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Water quality in Northern Province of Sri Lanka: A bibliometric analysis of publications 1960–2021

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Abstract

Groundwater contamination derived from human activities including farming is a serious problem threatening water security in the Northern Province (NP) of Sri Lanka. Gathering all existing research knowledge on the province's water resource base to create a digital repository is a key action in the 3-year action research project on water security. Papers gathered in the repository showed that water quality, particularly salinity in groundwater and its contamination, was a prominent theme in research over the past two decades. Thus, the scope of this bibliometric study is restricted to published work on water quality pertaining to the North during 1969–2021. Publications listed in four electronic databases, namely, Scopus, PubMed, Web of Science, and Google Scholar yielded 118 scholarly publications. This paper provides an overview of the publication types and distribution, titles of journals and conferences, authorship, institutions, countries, themes, and keywords used. Final 20 years of study period saw a substantial growth in publication rate of water quality papers in the NP with journal articles and conference papers being the dominant types at 63% and 35%, respectively. Authors from 52 different institutions contributed to production of these publications, 93% of whom represented public sector institutions in Sri Lanka. University of Jaffna was in the lead position

in numeric terms ($n = 82$), followed by the University of Peradeniya ($n = 28$). A significant 81% of the papers accounted for studies on water contamination, some indication of the degree of concern for this aspect among the research community. Around 65% of papers have been published in a wide range of international journals, some of which are less well established. This tendency has implications for the scientific output in terms of its quality, peer review process, and in turn also for usefulness of the work in the local context and in policy making.

KEYWORDS

bibliometric analysis, bibliometry, data visualization, Sri Lanka, water contamination, water quality

1 | INTRODUCTION

Groundwater contamination derived from domestic sewage, industrial effluents, and agricultural residues infiltrating into the soil in rural areas presents itself as one category of serious problems threatening water security in the Northern Province (NP) of Sri Lanka (Jeyaruba & Thushyanthi, 2009; Joshua et al., 2013; Li et al., 2020; Wijesekera, 2016). Prior to the 1970s, the predominantly rural livelihoods characterized by irrigated farming systems prevailing in the NP were not as extractive of land and water resources as what followed in the 1970s and 1980s in the name of Green Revolution agriculture with the high demands on resources it placed through the intensification that accompanied it. Whatever sustainable water management that was in place then was allowed to degrade during the violent conflicts which lasted for next three decades. At this time, water infrastructure collapsed and governance of water according to long held management practices was gradually abandoned (Janithra et al., 2018; Sivakumar, 2015; Thalpawila, 2016). Large-scale migration, both within the province and beyond, resulted in much disruption among the population, leading to depletion of water in some areas and degradation of the water resource itself due to neglect. This situation has only been worsened by the speed and unregulated nature of postwar development in the NP.

The NP (Figure 1) is nominally in the dry zone region though it can still receive average annual rainfalls of 1,750 mm and it covers a total area of 8,848.58 kms² (Northern Provincial Council, 2014). NP includes two geographical regions, Jaffna peninsula and the adjoining islands which are heavily dependent on groundwater sources, and the remainder of the province south of the peninsula relying on surface water in the form of small reservoirs traditionally called *tanks* fed by seasonal rivers which meet the agricultural, industrial, and domestic needs (Ranasinghe, 2014).

