Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XXV**, Issue **1** (**June 2026**), pp. **19-28;** DOI: **10.5775/fg.2026.1.3772**

Global trends in watersheds prioritization - a bibliometric analysis

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Received on 02-02-2026, reviewed on 13-03-2026, accepted on 11-05-2026

Abstract

The prioritizing of watersheds is a significant concern for researchers and decision-makers in the context of intensifying hydrological and geomorphological processes. Consequently, implementing territorial management measures has become a priority. The main objective of this paper is to conduct a quantitative analysis of scientific production over time at the global level, through bibliometric methods. A total of 957 scientific and review articles addressing the concept of "prioritization of watersheds" were identified in the Web of Science database. Using the VOSviewer application, trends, co-authorship relationships, country distribution, leading authors, and citation counts were evaluated. The results indicate a steady increase in the number of publications between 1993 and 2025, with 2021 recording the highest number at 114 publications. The most productive countries in terms of publications are India and the USA, with American articles receiving the highest number of citations (8,618) and exhibiting the most extensive collaboration network. Nevertheless, India stands out with two publications each exceeding 400 citations. The involvement of researchers from 55 countries across six habitable continents, each contributing at least three articles, highlights the widespread interest in watershed prioritization. Accordingly, this study suggests future directions for applying the concept and for selecting journals and collaborators to facilitate interventions aimed at sustainable watershed management.
Keywords: *watershed prioritization, VosViewer, metadata analysis, research trends, GIS, environmental science, scientific collaboration*

Introduction

Studies addressing the necessity of watershed prioritization begin with understanding the existence and functioning of a basin itself. The application of the "system" concept to analyze real-world phenomena was introduced by Chorley (1962), who defined the watershed as the "basic geomorphological unit of continents." A watershed is considered to operate as an integrated whole based on laws, models, and mathematical variables (Zăvoianu, 1978); however, the model does not fully coincide with the system concept, being more of an intuitive approach that envisions a behavioral pattern (Ichim et al., 1989). According to Zăvoianu (1978), a watershedis a complex system connected to its geographic environment through an exchange of matter, primarily from precipitation, and a continuous flow of energy supplied by solar radiation. Zaharia (1998) supports the open systems theory, where a watershed can reach a steady-state equilibrium when the inflow and outflow of matter and energy balance each other (this principle underpins the evolution and functioning of all watersheds). Nonetheless, such a system becomes highly susceptible to sudden changes caused by climate warming and human activities (Denissen et al., 2022). Both natural and anthropogenic factors can induce structural and irreversible changes to water and soil resources (Armaș, 1999; Chendeș et al., 2008; Constantin et al., 2011; Ebrahimi Gatgash & Sadeghi, 2024). The expected population growth to approximately 9 billion by 2050 will generate major imbalances in watersheds due to deforestation for urban expansion and irrational resource use (Murătoreanu et al., 2025), threatening food security (Zhang et al., 2024). Therefore, the studies on watershed prioritization can serve as valuable support for authorities in managing natural hazards, guiding decision-makers to focus on basins requiring immediate protection and conservation measures (Chaudhary & Pandey, 2022; Pathare & Pathare, 2021; Shelar et al., 2022; Sarkar et al., 2022).

The aim of this paper is to identify research trends and directions concerning the concept of "prioritization of watersheds" through an analysis of literature indexed in the Web of Science database. Bibliometric analysis provides a clear picture of the international visibility of this research topic. To achieve this, VOSviewer is used to:

- Visualize the temporal evolution of the number of published articles,
- Map the spatial distribution of publications,
- Identify the most influential authors and their co-authorship networks.

This study offers relevant insights into the development and analytical directions of this subject, as well as its scientific impact. Such understanding supports the foundation of research strategies and prioritization of topics based on their prominence, ultimately providing better guidance to decision-makers for effective and timely intervention.

