during the study period.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementry25.10.2022.docx