Trends in Groundwater Research Development in the South and Southeast Asian Countries: A 50-Years Bibliometric Analysis (1970-2020)

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Abstract

Groundwater plays a pivotal role in sustaining the water needs of the population of South and Southeast Asia. However, long-term over-exploitation and unsustainable practices have caused groundwater depletion, and deterioration in many parts of the region, further impacting human health and ecosystem services. Thus, understanding the current groundwater research activities and identifying the issues is crucial for improving future studies. This study conducted a bibliometric analysis to evaluate the groundwater-related literature available for South and Southeast Asia from the Scopus database for the last 50 years (1970-2020). Of the total, this study identified 7,895 documents, representing 13% of the total global research productivity. India was the most productive country, followed by Pakistan and Malaysia. National Geophysical Research Institute, Anna University and Indian Institute of Technology, Kharagpur were the top three institutions with the highest number of groundwater-related publications. In international research collaboration, the United States and Japan were the two most collaborated countries with the South and Southeast Asian countries. Environmental Science, Earth and Planetary Sciences and Agricultural and Biological Sciences were the top three disciplines. The Environmental Earth Sciences journal published the highest number of groundwater-related publications in the study period. Research topic trends were observed through keyword analysis revealing increased outputs for groundwater quality, availability and suitability, recharge, and management. Our results provide valuable insights on groundwater issues that have received the most attention in South and Southeast Asia and identify the potential research topics and opportunities for researchers working in the groundwater domain.

Introduction

Groundwater is one of the largest sources of fresh water on Earth and is an essential natural resource for human health, energy, food security, and the overall ecosystem (Wada 2016; Velis et al. 2017). It is also a vital water resource available in the semi-arid and arid regions as it supports agricultural, domestic, industrial, and ecological needs (Chen et al. 2016). However, due to exponential population growth and rapid agricultural and economic development, increased pressure has been imposed on the groundwater at alarming levels, resulting in drastic groundwater depletion (Bierkens and Wada 2019). Furthermore, along with groundwater quantity depletion, deterioration of groundwater quality is another major global concern that impacts human health, ecosystem services and sustainable economic development (Li et al. 2021). In recent years, groundwater pollution by arsenic, fluoride, and nitrate has become a serious issue worldwide, affecting aquifer health and human health (Shukla and Saxena 2019; Jha and Tripathi 2021). Unfortunately, this mismanagement of groundwater resources has raised concerns in terms of sustainability and has led to environmental problems affecting both the present and the future generations. Considering the indispensable role of groundwater in various dimensions of development and interconnection among several Sustainable Development Goals (SDGs); emphasis is now laid on the strategic and optimal utilization of groundwater resources in order to address the growing freshwater demand in the future and to maximize the potential stimulus of other SDGs (Chinnasamy and

Agoramoorthy 2015; Bhaduri et al. 2016; Rasul 2016). In this regard, over the past few decades, global awareness on groundwater resource issues has grown, and many groundwater-related studies have been conducted, ranging over addressing challenges, emerging techniques, models and management approaches (Niu et al. 2014). However, these studies have not been able to track growth and progress across the broader field of groundwater research (Jia et al. 2020). Thus, to fully understand the groundwater research landscape, a detailed quantitative assessment is required that provides an analysis of the groundwater research status and trending research themes that can guide future research.

On this context, bibliometric analysis aims to provide a more holistic and objective picture by applying quantitative and statistical methods to analyze trends in various categories (Velasco-Muñoz et al. 2018). It helps evaluate the publication characteristics, scholarly outputs of researchers, the contribution from countries and institutions, impact and productivity of journals, patterns of international-national research collaborations, and identify research strengths and weaknesses through keywords usage (Zare et al. 2017; Tianzheng et al. 2021).

In order to perform the analysis, the best database source that identifies with the research area is needed. Presently, some of the main bibliometric databases used in such analysis are - Web of Science (WoS), Scopus, Google Scholar, Microsoft Academia (MA) and Dimensions (Moral-Muñoz et al. 2020). Several bibliometric software tools are available to analyze databases and visualize the trends, patterns and relationships between different indicators, such as Bibexcel (Persson et al. 2009), Citespace (Chen 2006), CitNetExplorer (Van Eck and Waltman 2014), Gephi (Bastian et al. 2009), SciMAT (Cobo et al. 2012), and VOSviewer (Van Eck and Waltman 2010). With plethora of options to such open-source bibliometric software and easily accessible databases in recent years, bibliometrics has proved to be a powerful tool that helps explore, analyze and visualize research trends of a subject of interest (Niu et al. 2014; Zhang et al. 2017; Velasco-Muñoz et al. 2018). However, even with such options, there are only a few bibliometric studies that have been performed on groundwater-related research. For example, Niu et al. (2014) investigated the global groundwater research trends using the WoS database for 1993-2012, and found that groundwater related publications showed a notable growth and increased at an average annual growth rate of 6.62%, over the past two decades. The United States was identified as the leading contributor to global groundwater research, followed by Germany and Canada. This study revealed groundwater quality and contamination, research and treatment technologies for water quality improvement as the main research themes for the study period. Recently, Jia et al. (2020) traced the development trends for groundwater depletion, contamination, remediation and sustainable management for 40 years (1978-2017) using the WoS database. This analysis revealed the predominance of the developed countries (USA, China, and Germany) in groundwater-related publications, as also shown by Niu et al. 2014, but an increasing trend for studies from developing countries like China and India have been witnessed in last decade. Studies relating to groundwater depletion and sustainable management showed increasing trends over the 40 years' period while the topics on groundwater contamination and remediation showed varied trends over different periods. At a regional level, Zyoud and Hanush (2017) emphasized the need to analyze the groundwater research activity trends for the twenty-two developing Arab countries. Using Scopus database, the authors carried out comprehensive analysis on the evolution of groundwater research, contributions from countries and institution, author productivity and collaboration at the Arab world level. Some focused groundwater studies have also been addressed using bibliometric analysis on topics such as arsenic in drinking water and treatment (Abejón and Garea 2015), groundwater remediation (Zhang et al. 2017), the role of contaminants in sub-surface hydrogeology (Schwartz et al. 2018) and karst groundwater pollution (Zhou et al. 2020).

