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Review article

Mapping the optimization of groundwater abstraction research: A bibliometric review in the context of South Asian region

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ABSTRACT

Water scarcity has increased dramatically in many parts of the world and has become a major environmental problem globally in recent years. To address this challenge, researchers are continuously exploring and investigating different water sources and the relevant abstraction method. South Asian countries are not an exception in this regard. Specifically, how optimization has been done during the water abstraction process is becoming a key research agenda in South Asian region. This study attempts to systematically review the optimization of groundwater abstraction research in the South Asian region. First, bibliometric analysis has been performed to quantitatively assess the current research trends in the optimization of groundwater abstraction research. Second, a qualitative analysis has been done to get more insights into the different abstraction methods and simulation models used in groundwater abstraction research. This study has addressed the gap and explored research streams through scientific and conceptual mapping of the optimization of groundwater abstraction research. As revealed, the year 2020 is the most productive in groundwater abstraction research. Indian Institute of Technology and India were found to be the most impactful institution and countries in this field. The most studied area in groundwater abstraction research was found to be sustainable groundwater management, the geochemical process of controlling groundwater evolution, the Spatio-temporal variability of groundwater and the supply-demand of water during dry seasons. As revealed, statistical and mathematical modelling analysis is the most used approach in these studies. The findings of this study suggested that the water scarcity problem can be fixed by improving the design and operational techniques of the groundwater abstraction method and by using the different water sources collectively. This study further provides future directions and opportunities for research in the field of the groundwater abstraction process.

1. Introduction

Groundwater plays a pivotal role in the global agricultural economy, transforming vast swathes of arid territory into thriving croplands [1]. In most developing countries, it is the primary water source for irrigation, farming, and household operations. It is a

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primary source of drinking water for the people subsided near rural areas and accounts for a significant number of households, businesses, and industrial operations. Also, it can act as a reserve when shortages of water supply are experienced. However, a limited amount of rainfall often leads to the scarcity of the supply of water. Thus, water scarcity has been considered a significant threat to socioeconomic development and livelihood in many countries [2]. Recently, the demand for groundwater has increased considerably to supply the needs of economic sectors and domestic use [3]. To respond to water scarcity, groundwater has been extracted to meet the water demand. However, groundwater abstraction often creates significant challenges to manage water governance at the local, national, and transboundary levels [4].

Securing a safe and renewable supply of groundwater for drinking is one of the crucial drivers of sustainable development for a nation [5]. Research suggests that managing the sustainability of groundwater resources must be based on the requirements of the specific situation [6,7]. It is important to have a sustainable approach to extract groundwater to preserve this natural resource. Therefore, a balance should be kept, and a sustainable management system needs to be implemented in the abstraction of this abundant supply of natural resources to let the aquifer levels recover and prevent overexploitation.

Despite the importance of a sustainable approach to the abstraction of groundwater, only a few studies highlight the importance of abstraction methods and ways of optimization of groundwater in the South Asian region. Specifically, there is a lack of research that quantitively synthesizes the status quo of the optimization of groundwater. No systematic review has been done yet highlighting the optimization of groundwater abstraction research. Thus, it is imperative to undertake a review of research highlighting the current state of affairs of groundwater research in this region. A literature review will enable prospective researchers and policymakers to have a better understanding of the current trends in groundwater abstraction and preservation techniques highlighting the importance of its sustainable abstraction method.

There have been a few numbers of research papers highlighting the importance of groundwater sustainable abstraction and management process in the South Asian context. For example, Msangi and Cline [8] showed the divergence between current groundwater usage patterns and the optimal path in which the groundwater levels can be stabilized with better demand-side management. Zekri et al. [9] and Bhatti et al. [10] have discussed the current status of groundwater monitoring and management system in Pakistan. Faisal et al. [11] highlight a sustainable development project known as the Barind Multipurpose Development Project (BMDP) through the groundwater management system. Rejani et al. [12] highlight the optimization modelling by simulation for sustainable groundwater management in a coastal basin of Orissa, India. Pandey et al. [13] developed a structured framework that considers an index of means for achieving sustainability known as the 'groundwater sustainability infrastructure index (GSII)' to measure groundwater sustainability. Singh et al. [7] demonstrate the applicability of a sustainable pumping rate concept based on numerical modelling of the managed aquifer by the example of the city of Lucknow, India.

Some other studies also focused on the optimization of groundwater extraction in different parts of South Asian countries. For instance, Shrestha [14] discussed how the traditional culture of using public wells and sharing and optimizing groundwater resources is gradually fading due to the scarcity of water in Kathmandu, Nepal. Additionally, Dahal et al. [15] discussed aims to identify critical locations for groundwater recharge in the Kathmandu Valley of Nepal. Pandey et al. [16] discussed the distribution of groundwater storage and potential areas for groundwater development by mapping in GIS in Nepal. Other South Asian countries, such as Sri Lanka have also contributed to this research field. For instance, Kumar et al. [17] generated a groundwater potential zonation map using the integrated use of remote sensing and geographic information system (GIS) for the Killinochi area, Northern Sri Lanka. Villholth and Rajasooriyar [18] also discussed in their paper the geophysio-chemical groundwater conditions in Sri Lanka and the associated contemporary management challenges.

Ahmed et al. [19] demonstrated a modelling strategy combined with geostatistical analysis to highlight the key areas for groundwater level monitoring to maintain fresh groundwater in the Lower Indus Basin, Sindh, Pakistan. Khan et al. [20] evaluated the optimization of groundwater conditioning factors, the evaluation of groundwater potential, and other parameters for groundwater resource management in Northern Pakistan. Mehmood et al. [21] developed a calibrated model for the semi-arid irrigated area of Pakistan to optimize groundwater quality exploration for irrigation water wells. Bhatti et al. [10] discussed the status and commented on groundwater management and monitoring in Pakistan. Masoom [22] stated that groundwater is the primary source of water supply for the people of Afghanistan, and research was conducted to improve groundwater storage in the region to achieve sustainable supply. Jawadi et al. [23] studied the local groundwater quality in the Kabul Basin to determine its appropriateness as drinking and irrigation water then and in the future. The assessment of groundwater parameters and the calculation of the Water Quality Index (WQI), which was derived from 15 observation locations close to the city, helped to achieve this goal.

In general, conflicts and disagreements between various water users are common due to several driving factors, including climate change, urbanization, population, industrial, and agricultural growth. Allocating limited water resources is hence the problem for the integrated water resources management framework. As a result, several optimization techniques have been developed in Bangladesh over the past few decades in the field of water resources [24]. Adhikari et al. [25] asserted that efficient groundwater management requires modern technologies and approaches that can identify the critical states of water resources in the northwestern part of Bangladesh.