Theoretical background

The concept of "prioritization of watersheds" has broad applicability at both global and regional scales. Prioritizing anthropogenic interventions (Oli & Pandey, 2024) involves identifying watersheds that require immediate management actions (Halder et al., 2024) and ranking them according to their priority level (Ojha et al., 2023). Previous studies applied watershed prioritization to analyze phenomena, such as flash floods, landslides (Singh et al., 2021), floods (Avand et al., 2021), or pedological droughts (Sousa Estacio et al., 2022), with the aim of conserving both water and soil resources within the analyzed watershed (Pathare & Pathare, 2021). With the advancement of Geographic Information Systems (GIS) and modern techniques for integrating multiple parameters and variables influencing natural hazard occurrence, prioritization studies at the watershed level have become increasingly efficient and practical (Bogale, 2021).

Over time, analyses have incorporated various parameters related to basin area, shape, and length (Meshram & Sharma, 2017); relief configuration aspects such as slope, aspect, and maximum altitude (Chandniha & Kansal, 2017); and geometric factors of the drainage network (Ghosh & Gope, 2021). Basin shape serves as an indicator of the time water is retained and provides information about susceptibility to flash floods, especially in circular basins (Schumm, 1956). Vegetation cover is also relevant due to its capacity to absorb precipitation and reduce soil erosion (Esa et al., 2018). However, the literature reveals multiple approaches, methods, and integrated parameters (Tukura et al., 2021; Odiji et al., 2021; Sankriti et al., 2021), which can sometimes pose limitations. Whether 9, 13, or 18 morphometric parameters are used, the choice of a method that does not weigh the importance of each parameter in assessing hazard susceptibility may lead to the overshadowing of extreme values (Pastor et al., 2024). Therefore, it becomes imperative to identify the most robust model applicable to basins with similar physical properties.

Previous research is divided both methodologically and in terms of applicability. Approaches differ depending on objectives and parameters analyzed: some focus solely on identifying a single hazard type, while others integrate environmental factors with morphometric parameters for multi-hazard assessment. Applied methods range from classical techniques like fuzzy logic and analytic hierarchy process (AHP) (Ahmed et al., 2018) to advanced machine learning methods (ML) (Derakhshani et al., 2023; Darji et al., 2023).

Bibliometric analysis is a branch of scientometrics that quantitatively examines scientific output by applying mathematical and statistical indicators for graphical and cartographic representation of evolution and dynamics research (Donthu et al., 2021).

Bibliometric analysis has a broad range of applications across fields such as medicine (Barrington et al., 2023), education (Lozada et al., 2021), mathematics (Peng et al., 2020), and finance (Nath & Chowdhury, 2021). It can also be applied in environmental science to analyze the interest devoted to watersheds (Beigi et al., 2026). As an objective analytical method, it has the capacity to interrogate large datasets effectively.

Recently, bibliometric analysis has been used to map research evolution in the field of watershed stability, identifying publication trends, institutional collaborations, and spatiotemporal publication patterns (Beigi et al., 2026). However, there is currently no dedicated bibliometric analysis focused exclusively on watershed prioritization, highlighting the relevance and necessity of the present study.

Methodology

With the increasing emphasis on the concept of sustainable development, the importance of focusing research on territorial planning and watershed management has increasingly attracted the attention of researchers. Scientific production serves as a foundation for policymakers and administrators, with its quality measured by the impact of the studies (Pranckutė, 2021). The aim of this paper is to present the current state of research on watershed prioritization, focusing on the connections established among authors, countries, and institutions, as well as the progression and popularity of publications. Bibliometric analysis achieves these objectives.

The Web of Science Core Collection (WOS) database was selected for this study due to its extensive bibliographic resources and its status as one of the oldest and most widely recognized databases worldwide (Li et al., 2018), attributed to its interdisciplinary character and advanced citation analysis functionalities (Pranckutė, 2021). The keyword "prioritization of watersheds" was used to identify a total of 1001 records containing the term in the title, abstract, or keywords. Filters were applied to improve research efficiency by excluding document types such as proceedings papers, early access articles, and book chapters. The language was restricted to English, covering the entire available time span.