Most of the studies mentioned are done over a global scale. Groundwater related problems and their management, however, are arguably more severe in developing and underdeveloped countries, owing to rapid economic development, population growth and urbanization, as also highlighted by Zyoud and Hanush (2017). Therefore, there is a need for studies focusing on developing and underdeveloped countries, especially in the South and Southeast Asia region, as they are among the world's fastest-growing and most densely populated regions, hosting about 32% of the world population (Rasul 2016). The region includes eight South Asian countries (Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka) and 11 Southeast Asian countries (Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor Leste, and Vietnam). The South and Southeast Asia region is characterized by diverse geological formations, complex tectonic framework, climatological dissimilarities and various hydrochemical conditions (Sikdar 2019). These regions have the most extensive river basins (Indus, Ganges, Brahmaputra, Meghna, Irrawaddy, Mekong and Red) that host several of the high groundwater-producing aquifers of the globe, however, the availability and accessibility for safe and sustainable groundwater remains a major concern for many parts (Mukherjee 2018). Together, the two regions are the largest abstractor of groundwater and abstracts one-third of the global groundwater (1,432 billion cubic meters) and almost half of global groundwater withdrawals for agriculture (1,210 billion cubic meters) (FAO 2017). Groundwater, the primary facilitator for Green Revolution, helped to achieve food security and, in addition, also served for drinking and domestic water supplies and industrial supplies for rural, peri-urban and urban areas (Hirji et al. 2017a). At present, India, Pakistan and Bangladesh are respectively the first, fourth and sixth largest extractor of groundwater in the world (Hirji et al. 2017b). However, excessive pumping and unregulated use has resulted in declining groundwater levels, with high depletion rates observed in North India (12.5±1.4 mm/year), Upper Indus Plain Pakistan (13.5 mm/year), and Bangladesh (8.73±2.45 mm/year) (Bhanja et al. 2018; Iqbal et al. 2016; Khaki et al. 2018). The consequences of the depleting groundwater levels include seawater intrusion in coastal areas and land subsidence problems, reversing the trend from groundwater use to abuse and leading to further socio-economic complications (Chinnasamy and Agooramoorthy 2015). At the same time, groundwater quality in South and Southeast Asian countries has also been severely impacted due to contaminants such as arsenic and fluoride, arising from several anthropogenic activities (such as applying fertilizers and pesticides, discharge of untreated industrial effluent) and geogenic sources, thereby undermining the value of the resource and leading to significant health and environmental impacts (Mukherjee 2018; Ray and Elango 2019; Sikdar 2019). It has been estimated that almost 110 million people in several South Asian and Southeast Asian countries are exposed to arsenic contaminated groundwater (Shahid et al. 2020). The major hotspot regions include Lower Gangetic Plains in India, Indus plain in Pakistan, Bengal basin in Bangladesh, Mekong river Delta in

Cambodia, Red River and Mekong river delta in Vietnam, southern districts in Nepal and Irrawaddy delta in Myanmar (Lacombe et al. 2019; Uppal et al. 2019). Thus, it is essential to track and map groundwater research trends using bibliometrics and identify the research hotspots that will serve as a potential guide for the understanding the aforementioned issues and aid in management plans. On the same note, the objectives of this study are to apply bibliometric approaches to understand the status, growth and trends of groundwater-related research for South and Southeast Asia for a period of 50 years (1970-2020) and provide a scope for future research activities.

Data And Methods

The standard bibliometric analysis process includes the five steps – data collection, data pre-processing, data analysis, data visualization and data interpretation (as shown in Fig. 1) and is discussed further.

Data source and retrieval

The data used in this bibliometric analysis (Fig. 1) has been collected from the Scopus database, which is considered the world's largest abstract and citation database of peer-reviewed research scientific content (Zare et al. 2017). Additionally, the Scopus database has been freely accessible and used in many bibliometric analyses in the past (Zyoud and Hanush 2017; Baas et al. 2020). For this study, the database has been collected for 50 years from 1970-2020 for 19 South and Southeast Asian countries. Using the Boolean logical operators, the following formula was used in the advanced search for document titles related to groundwater:

TITLE ("groundwater" OR "ground-water" OR "ground water") AND PUBYEAR > 1969 AND PUBYEAR < 2021 AND (LIMIT-TO (AFFILCOUNTRY, "India") OR LIMIT-TO (AFFILCOUNTRY, "Malaysia") OR LIMIT-TO (AFFILCOUNTRY, "Indonesia") OR LIMIT-TO (AFFILCOUNTRY, "Bangladesh") OR LIMIT-TO (AFFILCOUNTRY, "Pakistan") OR LIMIT-TO (AFFILCOUNTRY, "Thailand") OR LIMIT-TO (AFFILCOUNTRY, "Viet Nam") OR LIMIT-TO (AFFILCOUNTRY, "Sri Lanka") OR LIMIT-TO (AFFILCOUNTRY, "Singapore") OR LIMIT-TO (AFFILCOUNTRY, "Nepal") OR LIMIT-TO (AFFILCOUNTRY, "Philippines") OR LIMIT-TO (AFFILCOUNTRY, "Cambodia") OR LIMIT-TO (AFFILCOUNTRY, "Laos") OR LIMIT-TO (AFFILCOUNTRY, "Myanmar") OR LIMIT-TO (AFFILCOUNTRY, "Afghanistan") OR LIMIT-TO (AFFILCOUNTRY, "Brunei Darussalam"))

The Scopus database is updated daily; thus, to eliminate any discrepancy in the publication entries, a one-time search was carried out on 19 October 2021, to retrieve the data. The database was retrieved in a comma-separated values (CSV) file containing information on authors, affiliations, the title of publication, publishing year, journal, keywords, language, and document type.

Data pre-processing

After retrieving the database, a broad check of the database was conducted manually. The check included filtering out any unrelated publication and duplicate entries and ensuring publications are related to the theme and selected countries. Further, it was observed that the Scopus database on the institution is not harmonized, i.e., the organization names are not in a consistent format. For example- multiple formats for “Indian Institute of Technology, Bombay” exists, including: “IIT Bombay”, “IITB”, etc., similarly “University of Dhaka”, “Dhaka University”. Thus, the next step after pre-processing included uniform naming of the institutions to avoid any bias. Similar to the case of institution naming, the keyword terminologies also varied a lot due to different spellings, abbreviated forms and usage. For example, “ground water” and “groundwater”, “WQI” and “Water quality index” “GIS” and “geographic information system” and “rs” and “remote sensing”, “ahp” and “analytic hierarchy process”. Therefore, to obtain accurate results, the author keywords were pre-processed where the singular and plural forms of the same terminology were merged, abbreviated forms were expanded, uniform spellings were applied.

Data analysis, visualization and interpretation

The selected publications were analyzed for different characteristics: the number of articles per year, author, institution, country, subject area, journal, and author keywords. All this analysis was done using Microsoft Excel 2019, and different tables and figures were created to analyze and visualize the trends correctly. GIS software was used to map the geographical distribution of articles and author locations. For keyword analysis, author keywords were used to understand the leading groundwater research themes over the 50 years. Co-authorship analysis and co-occurrence of keywords analysis were carried out using VOSviewer software, an open-source software developed by Van Eck and Whatman, to generate network-based visualization maps (Van Eck and Waltman 2010).

Performance indicators for research productivity

Different indicators have been used to evaluate the performance of different characteristics of publication records. The outputs from the bibliometric analysis on institutes, journals, subject area, and authors, are arranged as per the Standard Competition Ranking (SCR) following other bibliometric measures (Zyoud and Hanush 2017). The top 20 ranked outputs have been considered in each analysis. Any output having the same total or frequency will receive the same rank, and then a gap is left in the ranking numbers.

As a quality measure of publication activity, the h-index was calculated to evaluate the research performance of an author, institute, and the country in this study. H-index, introduced by Hirsch in 2005, provides a measure for both the productivity and impact of the researcher in a similar field of research/domain (Hirsch 2005). A scientist has index h if h of his or her number of papers (Np) have at least h citations each and the other (Np − h) papers have ≤h citations each (Hirsch 2005). For example, if a scientist has ten papers and each of his/her ten papers have received ten citations at least, then the h-index for the scientist is 10.

To measure the journal performance, the Impact Factor (IF) is mainly used as an indicator that reflects the number of citations an article has received over a particular year or period (Zhang et al. 2017). For this study, the impact factor has been taken from the journals' webpage.