Despite the number of papers highlighting the optimization of the groundwater abstraction process, there are some critical limitations. Firstly, the majority of the study areas have not reviewed the research front systematically, and there have been no papers highlighting a bibliometric review of groundwater abstraction research. Secondly, there have been only a few numbers of papers concentrating on the South Asian region, yet, the current research trends, and contributions of different authors, institutions, and countries in the field of optimization of groundwater were not discussed in any of the previous literature.

To address this gap, the current study attempts to examine the optimization of groundwater abstraction research using bibliometric and systematic review analysis. Bibliometric studies may be used for a variety of reasons, such as providing a general outline of a study

subject and analyzing notable scholars [26]. The effective application of current and developing bibliometric technologies can assist in the evaluation of academic production, including preparation for promotions and other honours [27]. Raghuram et al. [28] stated that structured literature reviews may deal with a wide range of research and analytical methods and can give an in-depth examination of the literature as well as an awareness of the background. Thus, bibliometric review allows us to examine the developmental subtleties of a certain discipline and offers insight into the field's developing regions [29].

This study attempts to explore research streams through scientific and conceptual mapping of the optimization of groundwater abstraction research. Additionally, relationships between the key themes, country, and sources have been analyzed. The quantitative synthesis has been done to understand the core part of the research front and the recent trends in the optimization of groundwater abstraction research in the South Asian region. Further, co-citation analysis and bibliographic coupling have been utilized to understand the influence of the documents and their authors in this field. This study helps us to answer the following research questions in the context of the South Asian Region:

RQ1. Which channels (authors, articles, journals, institutions, and countries) are the most influential in the optimization of groundwater abstraction research?

RQ2. Which research streams related to groundwater abstraction has received the most attention?

RQ3. How are optimization of groundwater abstraction research articles clustered, and which research streams are likely to emerge?

RQ4. What are the research aims and methods used in the articles on the optimization of groundwater abstraction research?

2. Methodology

This is a quantitative data dominant bibliometric review, though a substantial amount of systematic review components has been employed in this study to qualitatively map the themes, concepts, and research fronts in the optimization of groundwater abstraction research. Quantitative analysis has been done using a bibliometric procedure based on scientometric data. Bibliometric analyses are useful not only to measure the research trends and future research directions but also to the impact of specific authors and their publications and collaboration network on the given field [30]. Additionally, they expand the exposure of the published papers and aid researchers in locating the relevant regions [31]. A qualitative analysis has been conducted on the selected articles based on cluster analysis to examine the research themes and current trends of groundwater abstraction research. The following sections discuss in detail the methods of the review process-

2.1. Data sources

This study used the Web of Science (WoS) core collection database to select the relevant articles in the field of groundwater abstraction research. The WoS database is a reliable and widely accepted database, indexing the basic science, social science, and arts and humanities journals [30]. It indexes more than 22,000 journals and 50 million publications in 70 languages and 151 research categories [32]. For its comprehensiveness and top-tier quality, the WoS database has been preferred to other research databases by many researchers [33].

2.2. Article selection procedure and review methodology

Bibliometrics involves the analysis of publications and their properties and uses knowledge domain visualization to sense and monitor the development of a knowledge field [34]. This article uses bibliometric analysis to uncover the conceptual development, research front, key findings, and organizational framework of the research of groundwater abstraction in the South Asian region.

The quality of the dataset determines how well a bibliometric analysis performs. Therefore, this article used the SALSA framework suggested by Grant and Booth [35] to assure the impartial selection of articles from the extensive literature in this domain. The four stages of the SALSA framework are search, appraisal, synthesis, and analysis. These four steps—which are discussed in more detail below—made up the methodological procedure followed in this article.

According to Grant and Booth [35], for any given search criteria, there is a risk of missing important articles during the article selection process. To reduce this issue, the search phase was carried out utilizing the broadest definitions of groundwater abstraction. We used Boolean operators 'AND', 'OR' in combination with the following keywords to search the relevant articles in groundwater abstraction- Optimization, Optimal, Improvement, Enhancement, Refinement, Enrichment, Groundwater, Aquifer, Underground water, Abstraction, Pumping, Remediation, Exploitation, Management, Discharge, Disposal, Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka, South Asia, South Asian. The search formula returns 296 articles related to the groundwater abstraction process from the WoS database as of January 2021. We limit the selection of the documents to articles and book chapters only, which returns 273 documents.

The second stage, the appraisal phase, was developed based on the selection process described by Grant and Booth [35]. This phase involved reviewing the titles, abstracts, and, in some cases, entire contents of the articles to make sure they were included in the study. The complete text of an article was only studied when the title and abstract were insufficient to decide whether to include or omit the document for the bibliometric study. Thus, a huge portion of the articles were removed during this phase as they are related to other topics such as chemical and water pollution caused by heavy metals like arsenic, lead, etc. Also, the focus of this study is related to the groundwater abstraction process only, so the articles' focus on this domain had been retained for the final dataset. As a result, 67

publications were pulled from the Web of Science database for this study. These articles formed the input dataset for the analysis.

The following Fig. 1 shows the flow diagram of article selection procedures and the review methodology -

To find patterns in the research subject and create an analytical framework, the third stage, synthesis, was implemented. During the bibliometric analysis, all articles from the input dataset create a citation network composed of book chapters and articles. Consequently, the citation network represents the documents that are most pertinent in groundwater abstraction research and helps form the intellectual base and research front in the field. The sources referenced by scholars make up the intellectual base, which serves as the cornerstone on which they build their arguments. Contrarily, the research front is made up of citations between the documents and displays the most advanced understanding of this field. The most pertinent keywords used by researchers and how interest and focus have evolved were shown by building a co-occurrence network of keywords selected by researchers and journals. By building these networks and calculating the metrics, it is possible to see the trends and patterns of the groundwater abstraction research area.

To comprehend the significance of the patterns and information unearthed during the synthesis step, the analysis of the selected documents was done. We were able to understand how themes, concepts, interests, and research concerns have changed over time and what will likely be the key topic of discussion in future by sensemaking and interpretation of the citation and co-occurrence networks. Furthermore, bibliometric coupling and cartography analysis has been done to map the research horizons in groundwater abstraction research. We also analyzed the interconnected themes using three fields plot. Finally, we determine the objectives, research methodology of the documents, and the scientific contributions they have made in the domain of the groundwater abstraction research field.

2.3. Tools for the analysis

Using the bibliometric package in R and HistCite, we examined the selected 67 documents to find out the most influential authors, articles, journals, institutions, and countries. We used VOSviewer software to conduct a cartography analysis and bibliographic coupling. We also examined the interconnected flow of research works with different institutions, countries, authors, and keywords utilizing VOSviewer.

3. Bibliometric analysis and discussions

3.1. Key information in groundwater research

A total of 67 articles from 46 different sources were retrieved from the Web of Science database on the groundwater abstraction process in the South Asian region. The publication period ranges from 1992 to 2020. A majority of the retrieved documents were articles (65; 97.01%), followed by only 2 book chapters (2.99%). A total of 208 authors contributed to publishing these documents in different journal sources. Average citations per document are recorded at 13.18.