The retrieved results were downloaded in two files using the BibTeX format and the full records function. For data analysis, the VOSviewer software (Van Eck & Waltman, 2010), version 1.6.20, was employed. Within this software, bibliographic maps were created from the

two downloaded files. The following indicators were analyzed: the number of articles published between 1993 and 2025, country distribution, citation counts, and co-authorship patterns. The dataset was subjected to filters including full counting, limiting the maximum number of authors per document to 10, and setting a minimum of 5 documents per author to reduce author redundancy. Country-level values were visualized using the Map Chart feature in Microsoft Excel (version 365), which uses data provided by Bing Maps and its contributors (© Australian Bureau of Statistics, GeoNames, Microsoft, Navinfo, Open Places, OpenStreetMap, Overture Maps Foundation, TomTom, Zenrin).

Results

Publication trends

The data were extracted from the Web of Science, providing access to relevant scientific literature. The use of VOSviewer was used to visualize trends by exporting and processing data in Microsoft Excel, which highlighted the increasing research interest during specific periods. Figure 1 presents the evolution of scientific publications on watershed prioritization from 1993 to 2025. A total of 957 scientific articles and review papers were identified in the Web of Science database as of August 2025. The trajectory of the graph shows a rapid increase in the number of publications from 1993 to 2025. This growth can be attributed to a renewed research interest in watershed prioritization in the context of climate change and hazard management.

Moreover, the publication dynamics from 1993 to 2025 were grouped into three phases: slow growth, with an average of 4.71 publications per year (1993-2008); moderate growth, with an average of 29.7 publications per year (2009-2018); and rapid growth, with an average of 84.86 publications per year (2019-2025). The exponential regression coefficient of the graph was 0.75, indicating a positive growth trend in the research field. The highest number of publications (11.91%) was recorded in 2021. Among these, the majority were articles (907), followed by 55 proceeding papers and 16 review articles.

The results reveal that most publications related to watershed prioritization fall under the Environmental Sciences category (463 articles), reflecting a significant interest in environmental impact and land use planning. A considerable number of articles (322) were published in Water Resources, a field known for studies evaluating flood susceptibility and proposing water resource conservation and watershed management measures. Additionally, 85 articles were published in Remote Sensing, predominantly from India, which is also the origin of the "watershed prioritization" concept through a 1993 study titled “Watersheds Prioritization Using Remote-Sensing Techniques: A Case Study of the Mahbubnagar District, Andhra Pradesh, India.”

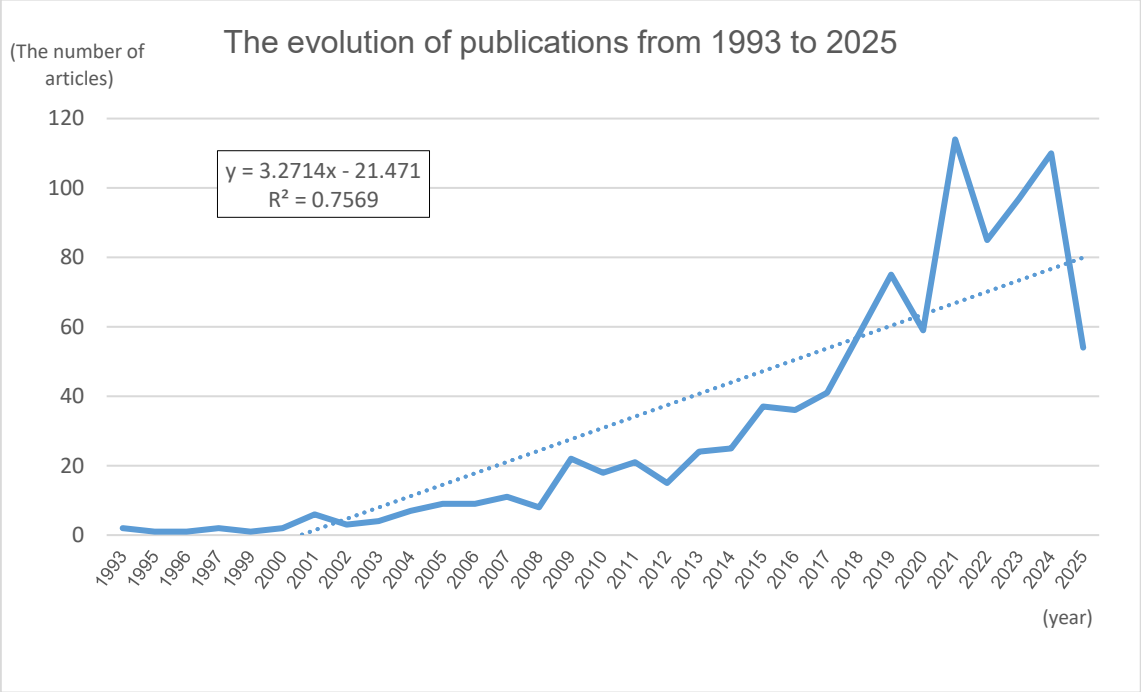

Figure 1. Evolution of scientific publications on watershed prioritization from 1993 to 2025