Results And Discussion

Research output trend

As per the extraction process of publications, 65,461 documents were identified as groundwater-related in the Scopus database. On fixing the study period from 1970-2020, 61,263 documents were obtained, and the exclusion of 355 documents published as erratum and 37 documents as retracted lead to a net total of 60,871 documents. When the search was limited to the South and Southeast Asian countries, the produced figure is 7,895 documents, which is 13% of the total global research productivity in the groundwater field for this period.

The two curves shown in Fig. 2 show the growth in groundwater-related publications globally and from South and Southeast Asian countries. The number of groundwater-related publications has increased over the past 50 years. At the global scale, the total annual groundwater-related publications were only 80 in 1970, whereas 3,930 documents were published in 2020, with an average annual growth rate (AAGR) of 9%. Meanwhile, for South and Southeast Asian countries, the total number of annual publications significantly increased from 1 (in 1970) to 894 (in 2020), with a 37% AAGR. However, for South and Southeast Asian countries, the growth in publication numbers from 1970-2002 was slow. The groundwater-related research gained momentum in the 21st Century, and the contribution of groundwater publications from South and Southeast Asian countries to the global groundwater-related output almost doubled from 2003 (12%) to 2020 (23%).

Among the various document types, articles constitute a majority (82%) of documents in this survey. The articles are published in the English language predominantly (99%). Table 1 summarizes by type in the final database. To ensure data consistency, our analysis is further restricted to research articles published in journals only.

Table 1 Publications by document type on groundwater from 1970-2020 from South and Southeast Asian countries

Document Type	Numbers	Percentage
Article[a]	6,478	82.05
Conference Paper	848	10.74
Book Chapter	260	3.29
Review	159	2.01
Letter	38	0.48
Erratum	33	0.42
Note	33	0.42
Data Paper	20	0.25
Book	13	0.16
Editorial	6	0.08
Short Survey	3	0.04
Retracted	3	0.04
Undefined	1	0.01
Total Documents	**7,895**	

[a] The number of articles presented here are before the screening/ pre-processing stage

Further analyzing the article trends obtained after the screening of articles, from Fig. 3, it can be seen that the total number of articles and total citations for groundwater-related research has increased dramatically in the last two decades. The entire 50-years study period can be divided into three distinct periods based on the number of articles published.

- Period 1 (1970-1980) introduces groundwater research in the South and Southeast Asian Countries focused on groundwater exploration studies. As this period was an early Green Revolution era, many South Asian countries started to utilize groundwater sources for irrigation. As documented in the Scopus database, the first groundwater-related article published was “Some geoelectrical investigations for potential groundwater zones in part of Azamgarh area of U.P.” It was authored by Singh C.L. and Singh S.N from the Banaras Hindu University, India and was published in Pure and Applied Geophysics in 1970 (Singh and Singh 1970).
- Period 2 (1981-2002) recorded publications from varied disciplines and themes. Increasing agricultural demand resulted in groundwater over-exploitation and groundwater contamination. Research efforts were made to understand the fluctuation in the groundwater levels and to identify the sources and transport of groundwater contaminants.
- Period 3 (2003-2020) showed the most growth in the groundwater domain. Employing remote sensing and GIS tools for groundwater mapping, pollution assessment and management options were actively explored during this period. The launch of NASA’s GRACE satellite 2003 also provided new perspective to monitoring of groundwater resources. Along with the extended detailed research on groundwater contamination and groundwater levels, focus on how to manage the resource sustainably became the utmost priority to achieve the targets of Millennium Development Goals (2000) and Sustainable Development Goals (2016).

The groundwater related studies were sporadic in the earlier years; however, the number of articles in the last 18 years (2003-2020) is 100 times that in 1970-1980. Additionally, the groundwater-related articles published during these last 18 years accounted for 90% during the entire 50 years.

Geographic and institution distribution analysis

Analyzing the data at the country level, as shown in Table 2 and Fig. 4, revealed a strong predominance of articles from India (4,584 articles, 72%), followed by Pakistan (309 articles, 5%), and Malaysia (289, 5%). Interestingly, no groundwater-related articles for Bhutan, Maldives, and Timor-Leste were found in the database. The publication numbers for the top 5 productive countries showed a significant increase from 2000 onwards.

Of the total 6,361 groundwater-related articles, 4,740 (75%) were single-country articles, and 1,621 (25%) were international collaborations. Single-country articles make up the largest share of the total number of articles in India, Indonesia, Pakistan and Malaysia. The highest collaboration rate was observed between South and Southeast Asian countries and the United States, followed by Japan and China. The total h-index of the retrieved articles for all the South and Southeast Asian countries was 128, implying that 128 articles had been cited at least 128 times during the period 1970 -2020. The highest h-index was 104 for India, followed by Bangladesh with 50 and Malaysia and Pakistan with 34.

Table 2 Bibliometric analysis for 6,361 groundwater-related articles published for South and Southeast Asian countries from 1970-2020

SCR[a]	Country	TA (%)[b]	h-index	TC[c]	IA (%)[d]	Most collaborated country	CC (%)[e]
1	India	4,584 (72.08)	104	79,122	638 (13.92)	United States	141 (22.10)
2	Pakistan	309 (4.86)	35	5,093	125 (40.45)	China	39 (31.20)
3	Malaysia	289 (4.54)	35	4,796	138 (47.75)	Iran	34 (24.64)
4	Bangladesh	267 (4.20)	50	11,229	186 (69.66)	United States	67 (36.02)
5	Thailand	154 (2.42)	23	2,400	79 (51.30)	United States	25 (31.65)
6	Indonesia	139 (2.19)	18	1,322	54 (38.85)	Japan	24 (44.44)
7	Vietnam	122 (1.92)	30	4,109	106 (86.89)	Japan	26 (24.53)
8	Sri Lanka	97 (1.53)	23	2,157	53 (54.64)	Japan	13 (24.53)
9	Singapore	51 (0.80)	21	1,448	44 (86.27)	China	18 (40.91)
10	Philippines	49 (0.77)	14	604	24 (48.98)	United States and Taiwan	8 (33.33)
11	Nepal	34 (0.53)	14	631	24 (70.59)	Japan	14 (58.33)
12	Cambodia	24 (0.38)	13	1,341	23 (95.83)	United States and United Kingdom	7 (30.43)
13	Laos	8 (0.13)	5	50	5 (62.50)	France	2 (40.00)
14	Afghanistan	7 (0.11)	5	87	7 (100.00)	United States, Turkey and Iran	2 (28.57)
15	Myanmar	4 (0.06)	3	42	3 (75.00)	United States and United Kingdom	2 (66.67)
16	Brunei Darussalam	2 (0.03)	1	6	1 (50.00)	Oman	1 (100.00)
17	Multi- Country[f]	221 (3.47)	40	6,111	111 (50.23)	United States	25 (22.52)

[a] SCR – standard competition ranking

[b] TA (%) – total number and percentage of groundwater-related articles by a country

[c] TC – Total citations

[d] IA (%) – total number and percentage of articles with international authors

[e] CC (%) – total number and percentage of articles with most collaborated country

[f] Multi-country includes articles written in collaboration between different South and Southeast Asian countries

At the institutional level, 160 institutions contributed to articles related to groundwater research and the top 20 institutions are presented in Table 3. The table shows the dominant position of India in groundwater research from South and Southeast Asian Countries. Among the top 20 institutes, 17 institutes are from India, two from Malaysia and one from Bangladesh. It should be noted that the Central Ground Water Board and the National Institute of Hydrology have several regional centers. For this analysis, the different branches are pooled under one major institute heading. The articles, if divided into their branch institutes, would yield different rankings.