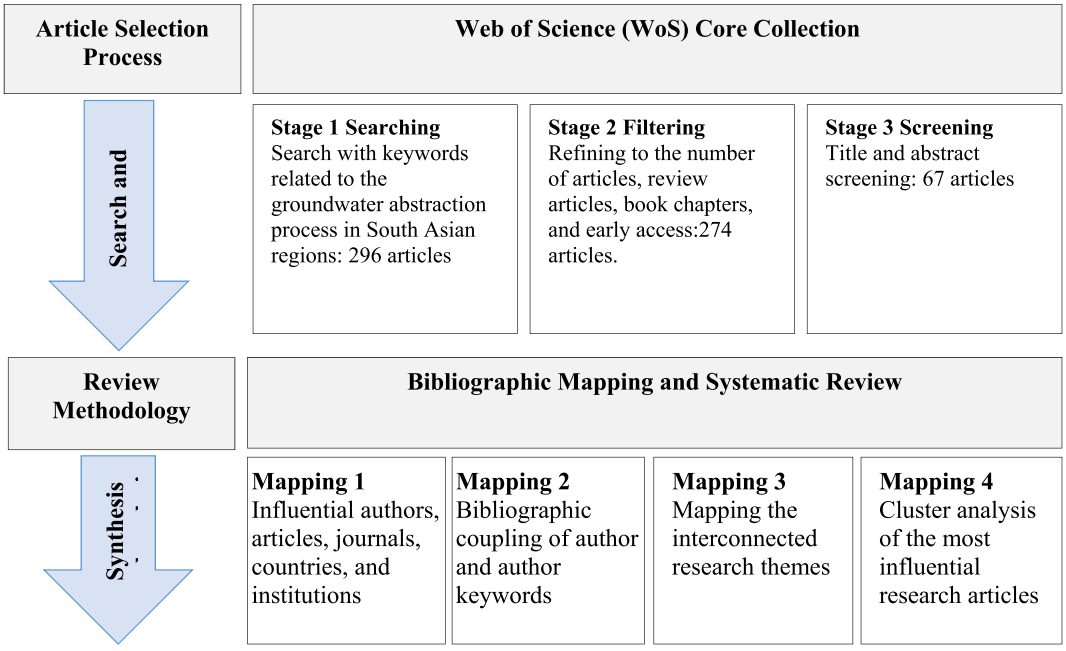

Fig. 1. Article selection process and review methodology, adopted from Grant and Booth [35].

3.2. Annual publications and citations of groundwater abstraction research

Fig. 2 shows the publication trend of the 67 articles on the optimization of groundwater abstraction. The figure indicates that only four articles were published between the years 1992–2002. The rest 63 articles had been published between the year 2003–2020, with 26 of these articles being published between 2017 and 2020. The year 2020 is the most contributing year with the highest number of publications (9). In contrast, there are fluctuations observed in the total citations of the documents published between 1992 and 2020. The highest total citation (147) had been received by the documents published in the year 2006, and the lowest total citation (4) had been received by the documents published in the year 1998, with the second lowest (6) achieved in the year 2020. This data suggests that the most influential documents on the optimization of groundwater abstraction were published in 2006 (2 articles only) as they have attracted many researchers in this field and consequently received the highest (147) citations.

3.3. The most influential documents and sources

To find the most influential authors from the data repository of 67 articles, this paper used total global citations (GC), total local citations (LC), and total global citations per year (GC/t), as shown in Table 1. The GC indicates how many times a particular article has been cited globally by other articles. The LC, on the other hand, indicates how many times a particular article had been cited by the set of articles that had been retrieved and included in the same data repository. As revealed, the citation of Sethi et al. [36] had remarkable growth, with a GC of 85 and a GC/t of 5.67 and positioned as the most influential document on groundwater abstraction research. Mandal & Sengupta [37] obtained the second rank by receiving a GC score of 62 with an average GC/t of 4.13 following Pandey et al. [13] and Sethi et al. [38] with a GC of 54 (GC/t = 5.4) and 53 (GC/t = 2.79), respectively. It is to be noted that the 10 most cited articles were all published from 2006 to 2013. This indicates that the most influential research studies had been done in this time frame.

The top 10 most significant journals were assessed and ranked with the help of GC, as shown in Table 1. The Journal of Water Resources Management and Agricultural Water Management are the only two journals focusing on the management of water and top the list with 8 and 3 publications respectively. The Journal of Water Resources Management has the highest GC (205) among the top 10 journals. 8 publications have been presented in this journal. Sethi et al. [38] are largely responsible for this score. Additionally, Singh and Panda [6], Rao et al. [42], and Rejani et al. [12] also published in this journal. Also, the Journal of Environmental Earth Sciences (GC = 28) and the International Journal of Water Resources Development (GC = 26) both have three publications each, i.e., they are the second most contributing journals in this domain though they received fewer citations.

Local citation (LC) in Table 1 detects critical research contributions of the published document and the journals in groundwater abstraction research. Local citation impacts reflect a document or journal's status and function better than (global) impact factors. The LC shows in Table 1 the total number of citations of an article or journal in the local collection of the current study. In this study, Khare et al. [39] is the most locally impacted document, whereas the Journal of Water Resources Management and Resources Conservation and Recycling are the most locally impactful sources in the domain of groundwater abstraction research in the South Asian region.

3.4. The most influential authors, institutions, and countries

Table 2 shows that a total of 208 researchers authored 67 articles on the optimization of groundwater abstraction. The most impactful author among these 208 researchers is Nayak MK, with a GC/P score of 85. The parameter which had been used to rank the most influential authors is the total global citation score per article (GC/P). Here, GC is the total number of global citations received by a document and NP is the total number of publications by an author. Three other authors, such as Sethi LN with a GC/P score of 69, and Mandal A and Sengupta D with GC/P scores of 62 have topped the list. It is interesting to note that both Panda SN and Singh A have the highest number of publications (e.g., 6 and 4 respectively) but their impact per article is the lowest among others as they have received

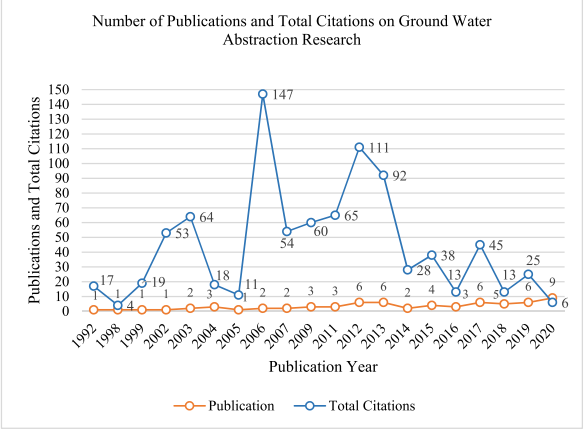

Fig. 2. Number of publications per year and the citations received by the documents published in that year.