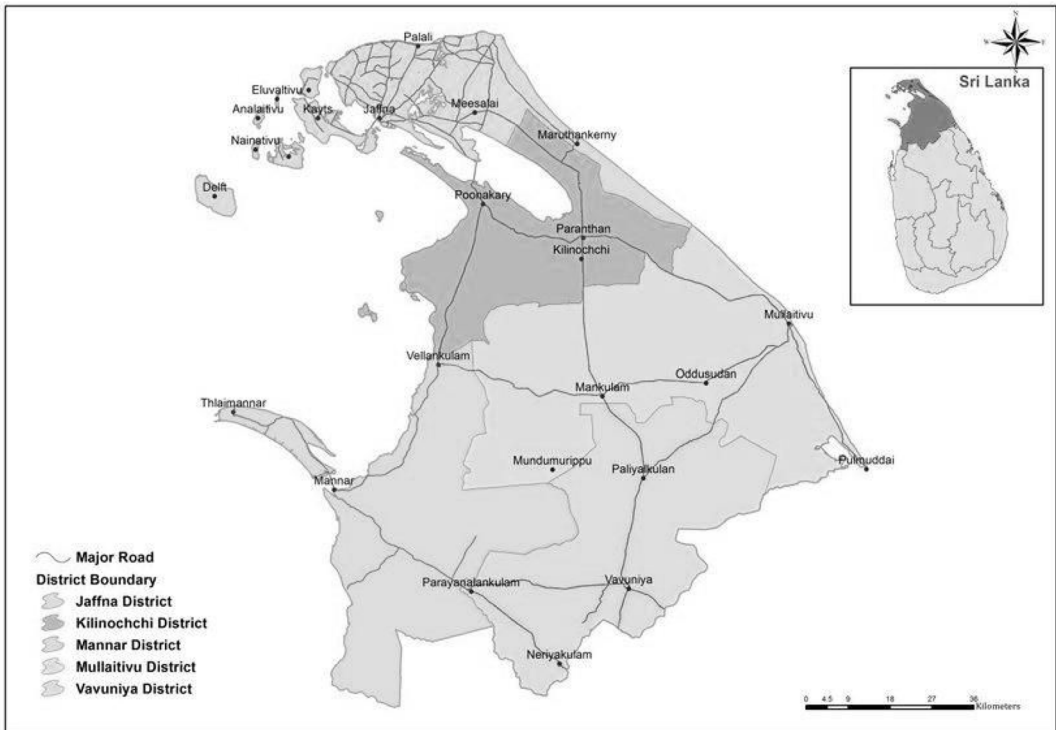


FIGURE 1 Map of Northern Province of Sri Lanka (obtained from Mallawatantri et al., 2014).

Investigations on the status of water resources of the NP have been conducted since colonial times in view of the heavy reliance of society on irrigated water for food production, particularly so from the beginning of irrigated colonization schemes in the forested areas of four districts together referred to as Vanni districts beginning in the 1950s (Arumugam, 1969; Brohier, 1934, as cited in Sivakumar, 2020). The focus on studying about quality and contamination of water is, however, a more recent phenomenon with the arrival of water supply and drainage scheme and the efforts to address the threat of increasing salinization of groundwater which is a vital resource for NP, and more particularly for Jaffna peninsula.

Even though several studies have been undertaken on water quality in different areas of the NP over the decades, reports and publications remained scattered and poorly integrated into policies and practice. No comprehensive or systematic review of the decades of water research has been undertaken to serve needs of policy. Reviewing and synthesizing existing research is an important way to obtain an overview of issues being studied in research publications, to recognize knowledge gaps at present to plan important areas of future research. Understanding previous studies on water quality in NP is, therefore, important to build appropriate management strategies and policy making to sustain available water resources through minimizing water pollution. The issue of utilization of water research outputs for water policy is claimed to be a blurred area in general, and the decision about what specific research needs to be done is often not made through a systematic process in many countries, according to the UN University's recent review (Mehmood, 2019).

Based on the above as one of its premises, the 3-year action research project on Water Security in NP (WASPAR) took as one of its key actions the task of gathering all existing research knowledge on the province's water resource base to create a digital repository. Analysis of

publications gathered in the repository pertaining to NP revealed the fact that water quality, in particular salinity in groundwater and presence of contaminants, were the most prominent themes in research over the past two decades. This bibliometric study is restricted to published work on water quality with the overall strategy of undertaking such an analysis first, with a complementary systematic review of the same literatures to follow.

In the tradition of bibliometric studies, physical published units such as journal publications or their bibliographic units are examined comparatively in quantitative terms (Broadus, 1987). Today, bibliometric analysis has been much enhanced through the arrival of a number of digital mapping and data visualization tools, and this is reflected in the increasing number of bibliometric studies published pertaining to very large range of fields, subfields, and even emerging new fields of study. Bibliometric studies enable the mapping of an area of knowledge, main lines of research, hotspots, and emerging trends, as well as the recognition of research gaps to be addressed in that area (Glänzel et al., 2019).