Spatial distribution of publications

Figure 2 illustrates the distribution of total publications across different countries worldwide. A selection of 55 countries was made, each with a minimum of three articles. To provide an overview of the global level of interest in this topic, the number of publications per country is represented cartographically. It can be observed that, during the period 1993-2025, the highest number of articles on watershed prioritization (23%) were published by India (302) and the USA (295), with the American articles receiving the most citations (8618), followed by the Indian articles (6502).

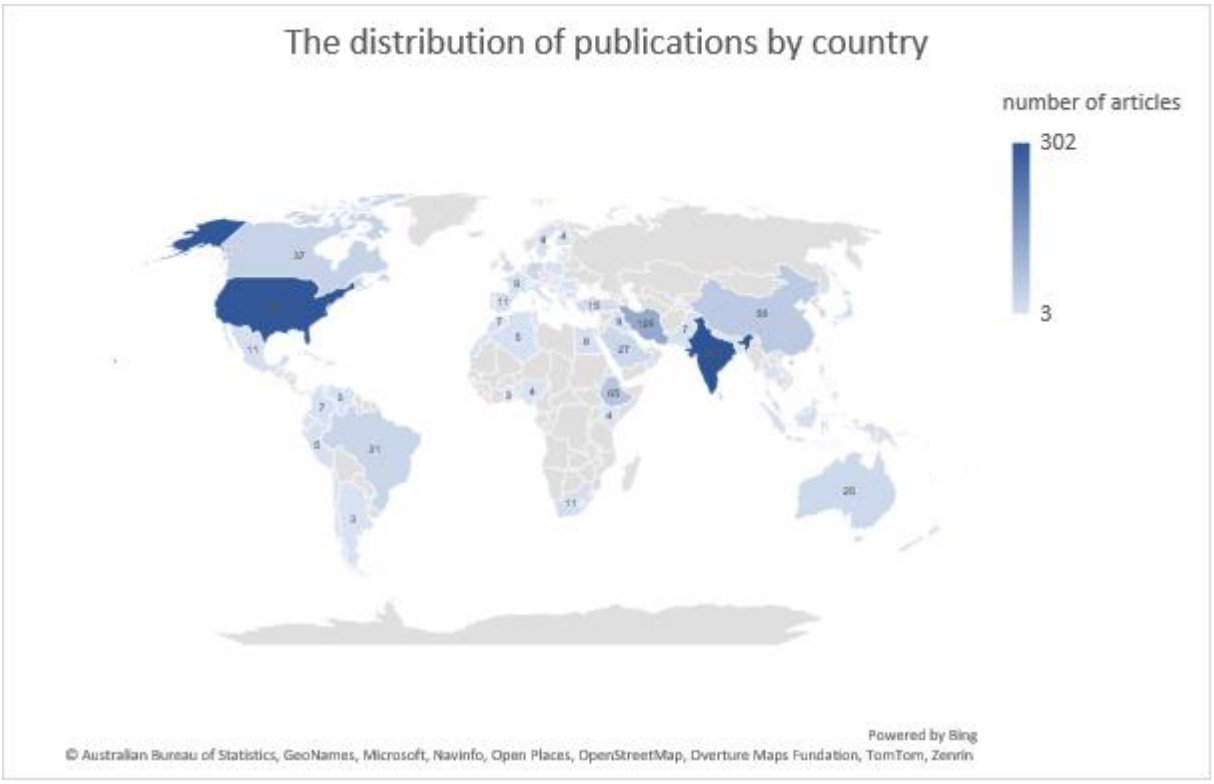

Figure 2. Distribution of the number of publications by country (*Visualized using Microsoft Excel Map Chart*)

Co-authorship networks and influence of publications

Figure 3 presents a visualization map of the co-authorship networks among the 55 selected countries. The scientific production map provides information about the number of co-authored articles published between researchers from two countries. Several trends can be observed. First of all, the size of the nodes indicates that two main countries are the most involved in the collaboration network, especially the USA and India, forming two regional poles.