Table 1
10 Most influential articles and sources on optimization of groundwater abstraction.

Documents	GC	GC/t	LC	Journal	NP	LC	GC
Sethi et al. (2006) [36], Agricultural Water Management	85	5.67	0	Water Resources Management	8	3	205
Mandal et al. (2006) [37] Environmental Geology	62	4.13	0	Agricultural Water Management	3	1	142
Pandey et al. (2011) [13] Environmental Science & Policy	54	5.4	0	Environmental Geology	1	0	62
Sethi et al. (2002) [38] Water Resources Management	53	2.79	1	Environmental Science& Policy	1	0	54
Khare et al. (2007) [39] Resources Conservation and Recycling	53	3.79	3	Resources Conservation and Recycling	1	3	53
Singh et al. (2013) [7] Water Resources Management	49	6.13	1	Journal of Irrigation and Drainage Engineering	1	1	47
Singh et al. (2012) [40] Journal of Irrigation and Drainage Engineering	47	5.22	1	Environmental Earth Sciences	3	0	28
Singh et al. (2012) [41] Agricultural water management	45	5	1	International Journal of Water Resources Development	3	0	26
Rao et al. (2003) [42] Water Resources Management	41	2.28	0	Water	1	0	25
Rejani et al. (2009) [12] Water Resources Management	37	0.08	1	Journal of the Geological Society of India	2	1	23

*GC = Total global citations, LC = Total local citations, GC/t = Total local citations per year, NP=Number of publications.

Table 2
10 Most Influential authors, institutions, and countries in optimization of groundwater abstraction research.

Author	GC/P	GC	NP	LC	Institutions	GC/P	GC	NP	LC	Country	GC/P	GC	NP	LC
Nayak MK	85	85	1	0	Phys Res Lab	62	62	1	0	Japan	54	54	1	0
Sethi LN	69	138	2	1	Asian Inst Technol	54	54	1	0	Nepal	54	54	1	0
Mandal A	62	62	1	0	Ctr Res Environm Energy & Water	54	54	1	0	Thailand	54	54	1	0
Sengupta D	62	62	1	0	Univ Yamanashi	54	54	1	0	Iran	17	34	2	0
Chapagain SK	54	54	1	0	Indian Inst Sci	53	53	1	1	Sri Lanka	17	34	2	0
Kazama F	54	54	1	0	Natl Res Ctr Cashew	37	37	1	1	India	14.64	688	47	12
Pandey VP	54	54	1	0	Indian Inst Technol	33.19	531	16	11	Germany	14	56	4	2
Shrestha S	54	54	1	0	Natl Inst Hydrol	18.33	55	3	0	Afghanistan	12	12	1	0
Panda SN	41.5	249	6	5	Leibniz Univ Hannover	14.5	29	2	2	Australia	6.4	32	5	0
Singh A	38	152	4	3	Int Water Management Inst	11.75	47	4	0	Pakistan	4.75	19	4	0

*NP= Number of publications; LC = Total local citations; GC = Total global citations; GC/P = Global citations per paper.

the lowest number of citations per article. The top impactful author Nayak MK and others following him in the list, all received the highest number of citations from a single document except Sethi LN [37] who received from two documents. Also, Chapagain SK, Kazama F, Pandey VP, and Shrestha S each had a score of 54 from one publication from the document by Pandey et al. [13].

This study has found 107 institutions have contributed to 67 articles on the optimization of groundwater abstraction research. As revealed, with a GC/P score of 62, *Physical Research Laboratory* ranked 1st in the list. The next three most impactful institutions i.e., the *Asian Institute of Technology* from Thailand, the *Center of Research for Environment, Energy and Water* from Nepal, and the *University of Yamanashi* from Japan all have the same GC/P score of 54. Similarly, Japan, Nepal and Thailand are the top influential country to

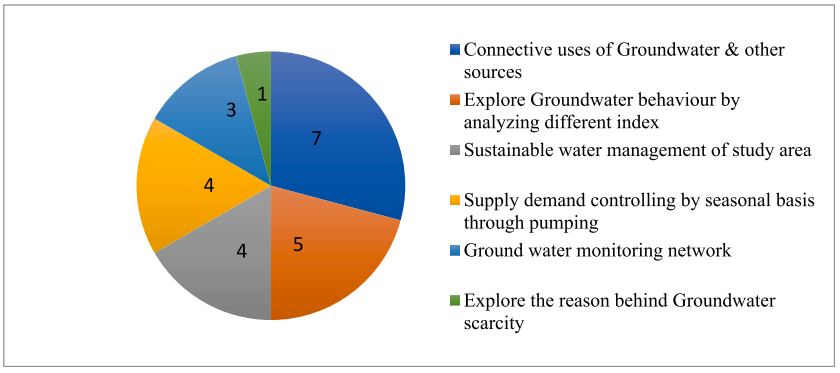

Fig. 3. Research front emerged from the 24 most cited articles on the optimization of groundwater abstraction.

produce the highest impact in this field. Table 2 also illustrates that there are a total of 47 publications coming from India, with a GC of 688 (the highest score), while Germany has taken the second position with four publications with a GC of 56.

In this study, we also analyzed the local citation impacts of authors, institutions, and countries. The higher the LC value of an author, institution, or country, the more they contribute to the domain of groundwater abstraction research. As revealed India is the most locally impactful country with 12 local citations, the Indian Institute of Technology is the most impactful university with 11 local citations and SN Panda is the most impactful author with 5 local citations in the South Asian region. Interestingly, Indian affiliation is the dominating factor in this domain.

3.5. Research front in the optimization of groundwater abstraction

The top 24 most cited articles were analyzed to examine the current research themes in the field of groundwater abstraction. After doing a critical review, the research front that emerged from the objectives of the 24 most cited articles has been illustrated in Fig. 3.

As revealed in Figs. 3 and 7 articles have focused on the connective uses of groundwater along with other sources like surface water, river water, or rainwater. Khare et al. [39] and Mohan and Jothiprakash [43] investigate the probable use of surface and groundwater collectively as well as stimulate a model based on different hydrological & socio-economic parameters, whereas Singh and Panda [41] and Raul et al. [44] have formed a model of collective uses of canal and groundwater to meet up the demand for irrigation and maximize net annual extraction. Also, Sethi et al. [38] have developed an optimization model for the effective management of river water and groundwater connectively to meet the demand.

Five of the 24 articles have explored the behaviour of groundwater by analyzing different parameters and indexes to build the infrastructure of the highlighted area & achieve sustainable groundwater management. Pandey et al. [13], Kumar et al. [45], and Kumar and Perry [46] analyze various parameters related to groundwater quality to achieve sustainable groundwater management. Sahu et al. [47], have discussed the geochemical process that controls groundwater evolution through detailed geochemical statistical analysis of groundwater, and Kaur and Rishi [48] analyzed the Spatio-temporal variability of groundwater.