A brief review of bibliometric studies of water-related research in recent years shows the global scope of such a study as seen in Mehmood (2019) on the one hand or pertaining to specific countries such as the work on Spain by Montoya et al. (2016) and from India by Nishy and Saroja (2018). Studies have also covered specific concepts, entire journals on certain topics or themes, and on emerging new fields. Examples include the one on role of narratives around water as a study topic (Leong, 2021) and water resource carrying capacity (Yang et al., 2022) as another; a systematic bibliometric study covering over 54 years of publications in *Desalination* journal (Ashraf et al., 2022) and in *Water Research* by Wang et al., 2010; and bibliometric analysis of worldwide research in the new field of sociohydrology (Herrera-Franco et al., 2021). There are two bibliometric studies on water resource management in Sri Lanka published (Janen & Sivakumar, 2020; Navaneethakrishnan & Sivakumar, 2015).

Our bibliometric study was done as a preliminary step towards knowledge synthesis and the aim of this paper is to provide an overview of the researchers, institutions, the nature of the collaborations among them, and the major research themes covered by the researchers in the context of water quality in NP. Bibliometric analysis of gathered literature on water quality in this study would allow the establishment of a base line about the flow of research in the NP in quantitative terms in relations to similar research in other regions of Sri Lanka. This way a quantitative narrative about the quality of water in the NP could be developed through community discussion. The targeted readership of this study, therefore, includes water researchers, library science researchers, policy makers, donors, and the media.

2 | MATERIALS AND METHODS

A literature search was conducted in January 2022 covering four electronic databases, namely, Scopus, PubMed, Web of Science, and Google Scholar. Based on the small number of documents retrieved from searching the first three databases, it was decided to include Google Scholar as a fourth one. Search queries were formulated using 40 keywords selected by subject specialists. A sample search query within Scopus for water quality publications in the NP, its five districts, and the whole of Sri Lanka read as follows: TS = Water quality AND NP OR Jaffna OR Mannar OR Kilinochchi OR Vavuniya OR Mullaitivu AND Sri Lanka.

In this study, peer-reviewed journal articles, conference papers in proceedings, and book chapters related to water quality in NP, collectively referred to as scholarly publications, have been included. Gray literature such as government and nongovernment publications as well as

theses and dissertations were excluded. Although the search was not limited to a specific period of time, the study covers publications from the time the first indexed article appeared (1969) to the end of 2021.

The initial search resulted in a wide-ranging number of entries, with 4,587 in Scopus, 96 in Web of Science, 4 in PubMed, and as many as 42,523 in Google Scholar. These records were screened initially to remove duplicates, then according to title and abstract for compatibility with selection criteria of water quality and NP. Figure 2 illustrates the selection and screening procedures leading to final number of documents used in the study.

Bibliographic information of all publications was collected for performing the bibliometric analysis. VOS viewer (1.6.17) software was used in the analysis to show co-occurrence among keywords as well as author and institutional collaboration (Van Eck & Waltman, 2020).

Bibliometric information of all paper was extracted in csv file format which is one of the appropriate formats accepted by the software. Then, the file was imported into VOS viewer, and the type of analysis and unit of analysis were selected to visualize the maps. When reading the visual outputs of analysis by VOS software typically, size of the note indicates the important of the particular factor such as author or institution, while the thickness of the line between two factors indicates the strength of association between those two.

3 | RESULTS

The 118 scholarly publications were subject to the common set of criteria in any bibliometric study, namely, publication distribution and types, titles of journals and conferences, authorship, institution, countries, themes, and keywords.