The small distance between nodes indicates a closer collaboration between researchers and institutions of the two countries. It can be observed that there are frequent collaborations between the two countries. The USA has a total of 87 publications produced in collaboration with 35 other countries, including India, Germany, New Zealand, Australia, and Argentina. India is the second regional hub that stands out, not only by the number of publications but also by its international collaborations. Collaborations with 33 other countries have been identified. According to the TLS (total link strength) indicators, the country is very influential and active in terms of the number of joint articles. On average, India published two articles in collaboration with the same state.

One can observe the subdivision of these countries, grouped by colors based on their geographical position or common interests. A first grouping is made by the states: India, Saudi Arabia, Morocco, and Egypt, highlighted in red. The cluster indicates that they collaborate more with each other, having common interests such as environmental issues related to drought, water stress, or agriculture, given their latitudinal positioning. Moreover, the geopolitical context can facilitate the development of common partnerships between North Africa, the Middle East, and South Asia due to their proximity. Another cluster can be observed among Asian states: China, South Korea, Pakistan, Indonesia, and Thailand, which further supports this pattern based on regional proximity.

Distant clusters can also be observed, such as Bangladesh or Ecuador. For example, Ecuador has limited collaborations with the USA but not few publications, a fact that can be supported by internal collaborations. It is part of the Latin American regional network, while the

USA is grouped in the central cluster, which is why connections have been made between the two states.

In Table 1, we present a list of authors with at least five publications in the field of watershed prioritization research, along with their citation counts and countries of origin. As of September 1, 2025, the most prolific authors are Pourghasemi, with a total of 489 citations, including 20 for the article titled "Prioritization of water erosion-prone subwatersheds using three ensemble methods in Qareaghaj catchment, southern Iran"; and Meshram Sarita, with a total of 448 citations, of which 124 are for the article "Prioritization of watersheds through morphometric parameters: a PCA-based approach" and 89 for "Comparison of AHP and fuzzy AHP models for prioritization of watersheds." Another notable contributor is Pandey, who has a total of 445 citations and holds the highest citation count for a single article on watershed prioritization (249 citations) published in 2007, titled "Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remote sensing."