Five papers have focused on sustainable water management by replacing old techniques to maximize the net annual water extraction from the groundwater basin. For example, Sethi et al. [36], have replaced the existing cropping pattern with sustainable land and water management. Zekri et al. [9] have measured collective aquifer water extraction and changed the crop pattern to avoid excessive groundwater extraction, whereas Qureshi et al. [49], Faisal et al. [11], and Krishnamurthy et al. [50] have focused on finding out improved design and operational techniques for groundwater extraction and integrating output from different techniques.

On the other hand, Rao et al. [42], Rejani et al. [12], Maheshwari et al. [51], and Holländer et al. [52] focused on the supply-demand controlling on a seasonal basis through pumping or other different abstraction processes meet up the demand during the non-monsoon and dry seasons.

Usman et al. [53], Singh and Katpatal [54], and Kavusi et al. [55] introduced a comprehensive approach to design quantitative

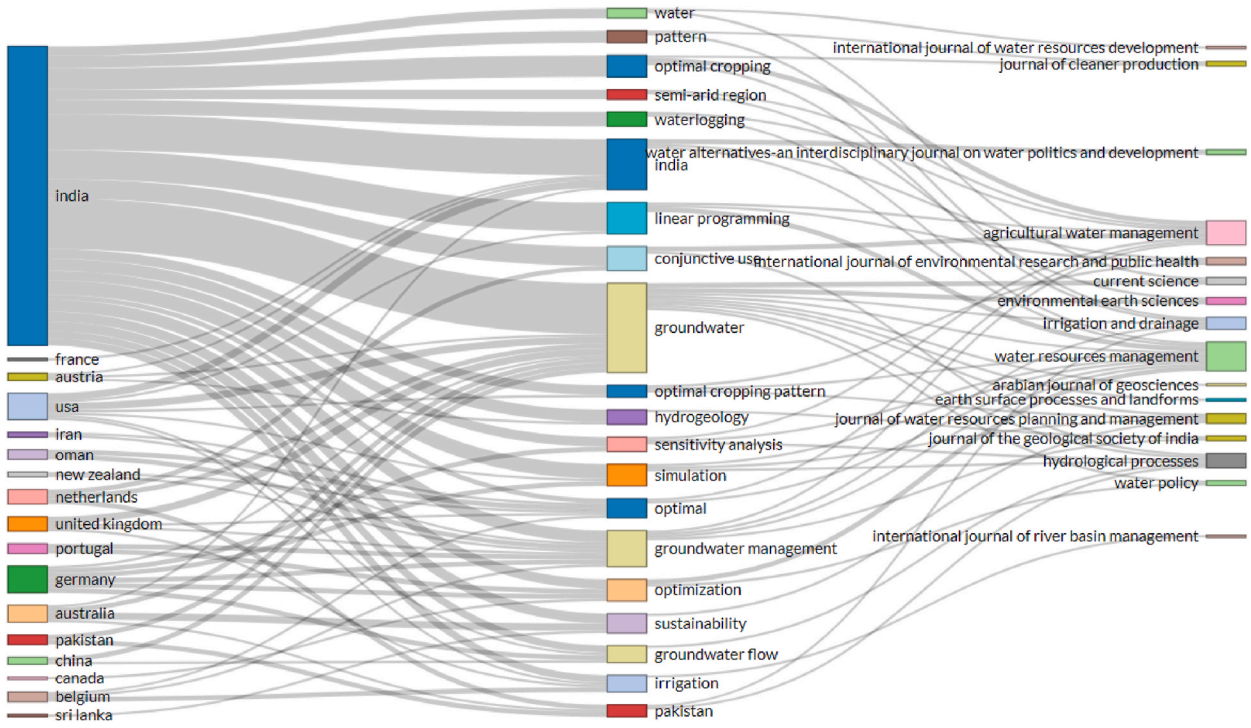

Fig. 4. Relationship flow between author keywords, country, and sources in groundwater abstraction research.

groundwater monitoring network. Varghese et al. [56] explore the casual association between water scarcity and groundwater use.

To summarize, all the articles are mainly focused on building up a sustainable groundwater management system. Additionally, it is necessary to maximize the net annual water abstraction or collective uses of different sources of water along with groundwater to meet the demand for irrigation or drinking water. Also, these papers analyze different groundwater parameters, indexes, and groundwater monitoring networks to build a sustainable groundwater abstraction method. These studies suggested water scarcity problems can be fixed by improving design and operational techniques for groundwater abstraction.

3.6. Three fields plot

In Fig. 4, the relationship flow of the key research themes between the country and sources was illustrated using three fields plot. Keywords, countries, and sources are represented with coloured rectangles. The height of each rectangle is represented by the number of relations that exist between the keywords, countries, and sources. The larger the size of a rectangle is the greater the relationships that exist among them.

The analysis of the following diagram shows that there were four key research topics (India, Groundwater, Groundwater Management, Linear Programming) and three sources (Agricultural Waste Management, Water Resources Management, and Hydrological Processes) showing a strong relationship with three countries (India, USA, and Germany).

Similarly, Fig. 5 shows the relationship between the key research ideas, affiliations, and sources. The notable sources are water resource management, agricultural water management, hydrological processes, and irrigation and drainage. Further analysis of Fig. 5 shows that the four keywords (linear programming, waterlogging, conjunctive use, and groundwater) and three sources (water resources management, agricultural water management, and hydrological processes) have a strong relationship with the three affiliations- the institution of technology, school of water resources and Indian institution of Technology, Kharagpur.

3.7. Distribution by research methods

Fig. 6 illustrates the evolvement of the research methodologies in the 24 most cited articles over the years. As revealed, statistical and mathematical modelling analysis is the most used approach in these studies and is categorized under 'other methods of modelling'. Practical surveys and case studies as research methodology have been used in several studies too. Field methods and sample collection have only been used twice, specifically in the years 2015 and 2016. The 'other methods of modelling' have been used throughout the years, as can be seen in Fig. 6.

The 'other methods of modelling' have been further analyzed into two categories. The first happens to be the statistical and mathematical modelling analysis, and the second happens to be the simulation model analysis.