As per the analysis, the National Geophysical Research Institute, India published the highest number of total articles, single-institution articles, inter-institutionally collaborative articles, and first author/institution articles in the groundwater domain. As of the academic efforts of these institutions during the 50 years, the Indian Institute of Technology, Kharagpur, has the highest quality index (h-index) of 43 amongst the top 20 institutes. This is followed by the National Geophysical Research Institute, India (39) and Jadavpur University (37) and the University of Dhaka (37).

Table 3 Top 20 most productive institutions publishing in the field of groundwater

SCR[a]	Institutes	TA (%)[b]	SI (%)[c]	CI (%)[d]	FA (%)[e]	CA (%)[f]	h-index
1	National Geophysical Research Institute India	245 (3.85)	95 (38.37)	151 (61.63)	148 (60.41)	97 (39.59)	38
2	Anna University	207 (3.25)	85 (41.06)	122 (58.94)	100 (48.31)	107 (51.69)	32
3	Indian Institute of Technology Kharagpur	174 (2.74)	59 (33.91)	115 (66.09)	66 (37.93)	108 (62.07)	43
4	Central Ground Water Board	140 (2.20)	47 (33.57)	93 (66.43)	71 (50.71)	69 (49.29)	29
5	Annamalai University	126 (1.98)	30 (23.81)	96 (76.19)	84 (66.67)	42 (33.33)	27
6	Andhra University	109 (1.71)	60 (55.05)	49 (44.95)	74 (67.89)	35 (32.11)	30
7	Jadavpur University	105 (1.65)	46 (43.81)	59 (56.19)	46 (43.81)	59 (56.19)	37
8	National Institute of Hydrology India	103 (1.62)	37 (35.92)	66 (64.08)	58 (56.31)	45 (43.69)	23
9	Bhabha Atomic Research Centre	102 (1.60)	29 (28.43)	73 (71.57)	32 (31.37)	70 (68.63)	20
10	University of Dhaka	101 (1.59)	6 (5.94)	95 (94.06)	14 (13.86)	8 (86.14)	37
11	Universiti Putra Malaysia	95 (1.49)	23 (24.21)	72 (75.79)	44 (46.32)	51 (53.68)	28
12	Jawaharlal Nehru University	88 (1.388)	42 (47.73)	46 (52.27)	42 (47.73)	46 (52.27)	36
13	Indian Institute of Technology Indian School of Mines, Dhanbad	87 (1.37)	35 (40.23)	52 (59.77)	55 (63.22)	32 (36.78)	20
14	Indian Institute of Technology Roorkee	74 (1.16)	21 (28.38)	53 (71.62)	41 (55.41)	33 (44.59)	18
15	Indian Institute of Technology Bombay	71 (1.12)	36 (50.70)	35 (49.30)	43 (60.56)	28 (39.44)	17
16	Banaras Hindu University	67 (1.05)	32 (47.76)	35 (52.24)	42 (62.69)	25 (37.31)	16
17	Osmania University	60 (0.94)	25 (41.67)	35 (58.33)	36 (60.00)	24 (40.00)	15
18	ICAR - Indian Agricultural Research Institute, New Delhi	59 (0.93)	20 (33.90)	39 (66.10)	29 (49.15)	30 (50.85)	23
19	Indian Institute of Science	55 (0.86)	14 (25.45)	41 (74.55)	15 27.27%	40 (72.73)	17
20	Universiti Sains Malaysia	53 (0.83)	11 (20.75)	42 (79.25)	23 (43.40)	30 (56.60)	15

[a] The institutes are arranged as per SCR (standard competition ranking) based on the total number of articles produced by an institute.

[b] TA (%) –Total number and percentage of groundwater-related articles by an institution

[c] SI (%) – number and percentage of single-institution articles

[d] CI (%) – number and percentage of inter-institutionally co-authored articles

[e] FA (%) – number and percentage of first author articles

[f] CA (%) – number and percentage of co-authored articles

Journal and subject area contribution analysis

Overall, groundwater-related research articles from the South and Southeast Asian countries have appeared in 951 academic journals, and Table 4 shows the top 20 active journals. These top 20 journals (2% of the 951 journals) account for 38% of the total article productivity. Overall, the majority of the groundwater-related articles from South and Southeast Asian countries are published in the *Environmental Earth Sciences*, followed by the *Indian Journal of Environmental Protection, Journal of the Geological Society of India*, *Pollution Research*, and *Environmental Monitoring and Assessment.* These journals are indicative of the fact that most popular themes of research are, hydrogeology, groundwater quality, groundwater contamination and pollution and its control. However, the journals have a different starting year; thus, to understand the journals' contribution to the groundwater field on a long-term basis, we calculated the average number of publications per active year. Therefore, normalizing by active years, we find that Environmental Earth Sciences still remains the top-performing journal with an average of 24 articles per year; however, the Groundwater for Sustainable Development has taken over for the second spot, followed by the Arabian Journal of Geosciences.

Table 4 List of top 20 most productive journals with production statistics

SCR[a]	Journal Title	TA (%)[b]	IF[c]	Active Years	Avg. no. of publications per each active year	Starting year of journal
1	Environmental Earth Sciences	284 (4.46)	2.784	12	24	2009
2	Indian Journal of Environmental Protection	258 (4.05)	NA[d]	23	11	1981
3	Journal of the Geological Society of India	211 (3.32)	1.459	26	8	1959
4	Pollution Research	184 (2.89)	NA[d]	22	8	1982
5	Environmental Monitoring and Assessment	182 (2.86)	2.513	24	8	1981
6	Arabian Journal of Geosciences	160 (2.51)	1.827	11	15	2008
7	Journal of Hydrology	120 (1.89)	5.722	35	3	1963
8	Groundwater for Sustainable Development	118 (1.85)	NA[d]	6	20	2015
9	Hydrogeology Journal	97 (1.52)	3.178	21	5	1992
10	Current Science	95 (1.49)	1.102	24	4	1932
11	International Journal of Earth Sciences and Engineering	91 (1.43)	NA[d]	7	13	2008
12	Environmental Geology	89 (1.40)	NA[d]	16	6	1975
13	Nature Environment and Pollution Technology	86 (1.35)	NA[d]	11	8	1994
14	Ecology, Environment and Conservation	84 (1.32)	NA[d]	22	4	1982
15	Water Resources Management	72 (1.13)	3.517	22	3	1987
16	Science of the Total Environment	70 (1.10)	7.963	17	4	1972
17	Journal of the Indian Society of Remote Sensing	62 (0.97)	1.563	27	2	1969
18	Journal of Earth System Science	60 (0.94)	1.371	13	5	1934
19	Sustainable Water Resources Management	58 (0.91)	NA[d]	6	10	2015
20	International Journal of Civil Engineering and Technology	55 (0.86)	NA[d]	4	14	2016

[a] The journals are arranged as per standard competition ranking (SCR) based on the total number of articles published in the journal.