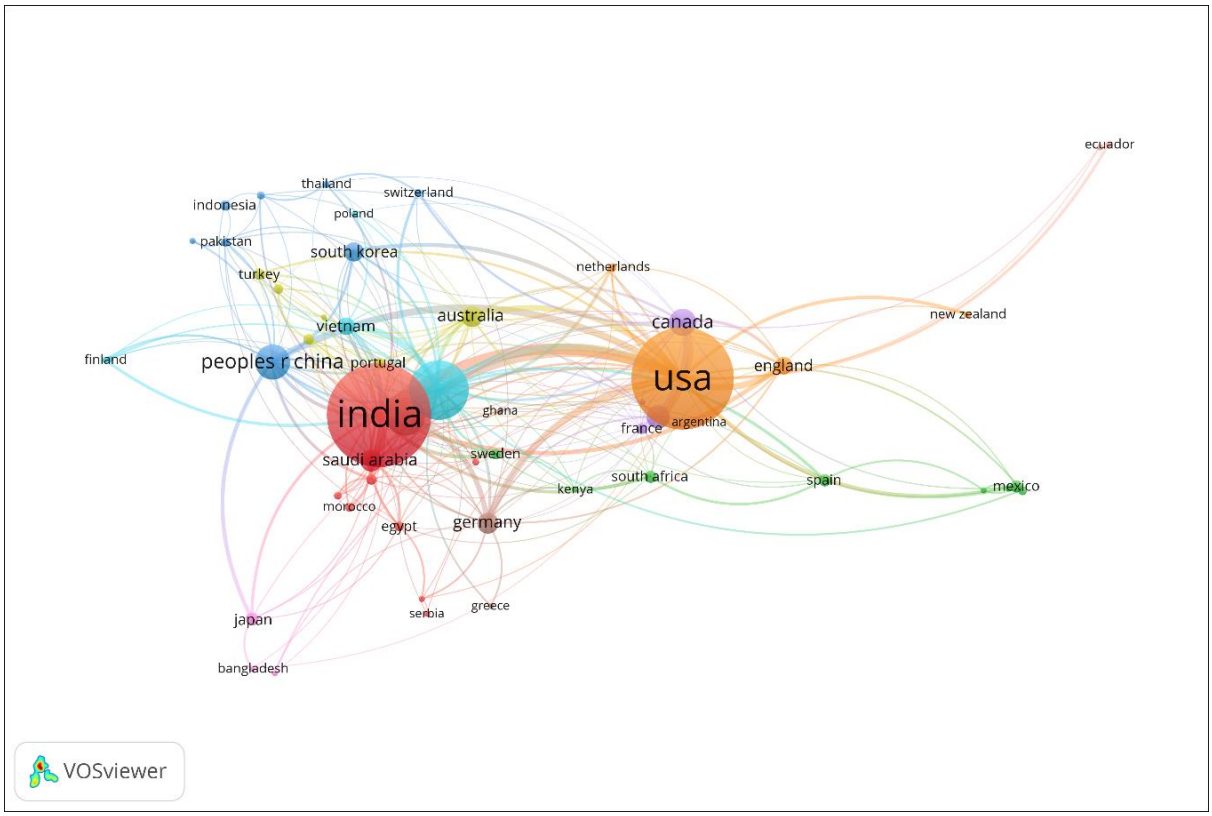

Figure 3. Bibliometric map of scientific output by country (*Source: Own processing in VOSviewer software*)

Table 1. Citation counts for authors with a minimum of 5 articles indexed in the Web of Science database

No.	Author (Web of Science)	Number of articles	Number of citations	Country
1	Alvandi, Ehsan	6	245	Iran
2	Chung, Eun-Sung	7	295	South Korea
3	Khiavi, Ali Nasiri	11	114	Iran
4	Mathew, Aneesh	5	55	India
5	Meshram, Chandrashekhar	8	238	India
6	Meshram, Sarita Gajbhiye	12	448	India
7	Pandey, Ashish	5	445	India
8	Patel, Dhruvesh P.	5	298	India
9	Pourghasemi, Hamid Reza	8	489	Iran
10	Sadeghi, Seyed Hamidreza	15	259	Iran
11	Saghafian, Bahram	6	58	Iran
12	Shekar, Padala Raja	5	55	India
13	Singh, Sudhir Kumar	7	63	India

14	Singh, Vijay P.	5	135	USA
15	Srivastava, Prashant K.	5	299	India
16	Vafakhah, Mehdi	9	57	Iran

The authors were affiliated with 5 countries: India (8 authors), Iran (6 authors), South Korea, and the USA (one author each). Based on what can be observed on the bibliographic map (Fig. 4), Meshram Sarita has the most articles co-authored with other authors (14 collaborators) and a total of 186 articles written in collaboration. This is immediately followed by Meshram Chandrashekhar, with 12 collaborators and 133 articles together, Sadeghi (12 collaborators) and Alvandi (10 collaborators). It has thus been demonstrated that the collaborative relationship is very close, which has led to an increase in the number of articles and the number of citations of these articles.