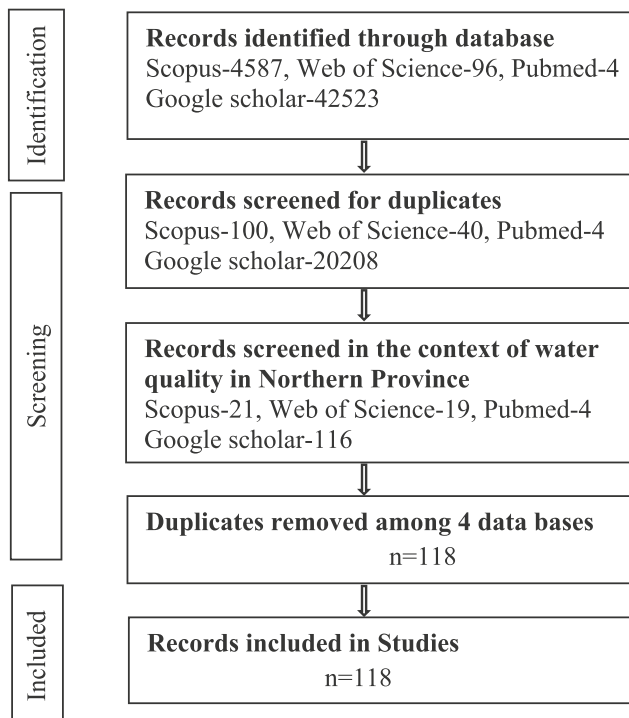


FIGURE 2 Selection procedure of documents.

These 118 publications included in this study on the basis that they arose from research in the NP, though conducted in different areas of the province. When these were analyzed according to which of the five administrative districts of the NP the research was situated in, it was revealed that a large majority of the studies (71%) came from Jaffna district and its islands, 15% from Vavuniya district, and 8% covering the three remaining districts of Kilinochchi, Mannar, and Mullaitivu. A small number of papers (6%) arose from work across all districts.

3.1 | Progression of scientific output

The year-wise distribution of retrieved scholarly publications for 1969–2021 is illustrated in Figure 3. As indicated above, the first indexed publication of the categories being examined in this study appeared in 1969. The number of publications remained low between 1 and 2 for the next 20 years. A close examination of the progression of the publications in 10-year blocks shows that in comparison with the low productivity observed in the first 30 years (1969–1999), publication rate showed a substantial increase in the subsequent 20 years.

3.2 | Publication types

The percentage distribution among the three types of publications retrieved for the study period is shown in Figure 4. Journal articles and conference papers were the dominant types with 63% and 35%, respectively, while only three out of the total of 118 retrieved publications were book chapters (2%). Among the journal articles, 48 were published in 41 different international journals, whereas the remaining 26 articles appeared in 13 different national journals. Out of the conference papers, 13 were present in the proceedings of 11 international conferences and 28 in proceedings of 17 national conferences.

Tables 1 and 2 list the titles of journals and conferences popular among authors (>1 publication), respectively. Two journals published in Sri Lanka ranked high carrying five and four articles during the study period. These were *Vignanam*, a Journal of Science published by the

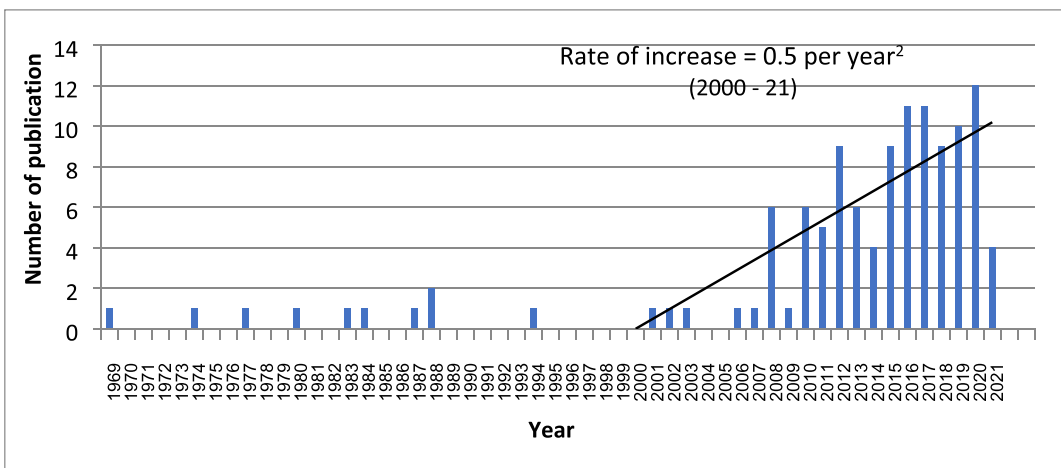


FIGURE 3 Year-wise distribution of scholarly publications for 1969–2021.