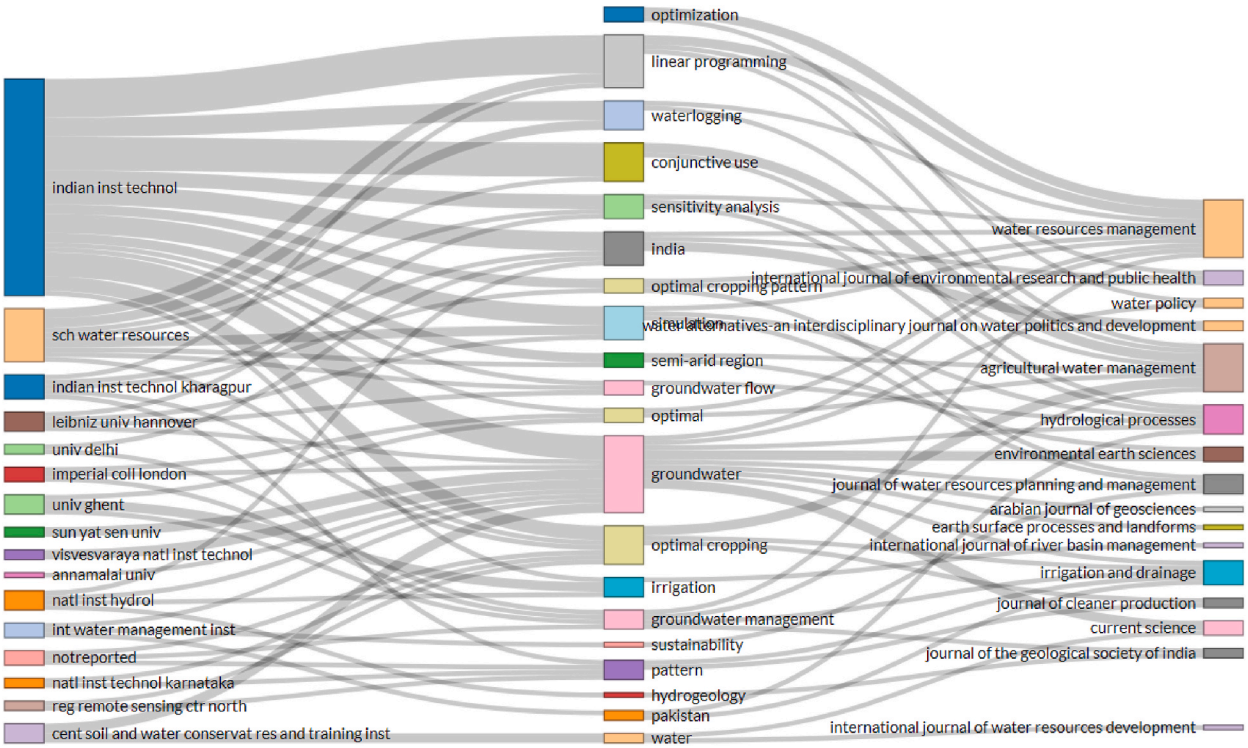

Fig. 5. Relationship flow between author keywords, affiliations, and sources in groundwater abstraction research.

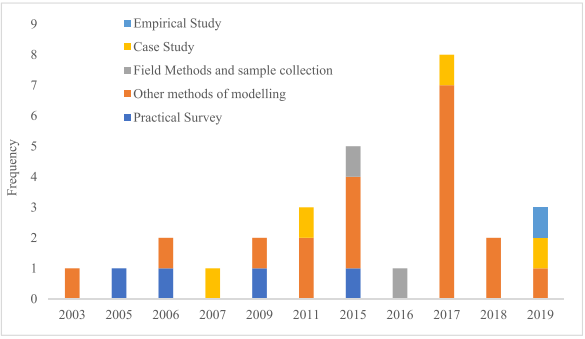

Fig. 6. The evolution of the methodologies of the 24 most cited articles.

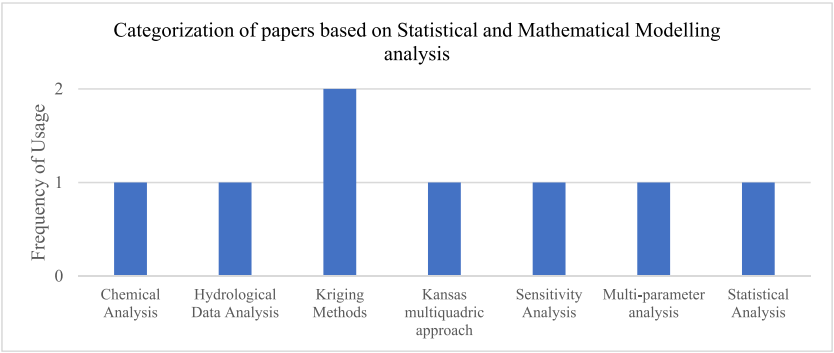

Fig. 7. Types of statistical and mathematical modelling analysis used in the 24 most cited articles.

Fig. 7 revealed that seven different statistical and mathematical modellings were used in 8 different studies. As observed, over the years, research methodologies have evolved towards a more data-centric analysis involving techniques such as multi-criteria analysis, hydrologic data analysis, sensitivity analysis, statistical analysis, multi-parameter analysis, and Kriging methods. It is found that the Kriging Method has been used twice, whereas the other modelling techniques were used only once.

Fig. 8 shows seven different simulation models in groundwater abstraction research. Geographical Information System (GIS) mapping is the most popular simulation model and has been used a maximum of three times. A second popular model is the Ground Water Simulation which has been used only twice. However, the rest of the models, such as the Regional Climate Model Simulated Data, Water Evaluation and Planning (WEAP) model, Visual MODFLOW, Geostatistical Modelling, and Groundwater Modelling have been used only once. There is also another simulation model analysis which has been used three times.

3.8. Cartography analysis using Co-occurring keywords

Using cartography analysis, we have explored all the keywords from the 67 articles on the optimization of groundwater abstraction

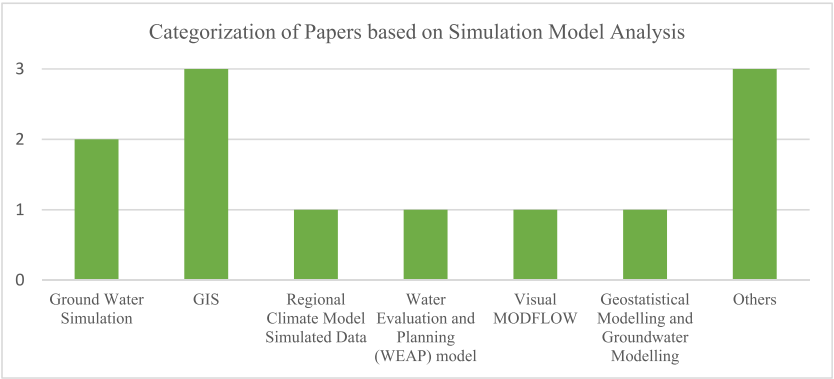

Fig. 8. Types of simulation model analysis used in the 24 most cited articles.

research to create a map of the most frequently occurring keywords. The minimum threshold of the co-occurring keywords is set to 5. Only 17 keywords met the threshold value and created a network visualization illustrated in Fig. 9. As revealed, the network visualization categorized the most frequently occurring keywords into three main clusters. The larger circles in the visualization network represent a strong relationship or linkage between the keywords. The keywords which have the same colour belong to the same cluster. The more important an item, the larger its label and its circle [57].