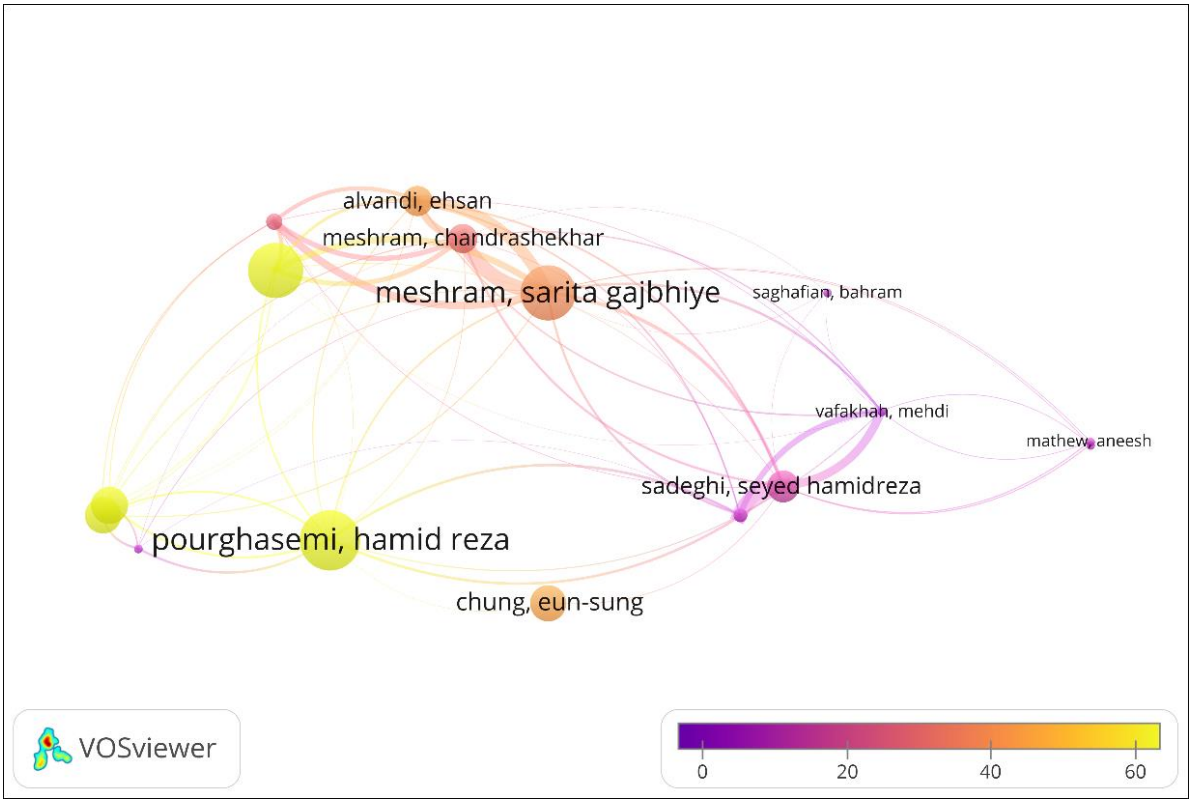

Figure 4. Bibliometric map of the number of citations per author (*Source: Own processing in VOSviewer software*)

Discussion

Socio-Economic analysis of scientific output in India

India's scientific output has increased from 62.46% during the period 2001-2006 to 72.7% between 2016 and 2020 (Kanaujia et al., 2022). Between 2017 and 2022, India produced approximately 1.3 million scientific articles, significantly exceeding the global average of 22% (https://www.scival.com/landing). In 2023, India ranked among the top 4 countries producing over 100 000 publications, according to the Science and Engineering Indicators report by the National Science Foundation (https://ncses.nsf.gov/pubs/nsb20257/publication-output-by-geography-and-scientific-field#publication-output-by-geography-and-scientific-field). Furthermore, data from the Nature Index reveal a steady increase in output, reaching 1,783 publications in 2024 (https://www.nature.com/nature-index/country-outputs/India).

This upward trend is supported by government funding, which accounts for over 45% of the country's gross expenditure on research and development (Kanaujia et al., 2022).

The advancement of research is closely aligned with socio-economic priorities aimed at fostering innovation, enhancing global competitiveness, and developing a highly skilled workforce (Singh et al., 2020). Inclusion in international databases further enhances the visibility of Indian research, while the large number of universities and research and development centers (exceeding 1,000 universities and numerous government-funded research institutes) provides substantial support for this growth (Garg & Tripathi, 2018).

Investments in the R&D sector represent a model to follow for increasing global publications. For Romania, India's policies can serve as a model in terms of resource management and prioritizing research areas. Moreover, promoting international collaborations, especially with renowned institutes and researchers, can contribute to increasing international visibility and facilitating the exchange of ideas and data (Dua et al., 2023).