[b] TA (%) – Total number and percentage of groundwater-related articles published by a journal

[c] IF – Impact Factor extracted from the journal homepage for the year 2020

[d] NA – impact factors not available for journal

Groundwater theme requires a more interdisciplinary approach that connects the physical and social aspects of groundwater resources availability and accessibility. Fig. 5 shows the subject areas on which groundwater related research has been focused. The top 3 disciplines are *Environmental Science*, *Earth and Planetary Sciences* and *Agricultural and Biological Sciences*. Although groundwater-related studies have now interlinked natural science with engineering and social sciences, the central focus is still on environmental sciences, geological and agriculture science. This shows the lack of actual status of interdisciplinary collaboration between natural and social sciences and even economics and policy studies.

Author contribution analysis

To analyze the most productive authors, the frequency of occurrence for the authors was calculated. Fig 6 and Table S1 (Supplementary File) shows the top 20 most productive authors during 50 years' study period. Most of the authors in the list are affiliated with Indian institutions. As seen in the figure, Elango L. has the highest number of publications, followed by Ahmed S., Chidambaram S., Ahmed K.M., and Mukherjee A. However, based on the quality performance of authors, Ahmed K. M. from Bangladesh has the highest h-index of 33, followed by Indian authors Chakraborti, D. (27), Chidambaram, S. (25), and Subba Rao, N (25). This analysis also reveals the predominance of male researchers with only one female researcher (Brindha K.) making it to the top 20 most productive authors list.

Additionally, author collaboration is equally essential for the growth of the research sector. Thus, the number of authors mentioned in the articles was counted and analyzed to identify the extent of research conducted by authors individually and in collaboration. Fig. S1 (Supplementary File) reveals the authorship pattern for groundwater-related research from South and Southeast Asian countries researchers during 1970-2020. It is clear from the analysis that articles with multiple authors (93%) have a majority over the single-authored articles (7%). Amongst the multiple authorship, two authors (24%) and three authors (24%) collaborations form the most significant contribution to groundwater-related research. This was followed by articles with four authors (18%), more than five authors (16%) and five authors (11%). Thus, this demonstrates that more and more researchers are collaborating to assess and manage the groundwater challenges that have emerged in all the South and Southeast Asian countries.

Further to investigate the collaborative patterns, co-authorship analysis was carried out using the full counting method in the VOSviewer software. A threshold of 15 minimum number of documents by an author and 15 minimum citations of an author was fixed. Basis the threshold, of the 12,184 authors, 96 authors met the threshold, and for each of these 96 authors, the total strength of co-authorship links with the other authors was calculated, and the network graph was obtained (Fig. 7). Based on the author link strength, 8 clusters were formed. The biggest clusters are Cluster 1 (shown in red color) and Cluster 2 (shown in green color) with 24 authors each, followed by Cluster 3 (shown in blue color) and Cluster 4 (shown in yellow color) having 13 and 9 authors respectively. As seen from the Fig. 7, Mukherjee A. has co-authored with the maximum number of authors (21), appearing in the Cluster 2. Following Mukherjee A., Ramanathan A.L. (from Cluster 2) co-authored with 20 other authors and Ahmed S. (from Cluster 3), co-authored with 19 authors. From this network analysis, Prasanna M.V. and Chidambaram S. from

Cluster 5 (shown in purple color) co-authored in highest number of groundwater-related articles (45). Thus, it shows that in the field of groundwater research, researchers have formed an academic pattern of close contact and mutual cooperation.

Keywords analysis

For this study, only author keywords have been considered and keyword cloud and frequency analysis were conducted to present a general overview of the most prevalent research themes for the South and Southeast Asian countries.

Of the total 10,240 keywords, 185 keywords (~2%) have been shortlisted, which have been used more than fifteen times in the groundwater-related articles. The most frequently used keywords for the 50 years of this study are illustrated in Fig. 8, and the top 20 keywords are listed in Table 5. Except for Groundwater, which is the top search keyword for this study, the top five most frequently used keywords are “Groundwater quality”, Geographic information system”, “India”, “Arsenic”, and “Fluoride”. Interestingly, from the country level perspective, India and Bangladesh are the two countries occurring the most frequently within the keywords, possibly for India it is due to a relatively higher share of publications in comparison to other countries. Additionally, both of these countries face serious groundwater challenges due to agricultural intensification, industrial development, population growth, climate change, and thus extended research.

Table 5 Top 25 most frequently used author keywords for the study period

SCR[a]	Keyword	Frequency
1	Groundwater	1996
2	Groundwater quality	495
3	Geographic information system	429
4	India	337
5	Arsenic	302
6	Fluoride	267
7	Water quality	249
8	Water quality index	222
9	Heavy metal	171
10	Hydrogeochemistry	160
11	Remote sensing	155
12	Contamination	139
13	Irrigation	126
14	Nitrate	117
15	Groundwater recharge	110
16	Aquifer	108
17	Hydrochemistry	107
18	Bangladesh	106
19	Groundwater pollution	104
20	Groundwater management	91

a Keywords are arranged as per standard competition ranking (SCR)

From Table 5, it is evident that groundwater research in groundwater quality has got the most attention over the 50 years in South and Southeast Asian countries. Besides Singapore and Malaysia, the rest all the countries come under developing countries categories who have undergone intensive agriculture and industrial development over the 50 years and thus are under greater threat of groundwater pollution and contamination (Mukherjee, 2018). Researchers from South and Southeast Asian countries have investigated widely in this domain, catering to different pollutants, sources, concentrations, pathways of transport, impacts on human health and the environment, control and removal/ remediation. Under this research theme, research trends on the most studied contaminants are shown in Fig. 9.

Among the vast list of groundwater contaminant studies, arsenic and fluoride are most widely researched in South and Southeast Asian countries, with 606 and 443 articles published, respectively. The number of studies on arsenic has increased quite rapidly post 2002, with an average growth rate of 21%. On the other hand, the research on fluoride has increased significantly post 2005, with an average growth rate of 31%. Heavy metals, nitrate and salinity related publications also have displayed an increasing trend post-2007.

The research contribution from different countries on different groundwater contaminants was also explored (Fig. S2 – Supplementary file). The analysis shows that South Asian countries India and Pakistan have done extensive research on groundwater contamination. The arsenic-related publications from India, Bangladesh, Pakistan, and Vietnam showed an overall fluctuating or decreasing growth trend. Fluoride publications were mainly contributed by researchers based in India, Pakistan and Sri Lanka. Significant contributions to nitrate-related studies came from Indian researchers, and the number of studies has shown an increasing trend. India, Pakistan and Bangladesh are the three major contributors to salinity related studies; however, research productivity has been quite fluctuating. In India, Pakistan and Malaysia, the research output on heavy metals research has continuously increased from 2010 onwards.

To assess and express the groundwater quality and its suitability for different purposes, Water Quality Index (WQI) has been extensively used by researchers. The WQI utilizes several physicochemical and biological parameters and transforms them into a single expression. Due to its concise and straightforward application and interpretation of water quality status, its significance has been widely accepted and appreciated (Ram et al. 2021), thus its prominence among keywords.

In Asia, 15 out of 19 South and Southeast Asian countries are among the largest groundwater consumers for agriculture worldwide. One of the primary reasons is the introduction of the Green Revolution in select countries (India, Pakistan, Bangladesh, Philippines, Afghanistan, Sri Lanka, Indonesia, and Thailand), resulting in the spread of groundwater irrigation (Hirji et al. 2017b). For countries like Nepal (Yadav 2018), Bhutan (Dorji 2016), Vietnam (Ha et al. 2015), climate variability and decline in surface water availability led to the expansion of groundwater irrigation. Thus, irrigation becomes one of the most researched keywords and the themes that have been studied mainly include (i) groundwater quality suitability analysis for irrigation purposes; (ii) estimating the groundwater abstraction for irrigating different crops in different agro-ecological zones; (iii) cost-effective technological solutions for irrigation for different categories of farmers as well as for optimum groundwater utilization.