Fig. 9 shows that the keywords in the last two clusters have relatively large distances from each other, signifying weak relationships among them compared to other clusters. The keywords are ranked in Table 3 in terms of the total link strength. In cluster 1, the keyword "aquifer" has been ranked first in terms of total link strength (214), followed by "management" (56). The keywords "optimal cropping pattern" and "recharge" had the same total link strength (17). In cluster 2, the keyword "groundwater" had the highest total link strength (40), with the keyword optimization having the lowest total link strength (12). The keyword "irrigation" had the highest total link strength (42) in cluster 3, and the keyword "Genetic algorithm" had the lowest total link strength (18).

3.9. Bibliographic coupling of the documents

The bibliographic technique has been used to create a visualization network for citation mapping in this study. Bibliographic coupling happens once two documents cite a common document emphasizing a probable research front of a subject matter. The bibliographic coupling illustrates the total strength of the links with other documents. The larger the number of references the two publications have in common, the stronger the bibliographic coupling relation between the publications exists [57].

In doing the analysis, the minimum number of citations of a document has been set to 5. Only 26 documents met this threshold value. The minimum threshold value has been selected to prevent greater fragmentation of the links and to ensure the thoroughness of the analysis. The analysis has led to the formation of five clusters in total, signifying the groups of documents that are connected (see Fig. 10). A detailed overview of the clusters has been presented in Table 4. The analysis of the cluster showed that the main theme of cluster 1 (red cluster in Fig. 10) happened to be sustainable groundwater abstraction and the effect of groundwater harvesting. The theme of cluster 2 (green) highlighted optimal water resource allocation and crop planning. Cluster 3 (blue) highlighted groundwater recharge and salinization. Cluster 4 (Yellow) highlighted groundwater monitoring, and Cluster 5 (violet) showed the importance of optimal groundwater management using simulation models.

In Table 4, the link strength indicates the relationship of the articles with each other. The stronger the relationship, the higher the value of the total link strength is. The accumulation of all the links of a given article is called total link strength.

Cluster 1 is comprised of 9 documents. It is found that Pandey et al. [13] contributed the most in cluster 1 with a GC of 54 but with a total link strength of 7. Analysis of the paper had shown that Pandey et al. [13] focused on the development of a structured framework that used an index known as the groundwater sustainability infrastructure index (GSII) to measure groundwater sustainability. However, this article received much less attention (total link strength 7) compared to other papers which happen to be closely related to groundwater abstraction. Raul et al. [44] presented how groundwater abstraction can be increased using enhanced pumping and proposed an integrated water resources management in a major canal command in eastern India, which had received much attention (24 total link strength) despite having a lower GC (9). Additionally, it can be seen from Table 4 that Holländer et al. [52] had considerable weight (18 total link strengths) and had the second-highest GC (20) in the cluster. Holländer et al. [52] highlighted the sustainable methods of groundwater resource management and focused on the sustainable abstraction of groundwater resources in alluvial coastal aquifers in Eastern India. Other articles such as Adhikari et al. [25] had a total GC of 11 but had a low total weightage (total link strength 1). The analysis of the paper showed that it had highlighted the study of the effect of water harvesting structures on groundwater recharge and water quality in a watershed situated in a semi-arid region in Andhra Pradesh, India. The assessment was done on two percolation tanks and two check dams to analyze their effect on groundwater recharge and water quality within the perimeter of the water harvesting structures.

Sethi et al. [38] had a total GC of 85 with 23 total link strengths and topped the list in Cluster 2. The article focused on optimal crop planning and conjunctive use of water resource news in a coastal river basin in India. Khare et al. [39] had the second-highest GC (53) along with Sethi et al. [38] but had a low weightage (12 total link strength). These articles focused on the study of the water resources allocation options with a proposed link canal command. Singh and Panda [41] had GC (47) and had a higher weightage (65 total link strength) compared to Khare et al. [39]. Khare et al. [39] showed a linear programming model for the optimal allocation of resources for the maximization of net agricultural return.

In Cluster 3, the most influential document is Usman et al. [53], with the highest weightage (17 total link strength) and highest GC (16). This document focused on using pixel-based methods for groundwater recharge at 1 km^2 spatial resolution using remote sensing data employing water balance methods. Singh et al. [7] had the second-highest weightage (6 total link strengths) and the second-highest GC (11). As found, the research articles which were closely related to the optimization of the groundwater abstraction have a higher weightage value. Bhatti et al. [10] had a low GC, and a low weightage (2 total link strength) compared to other research articles and highlighted new methods to collect groundwater data and demonstrate the use of automatic recording instruments for groundwater monitoring in a tertiary canal command area in Punjab region of Pakistan.

Clusters 4 and 5 both consist of only three articles and all the articles had low total weightage. The key themes of these articles include the development of a groundwater model that examines groundwater depletion in the alluvial aquifer region, the efficient utilization of water resources in basin areas during non-monsoon periods, and so on.

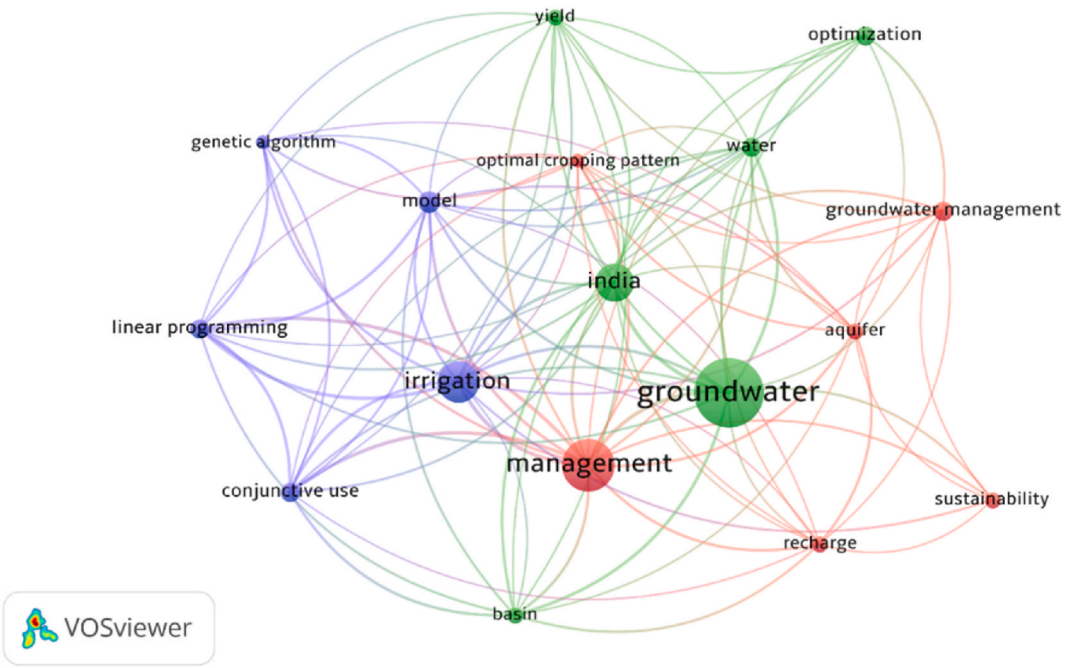

Fig. 9. The Most frequently occurred keywords in optimization of groundwater abstraction research.