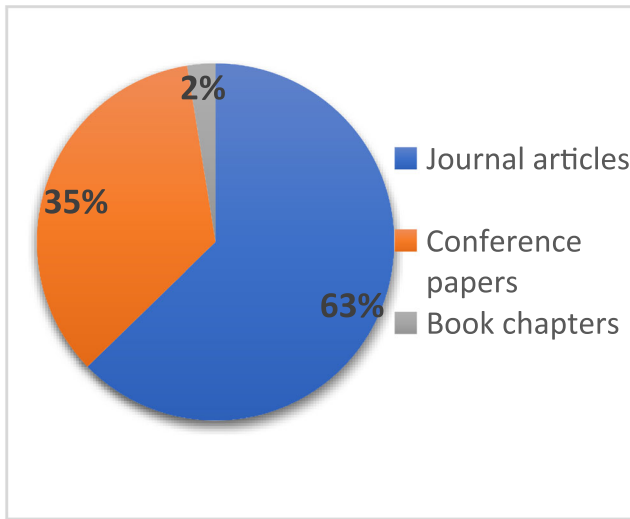


FIGURE 4 Publication types expressed as % of total number of documents ($n = 118$).

TABLE 1 List of titles of journals with high number of articles.

Title of journals	Country of publication	Number of publications
Vignanam (Journal of Science)	Sri Lanka	5
Journal of the National Science Foundation of Sri Lanka	Sri Lanka	4
International Journal of Scientific & Engineering Research	India	4
Ceylon Journal of Science	Sri Lanka	3
Middle-East Journal of Scientific Research	Middle East	2
Tropical Agricultural Research	Sri Lanka	2
Aqua	Italy	2

TABLE 2 List of titles of conferences with high number of papers.

Conference title	Conference type	Number of papers presented
Water Professionals' Day	National	5
Vavuniya Campus Annual Research Session	National	3
International Conference on Sustainable Built Environment	International	3
Young Water Professionals Symposium	National	3
Annual Session of Jaffna Science Association	National	2
Symposium on Water Supply, Sanitation, and Wastewater Management	National	2

University of Jaffna, and *Journal of the National Science Foundation of Sri Lanka*, respectively. The *International Journal of Scientific and Engineering Research*, by an Indian publisher, was the next in the list with four articles. Among the conferences, highest number of papers ($n = 5$)

were published in “Proceedings of the Water Professionals’ Day” published by the University of Peradeniya as part of their annual symposium series.

Of the six popular conferences, three appeared to be events dedicated to subject of water while the rest cover the general field of science.

3.3 | Authorship pattern

Authorship pattern in bibliometric study reflects the authors’ characteristics, authorship of articles and degree of collaboration among the researchers in specific studies (Manikumar & Chandrasekar, 2020). According to Subramanyan (1983), degree of collaboration can be defined as the ratio of the number of multiauthored research papers to the total number of research papers during a certain time period.

Examining the authorship pattern in this study, as shown in Table 3, indicated that a significant number of studies was carried out with collaborative authorship ($n = 102$, 86.44%) compared with single authorship ($n = 16$, 13.56%). Under collaborative authorship, a high number of publications were contributed by three author collaborations ($n = 31$) followed by those with two and five author collaborations ($n = 22$).

Names of authors who contributed more than three publications are shown in Figure 5. It is observed that a total of 231 authors from a number of different institutions contributed 118 publications in the area of water quality pertaining to NP, Sri Lanka. Out of the 231 authors, 17 authors have contributed for more than three publications while the rest have been associated with fewer than four publications. Further, out of these 118 publications, 28 had the name of one researcher, Thushyanthy, M., followed by that of Saravanan, S. who has contributed for 14 publications.

With regard to the corresponding author named in the publications, it was observed that in 35 publications, no corresponding author was mentioned. Further analysis revealed that among the publications where corresponding authors are indicated ($n = 83$), 50 publications mentioned the first author as the corresponding author, including 16 single author publications.