Additionally, groundwater also serves as a vital source of drinking water supply in many rural and urban areas in the South and Southeast Asian Countries (Mukherjee 2018; Carrard et al. 2020). Groundwater composition is majorly driven by geological structure and anthropogenic activities. However, agricultural practices, industrial and commercial activities, and climate change has progressively deteriorated the groundwater quality in many regions (Li et al. 2021). Consumption of the polluted water has raised many health problems such as toxicity of arsenic, fluoride, nitrate, boron etc. (Sikdar 2019; Shahid et al. 2020). Thus, research studies on assessing the suitability of groundwater quality for drinking water have also begun to gain importance to diminish health related problems and protect the groundwater resources.

Thus, looking at the attention received to water quality and contamination, Hydrochemistry and Hydrogeochemistry emerged as the two major fields of inquiry in groundwater research. The research productivity for hydrogeochemistry has increased constantly from 1999 onwards while the usage of hydrochemistry has been fluctuating and decreasing. This clearly shows the increased consideration given to hydrogeochemical processes that govern the water quality to assess its suitability for different purposes.

Aquifer is the most frequently used keyword in groundwater research, as it is vital to understand groundwater occurrence within rocks and other geological formations. Different studies under this keyword category include (i) to investigate and estimate aquifer parameters using different hydrogeological and geophysical methods (such as vertical electrical sounding); (ii) to map groundwater potential zones by studying the occurrence, distribution and movement of groundwater flow; (iii) to quantify and predict contaminant transport. Linked with the aquifer, quantifying groundwater recharge and storage are historically the most productive research topic. Different methods such as isotopic investigations, modelling techniques, hydrographic analysis and remote sensing have been explored. The first research article on groundwater recharge estimation was published in 1973 and the study was conducted using tritium isotope. However, the research on groundwater recharge was still at a very nascent stage, and on average, there was only one publication coming up per year till 1995. From 1996 - 2006 there was an increase in the number of articles originating mainly from the South Asian countries – India, Pakistan and Sri Lanka. This rise in research interest in India and Pakistan can be due to the aftermath of the Post Green Revolution Era (1990 onwards), which could have led to over-abstraction of groundwater for agriculture leading to declining availability of groundwater resources. Therefore, efforts to evaluate and enhance the groundwater recharge became the topic of concern, and publications grew in number with an average annual growth rate of 34%. Post-2004, the groundwater recharge studies increased furthermore, and contribution came in from both South and South-East Asian countries with an AAGR of 23%

Remote sensing (RS) and Geographic Information System (GIS) are among the top 10 most frequently used keywords during the study period. Together they have played an increasingly important role for the hydrologic community. They have proved to be the cost-effective technologies over traditional methods by producing valuable data for monitoring and management for the current groundwater research (Masud and Bastiaanssen 2017; Thakur et al. 2017). The studies based on the application of RS data and GIS techniques in groundwater research saw the light in the late 1970s with its first research on the delineation of hydromorphic units for groundwater studies using Landsat Multispectral Scanner (Roy 1978). However, the research using these techniques grew only in 21st Century. At present, the integrated application of the RS and GIS has become a breakthrough in groundwater research, for both quality and quantity assessment and management, with the publication growing at an average growth rate of 34%.

Despite the major threats posed to groundwater availability and quality in the South and Southeast Asian Countries, as seen through the keyword analysis, the research on groundwater management has gained lesser attention. The concept of groundwater management was introduced in research in the early 1980s (1985); however, the studies on groundwater management gained momentum post-2000 only. Fig. 10 shows trends for the major themes that are being studied under groundwater management.

Under groundwater management, evaluating the impacts of climate change and climate variability on groundwater resources is critical because it directly and indirectly affects the hydrogeological processes (Green 2016). However, the studies on how groundwater resources respond to climate change and anthropogenic activities have started to pick up from the last decade only, with notable contributions coming from India, Thailand and Bangladesh. The themes mainly included (i) impact of climate change on groundwater levels and recharge under present and future scenarios; (ii) building resilience and adaption for agriculture and livelihood under climate change conditions and natural disasters (iii) impact of climate change on groundwater quality.

Vulnerability, adaptation and resilience-based studies, forming the basis for the sustainable management of groundwater, are also being explored by researchers from South and Southeast Asian countries. Groundwater vulnerability studies done in the past decade mainly focus on mapping vulnerable zones to select groundwater contaminants using GIS and DRASTIC model approaches. A growing scientific base on Managed Aquifer Recharge (MAR) or Artificial Groundwater Recharge supports its rapidly increasing use as an important water adaptation and management strategy to enhance and secure groundwater systems impacted from climate change and natural disasters and the hydrological variability (Dillon et al. 2019). However, resilience-based studies that should be focusing on the rural communities are still to be explored.

Since a majority of the South and Southeast Asian countries are bordered around major seas (the Arabian Sea, Bay of Bengal, Jawa Sea and the South China Sea), Seawater intrusion or saltwater intrusion has become one of the major environmental issues in their coastal regions (Tianzheng et al. 2021). Over the last 20 years, saltwater intrusion research has been carried out to manage coastal groundwater resources. An increased recognition is also being given to understand the importance of surface and groundwater interactions and to understand and control the impact of groundwater salinization. Understanding their interactions has also been helpful in formulating effective conjunctive water resource management plans. It provides an effective adaptation to meet the increasing demands and shortages problems, especially in arid and semi-arid regions (Zhang 2015).

Furthermore, co-occurrence analysis was conducted using the author keywords to understand theme distribution and analyze the relationship and structure between different keywords. Fig. 11 shows the author keyword co-occurrence network visualization map. A threshold of 15 as minimum number of occurrences of a keyword was set. Out of the 10,240 keywords, 195 meet the threshold and based on that the number of co-occurrence links was calculated. Based on the keyword strength, 7 clusters were formed. Cluster 1 (shown in red) has 56 keywords and highlights on issues related to depleting groundwater levels, discusses its assessment through modelling approaches, and the management techniques and approaches for future scenarios. Cluster 2 (shown in green) and Cluster 3 (shown in yellow) contains 30 and 23 keywords, respectively. The keywords in these clusters are connected with the groundwater quality and suitability assessment based on several physico-chemical parameters and evaluated through WQI and multivariate statistical techniques. Cluster 4 (shown in blue) includes 28 keywords present the importance and application of remote sensing and GIS in evaluation groundwater resources for quantity and quality. Cluster 5 (shown in purple) includes 22 keywords which highlights on the health and risk assessment associated with the consumption of contaminated groundwater, mainly with heavy metals. Cluster 6 (shown in cyan) and Cluster 7 (shown in orange) contains 22 and 10 keywords, respectively. The two clusters emphasize on the groundwater contamination by arsenic and fluoride transport, assessment and its removal.