Table 3
Keyword Co-occurrence cluster analysis.

Cluster 1			Cluster 2			Cluster 3		
Keywords	Co-occurrences	TLS	Keywords	Co-occurrences	TLS	Keywords	Co-occurrences	TLS
aquifer	6	214	groundwater	25	40	irrigation	14	42
management	19	56	India	14	34	Linear programming	7	32
optimal cropping pattern	5	17	basin	6	23	model	8	30
recharge	6	17	water	7	21	Conjunctive use	7	29
Groundwater management	7	14	yield	6	16	Genetic algorithm	5	18
sustainability	6	9	optimization	7	12			

*TLC = Total Link Strength.

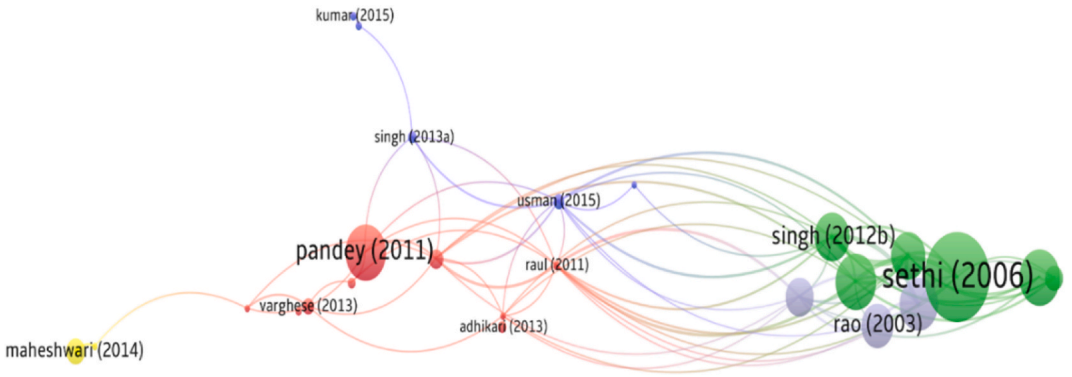

Fig. 10. Bibliographic coupling of documents of the 26 articles in optimization of groundwater abstraction research.

4. Implications, limitations, and future recommendation

This study brings some implications for academics and future research development on the optimization of groundwater abstraction methods in the context of South Asian regions. The findings of this study can be used by researchers and future

Table 4
Cluster Analysis of the Bibliographic coupling of the number of documents.

Cluster 1			Cluster 2			Cluster 3		
Documents	*TLS*	*GC*	*Documents*	*TLS*	*GC*	*Documents*	*TLS*	*GC*
Raul et al. [44]	24	9	Singh [40]	71	45	Usman et al. [53]	17	16
Holländer et al. [52]	18	20	Singh and Panda [41]	65	47	Singh et al. [7]	6	11
Sethi et al. [36]	9	5	Sethi et al. [38]	40	53	Shekhar et al. [58]	4	8
Pandey et al. [13]	7	54	Sethi et al. [36]	23	85	Kumar et al. [45]	3	9
Varghese et al. [56]	6	17	Mohan and Jothiprakash [43]	13	23	Bhatti et al. [10]	2	7
Ranjan [59]	5	7	Khare et al. [39]	12	53			
Tyagi et al. [60]	3	10						
Adhikari et al. [25]	1	11						
Kumar and Perry [46]	1	10						
Cluster 4			**Cluster 5**					
Sayre & Taraz [61]	4	7	Singh and Panda [6]	42	49			
Zekri et al. [9]	3	12	Rejani et al. [12]	23	37			
Maheshwari et al. [51]	2	25	Rao et al. [42]	11	41			

*TLS = Total Link Strength; GC = Total Global Citations.

academicians to identify the core framework of the groundwater abstraction method and know about the most influential authors, institutions, sources, and countries in this field. Also, researchers can identify the most recent developments and trends in this area. This will lead the researcher to create new ideas and a research front for the future development of groundwater abstraction methods.

This study has some limitations, such as the database has been limited to the Web of Science only. Other research databases such as Scopus, ScienceDirect, Google Scholar and so on have not been included in the current study. However, a well-established and stated methodology has been followed to select the relevant articles from the Web of Science (WoS) database. For searching the relevant articles in the South Asian region, we have used a combination of keywords highlighting all the South Asian countries. We do acknowledge the possibility of further groundwater extraction studies being included in other databases. Therefore, the current study lacks these possible articles. To include a wider range of research studies in the field of optimization of groundwater abstraction, this study recommends including Scopus and other databases in future studies.

Moreover, the research stream only focused on the South Asian region, excluding other parts of the world. Additionally, concentrating on a specific country within the South Asian region would result in a more comprehensive understanding of the research front on the groundwater optimization process.

5. Conclusions

This study uses a bibliometric analysis technique and to some extent a systematic review to provide insight into the recent research trends on the optimization of the abstraction of groundwater in the South Asian region from 1992 to 2020. This study quantitatively synthesizes the contributions of the most influential authors, institutions, countries, and documents in this field based on scientometric data. The findings of the study reveal that in terms of the total global citations, Panda SN was the most influential author, and Water Resources Management and Indian Institute of Technology happened to be the most influential source and institution. The optimization of groundwater abstraction has gained interest among researchers from Germany, Japan, Nepal, and Thailand to contribute to the South Asian region. However, India happened to be the most influential country by publishing 47 documents related to the optimization of groundwater abstraction in the South Asian Region. The publication trends indicate that the optimization of groundwater abstraction in the South Asian region has seen a very slow increase in the number of publications as it did not even exceed ten publications per year during the given time frame between 1992 and 2020. The total citations fluctuated throughout the years, with the highest citation of 147 being achieved in the year 2006 and the lowest being achieved in the year 1998. A few numbers of documents have received global citations above 50.

The sustainable groundwater management system was the key research theme that have been published during the given time frame between 1992 and 2020. To create a sustainable groundwater extraction technique, the chosen articles investigate various groundwater parameters, indices, and groundwater monitoring networks. These studies suggest that by enhancing groundwater extraction design and operational methods, the problem of water scarcity can be resolved. To meet the demand for irrigation or drinking water, it has been suggested to maximize net annual water extraction or the collective use of different water sources, including groundwater. The results of the analysis showed that the simulation model and statistical and mathematical modelling analysis are the most popular methods used by researchers in this category of scientific studies.

The keyword co-occurrence visualization network showed three different clusters related to this research trend in which keywords such as 'management,' 'groundwater', and 'irrigation' had the highest number of co-occurrences showing a high opportunity for future research works to be conducted in this field. Lastly, the bibliographic coupling of the number of documents has illustrated results in five distinct clusters of research front contributing to different areas of groundwater abstraction and optimization process.

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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