To guide researchers, the efficient identification of gaps in the specialized literature becomes necessary. Choosing modern methods for quantifying research history facilitates the quantification of a large dataset, but it can exclude relevant articles indexed in other databases, such as Scopus or regional ones from ScienceDirect, SpringerLink, or Google Scholar.

Recent publications and those from less visible journals may be underrepresented. Thus, in the future, integrating more databases could reduce this limit and improve the result. Recent studies on environmental protection or water resource utilization use traditional visualization methods (CiteSpace) for the purpose of identifying keywords or co-citations (Zhao et al., 2025). Machine learning-based methods can improve these analyzes by more quickly and efficiently identifying the methods or parameters analyzed in watershed management (Mingaleva et al., 2023).

Literature can be fragmented, so the concept of "prioritization of watersheds" may not be mentioned directly in the title or may be expressed differently in another language. In the case of Romania, it can be observed that 3 articles registered in the VosViewer database have been published over time. However, a limitation of this software is that it queries the authors' affiliation, so articles written in teams can be registered multiple times. Analyzing in detail, I observed that as of this moment, there is only one article registered in the aforementioned database that addresses the topic of "prioritization of watersheds" in Romania. This article is published by Pastor et al. (2024) and authored by researchers and professors from 3 universities in the country, which explains its appearance in issue 3 in terms of co-author affiliations. Thus, one of the main limitations of bibliometric analysis is the masking of the actual number of publications, as VosViewer by default applies full counting.

Furthermore, citations do not necessarily reflect the scientific quality or relevance of the article but are influenced by their accessibility or the year of publication. A recent article is receiving a much smaller number of citations compared to a previous one (Preciado Ortiz et al., 2018), and it is not possible to estimate its long-term impact at this time.

Conclusions

This paper provided a quantitative analysis of the term "watershed prioritization" through Web of Science and bibliometric analysis performed in VOSviewer. The following were analyzed: the evolution of the number of publications, the distribution by country, and the collaboration relationships among researchers.

The results showed a trend of increasing the number of publications during the period 1993-2015, with the most articles published in 2021. Most of them were published in the journals Environmental Sciences and Water Resources, supporting their applicability in water resource management and land-use planning decision-making. The results of the spatial distribution of publications globally indicated that India holds the largest contribution to scientific production (23%), followed by the USA. India has stood out as an important hub of expertise. In the citation ranking, most of the authors affiliated with Indian institutes and universities have positioned themselves, with Pandey Ashish standing out with a total of 249 citations for a single article, followed by Meshram Sarita Gajbhiye, who has the most extensive collaboration network.

Funding policies in the field of Indian research and development represent support in increasing the international visibility of research products and contribute to encouraging collaborations. Thus, decision-makers can adopt policies to stimulate the formation of partnerships between institutions and researchers. This would allow for the exchange of knowledge and access to diverse resources. Funding strategies could strengthen the country's position in global rankings.

However, while bibliometric analysis is applicable in guiding researchers to understand the concept and identify the most relevant publications and methods, it also has some limitations. Firstly, the analysis was conducted exclusively using the Web of Science database; integrating datasets from other platforms such as Scopus or Google Scholar, doctoral theses, and other works from regional databases can improve the quality of the study. Secondly, a qualitative assessment is also necessary, as VOSviewer can multiply the number of publications per country, taking into account the affiliation of each author. Furthermore, the number of citations can be easily quantified, but this indicator does not automatically guarantee quality, relevance, and scientific and methodological validity. The use of machine learning algorithms could improve bibliometric analysis in the future.

However, this paper serves as a starting point for more extensive future research that would include an optimal and representative database: It can also guide researchers in choosing the optimal methods used, bibliographic sources, publishing journals, and collaboration partners. In the long term, analyzing trends and identifying the best advanced analytical methods can facilitate the identification of the most hazard-prone watersheds and help authorities allocate resources efficiently and adopt effective prevention and adaptation measures.

Funding

This research received no external funding.

Author contribution

Conceptualization, IP, AN and SB; methodology, IP, AN and SB; formal analysis, IP, AN and SB; investigation, IP, AN and SB; writing—original draft preparation, IP; writing—review and editing, AN and SB. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors declare no conflict of interest.

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