Overall Research Implications and Outlook

The bibliometric analysis showed that the groundwater-related research from South and Southeast Asia started very late compared to the global groundwater research contribution. Globally, the first groundwater-related document was published in 1889 on "*Disinfection of springs, and number of germs in ground-water*" in the Science journal (Science 1889). However, the first publication from South and Southeast Asia came only in 1957, i.e., 68 years later, on studying the geological and hydrological conditions and the groundwater development potential in the Narmada Valley in Madhya Pradesh, India (Roy 1957). The next thirteen years (1957-1970) had shown almost no growth in groundwater research from South and Southeast Asia. But since the 1970s, groundwater research in the South and Southeast Asian countries showed significant growth over the next 50 years. The growth rate for groundwater-related studies from the region was more than the global growth, signifying the sensitization of the groundwater issues and concentrated efforts made by the researchers from South and Southeast Asian countries to assess and manage their groundwater resources and contribute to global literature.

The bibliometric analysis showed that the contribution from South Asian countries was much higher than the Southeast Asian countries. From 1970-1983, groundwater-related studies mainly originated from India, but from 1983-1999, contributions began to come in from Pakistan, Bangladesh, Thailand, Indonesia, Sri Lanka, Vietnam, Sri Lanka and the Philippines. Some of these countries benefitted from the Green Revolution and improved agriculture productivity by exploring groundwater resources. Post-2000, a remarkable increase in the number of publications is observed and contributions from the other countries. Particularly for India, the contribution to groundwater research has been exceptionally high, and India also became the third-largest contributor in the early 2010s globally (Jia et al. 2020). The high contribution is because India's groundwater usage is more than the combined usage by the United States and China, the second and third largest groundwater users (Hirji et al. 2017b). The groundwater usage has drastically increased over the years and has enabled higher crop yields, which helped the country achieve its food security and reduce poverty. However, the rising demand for food and intensive levels of groundwater pumping for irrigation have led to overexploitation of the resource followed by severe groundwater depletion and contamination issues, which needs extensive research for better planning and management. Additionally, the involvement of several central and state universities as well as government-operated research institutes showed high productivity and impact in the groundwater research domain.

Research trends established through author keywords analysis provided an insight into the significant groundwater issues South and Southeast Asian countries are facing. Groundwater quality assessment gets major attention, specifically arsenic. India, Bangladesh, Pakistan and Vietnam are amongst the most polluted arsenic areas (Abejón and Garea 2015; Mukherjee 2018). Thus, studies focusing on quality assessment, mapping of hotspot areas, contaminant transport and remediation technologies have been extensively researched in recent years. The research efforts also resonate in the high research productivity of the top 20 journals like - *Indian Journal of Environmental Protection, Pollution Research*, and *Environmental Monitoring and Assessment* publishing in this domain. It is also important to note that groundwater quality studies have mainly been done for inorganic and microbiological contaminants. Since most of these countries are agro-based, emphasis on organic contaminants should also be laid.

The number of groundwater studies related to groundwater depletion and management displayed increasing trends. Current rate of overexploitation of groundwater resources have posed serious threats to the long-term food, water and energy security and livelihood of the South and Southeast Asian countries- especially in the semi-arid and arid regions (Rasul, 2016). Thus, research efforts have been made to understand the groundwater behavior using modelling approaches, quantify the groundwater reserves through remote sensing, explore interventions and technological solutions to enhance groundwater recharge, implement better irrigation practices for sustainable management of groundwater resources.

As highlighted through keyword analysis, groundwater issues are interrelated with a wide range of disciplines and subject areas; thus, more collaborated research needs to be done beyond the environmental and engineering aspect to understand the challenges and opportunities and expand the horizon of groundwater research.

With data and information acknowledged as critical for effective groundwater management, there is an urgent need to invest in more extensive monitoring networks to improve the frequency and quantity of groundwater data (Jia et al. 2020). Integrated satellite-based investigations using remote sensing and GIS techniques is one solution that has increased groundwater data availability and spatial and temporal resolutions. Crowdsourcing is another solution that has become a promising approach in recent years to obtain supplementary data by involving citizens (Maheshwari et al. 2014). These solutions need support in order to upscale and be useful at the national level. Along with this, these solutions will lead to more data generation, and thus, data mining techniques and machine learning algorithms will have to be explored.

Through this analysis, it was also observed that the number of female researchers in groundwater research lags behind the number of male researchers, and it was more pronounced in the most productive authors and author collaboration groups. The research community should make efforts to nurture the junior female researchers and encourage and support the senior female researchers at every stage of their careers to reduce the gender imbalance.

Limitations And Prospects

This study brought valuable insights into research trends and themes prevalent in South and Southeast Asian countries and the rising areas of groundwater research; however, there are certain limitations. From the data collection point of view, first, this study has considered only a single database (Scopus) to retrieve groundwater-related publications. Also, there are a lot of non-Scopus indexed national/regional journals where the countries like India, Bangladesh, Sri Lanka, and Pakistan publish in order for a wider local reach and readability. Second, this study search was done only using groundwater terms in the document titles and not the abstracts and keywords. This advanced search might give a more detailed analysis of all the groundwater-related research, however that can also lead to tremendous amount of time needed to skim through abstracts. Third, the analysis for the research productivity was limited to research articles published in journals only without looking into conference papers, book chapters, letters and others. However, the paper has adopted a robust methodology, as done in previous studies (e.g., Zyoud and Hanush 2017; Velasco-Muñoz et al. 2018; Olusanmi et al. 2021; Pham et al. 2021), with the selection of database, providing reliable outputs and trends.

Concerning most researched or rising themes, keyword analysis was done using only author keywords based on frequency count in the database. This leads to the fact that these are the hottest topics and even the major problems of concern. However, some basic concerns have been left out due to more minor arguments or less uniform terminology. For example, the depleting groundwater levels result from unsustainable pumping for irrigation, but the keywords – pumping, or over-abstraction, have not appeared in the top ranks. Furthermore, the study was limited to using only author keywords, and there were few studies (928 articles, 15%) in the database that lacked keywords. To tackle the missing data, the authors have considered article titles to identify the trends in the growth of particular themes.

Ambiguity in the author names and non-uniformity in institute names and keywords can seriously affect the results of bibliometric analysis. This study involved manual cleaning and processing; however, some exceptions remained. For future studies, these challenges can be taken care of by applying heuristic and machine learning approaches. Despite all the limitations, this study provides a holistic and representative picture of groundwater research productivity from the South and Southeast Asian countries.

Summary And Conclusion

A bibliometric analysis was conducted to identify and evaluate the impact of groundwater research from South and Southeast Asia and its contribution to global research during 1970-2020 using the Scopus database. This study evaluated a total of 6,361 groundwater-related articles published in journals, and the research output trends, geographical and institutional distribution and collaborations, subject/discipline categories, journal contribution, author productivity were explored.

Overall, the study gives strong evidence on increased research attention given to groundwater studies by the South and Southeast Asian countries. Regarding the geographical distribution, India has maintained the lead in terms of productivity and deepening research in different fields of groundwater domain, carried out by many central and state universities and research institutes. Some of the South and Southeast Asian countries like Cambodia, Afghanistan, Myanmar, which are also dependent on groundwater resources for domestic and irrigational demands, need to explore more in the domain and address the challenges of groundwater availability, accessibility and quality that have been critical concerns for a long time in their regions.

Trends in different groundwater themes were examined using keyword analysis. The majority of articles were focused on assessing the groundwater quality and contamination, groundwater potential and recharge, groundwater suitability for irrigation and drinking purposes, and groundwater management. In addition, research techniques and methods such as remote sensing and GIS, isotope techniques, numerical modelling, analytical hierarchy process, multivariate statistical approaches and water quality indices showed increased application. Along with this, the current trending research themes such as climate change, artificial recharge, and conjunctive surface and groundwater resources gained attention for sustainable management of the groundwater resources.

Ultimately, through this analysis, we observed that most of the South and Southeast Asia countries are affected by groundwater-related problems driven by economic development and population growth. The problems of availability and accessibility may get worsened in the years to come due to climate change. Thus, it is expected that research efforts will be made to understand the multifold problems to avoid groundwater crisis and enhance sustainable management and security of groundwater resources. This study thus consolidates most of the aspects of ongoing research about groundwater resources in South and Southeast Asia and provides a valuable base for identifying essential topics for future research and exploring opportunities for scientific collaboration.

Declarations

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Authors Contributions

Meeta Gupta: conceptualization, methodology, data collection, analysis, and original draft writing.

Pennan Chinnasamy: conceptualization, methodology, writing, supervision, review and editing.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose

Ethical Approval and Consent to Participate

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Consent for publication

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Availability of Data and Materials

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Figures

Figure 1

Bibliometric process flowchart

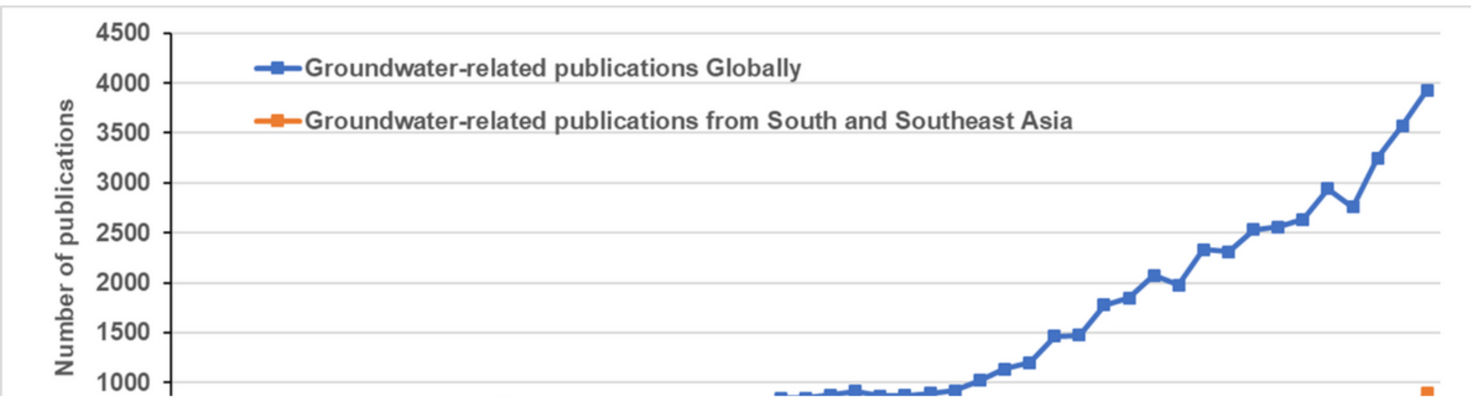

Figure 2

Growth of groundwater-related documents from South and Southeast Asian countries compared to Global groundwater research publication

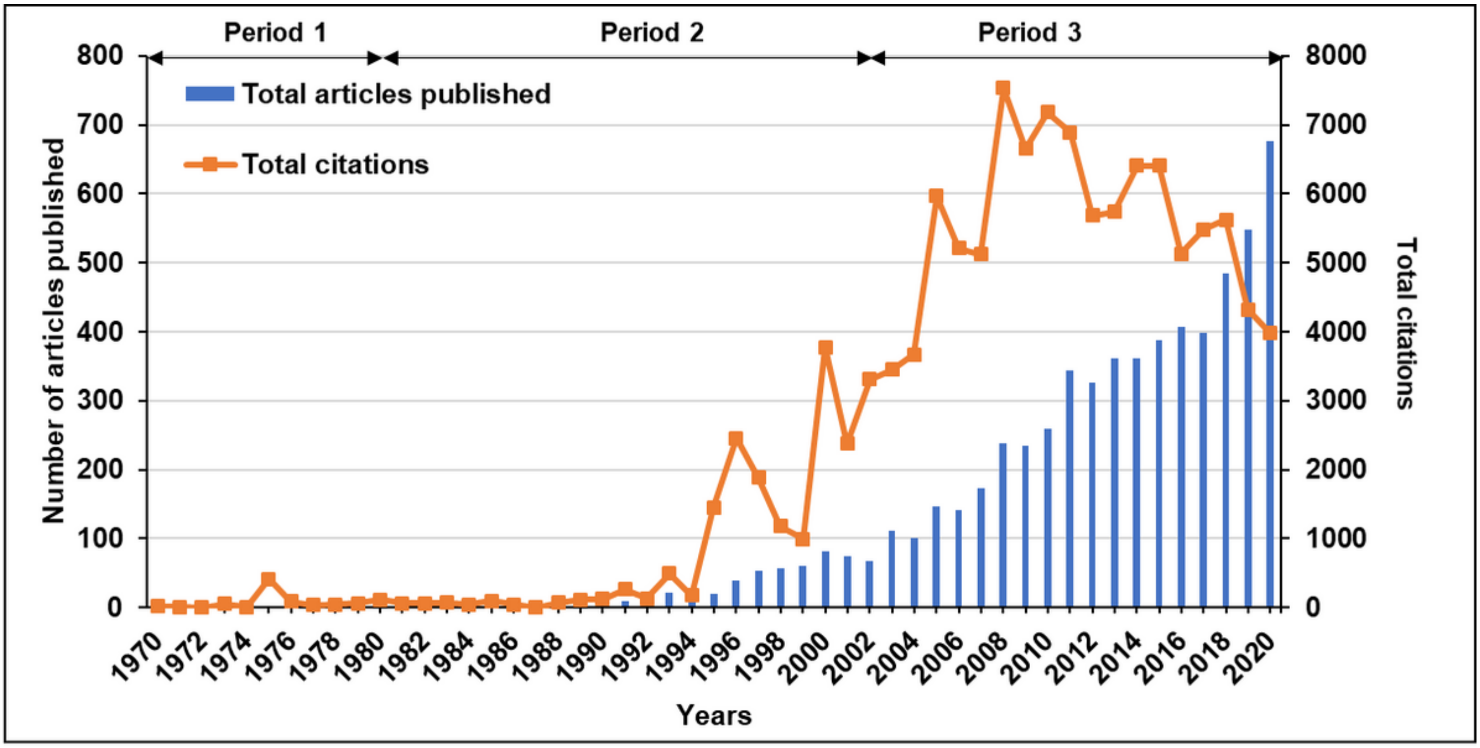

Figure 3

Article productivity and citations trend from the South and Southeast Asian Countries during 1970-2020

Figure 4

Geographic distribution for groundwater-related studies across South and Southeast Asian countries for the study period

Figure 5

Proportion of groundwater-related articles in related subject areas/ disciplines

Figure 6

Top 20 most productive authors publishing in the groundwater field from 1970-2020

Figure 7

Co-authorship network of the authors from South and Southeast Asian countries

Figure 8

Word cloud of the most frequently used author keywords

Figure 9

Research trend for the number of articles for different groundwater contaminants

Figure 10

Trends for different themes related to groundwater management

Figure 11

Network visualization map for the co-occurrence of author keywords

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