TABLE 3 Authorship pattern among retrieved publications during 1969–2021.

Years	Number of authors						Total	Multiauthored	Degree of collaboration
	Single	Two	Three	Four	Five	>5			
1969–1974	2						2	0	0
1975–1980	1				1		2	1	0.5
1981–1985	0	1	1				2	2	1
1986–1990	0	1	1	1			3	3	1
1991–1995	1						1	0	0
1996–2000	0	0	0	0			0	0	-
2001–2005	1		1	1			3	2	0.66
2006–2010	3	7	2	1	2		15	12	0.8
2011–2015	3	4	12	6	7	1	33	30	0.91
2016–2021	5	9	14	9	12	8	57	52	0.91
Total	16	22	31	18	22	9	118	102	0.86

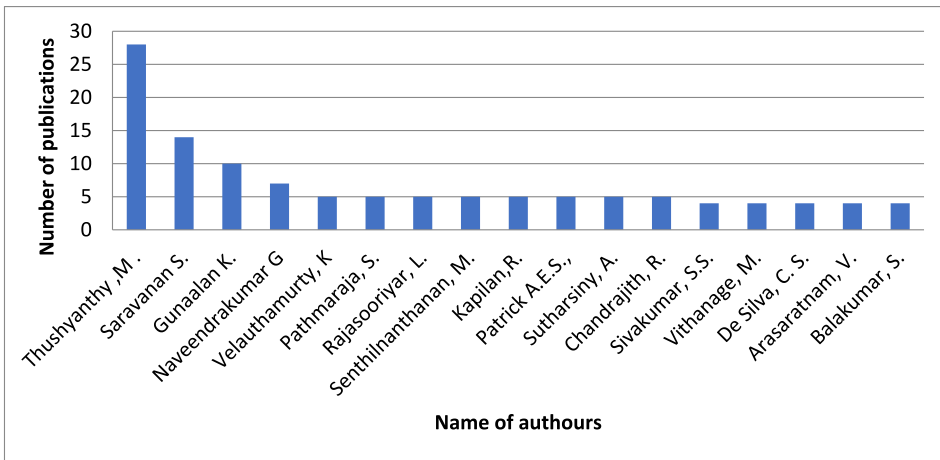


FIGURE 5 Names of authors contributed in more than three publications.

Figure 6 is the VOS-derived visualization map showing the collaboration network among authors. Authors who did not have any collaboration with others were excluded in this map. Each node in the visualization represents an author, and the links among the nodes represent the collaboration relationships among them. The weight of a link indicates the number of publications co-authored by two authors—the thicker the line between the nodes, the stronger the collaboration between them. According to the size of the node, Thushyanthy, M. is the leading contributor of water quality studies in the NP of Sri Lanka during the study period. Furthermore, Figure 6 demonstrated a high degree of collaboration by her with other researchers, and in particular with three authors, namely, Saravanan, S., Pathmaraja, S., and Gunalan, K.

3.4 | Institutional contribution and collaboration

An analysis of the distribution of co-authors with different institutional affiliations revealed that authors from 52 different institutions contributed to the production of the collected publications. Of these, approximately 93% of the authors were affiliated to government departments and institutes, public universities, and private institutions in Sri Lanka. The remaining 7% of the authors were from universities and institutions from outside Sri Lanka.

Table 4 indicates the names of institutions from which more than two publications were derived in the study period and also the number of links each of those institutions had with others, as analyzed through the VOS viewer software.

University of Jaffna, which was the only state university situated in the NP during the study period, is in the lead position in numeric terms ($n = 82$). This is followed by the University of Peradeniya ($n = 28$) and the National Water Supply and Drainage Board with a total of 21 publications—the remaining five institutions each accounted for under 10 publications during the study period. The same three institutions in the top of the list in terms of the number of papers were also the ones with strong links indicating a stronger tendency for collaboration among them.

Network visualization map of research collaboration among the institutions is indicated in Figure 6. The link strength is proportional to the extent of research collaboration between the

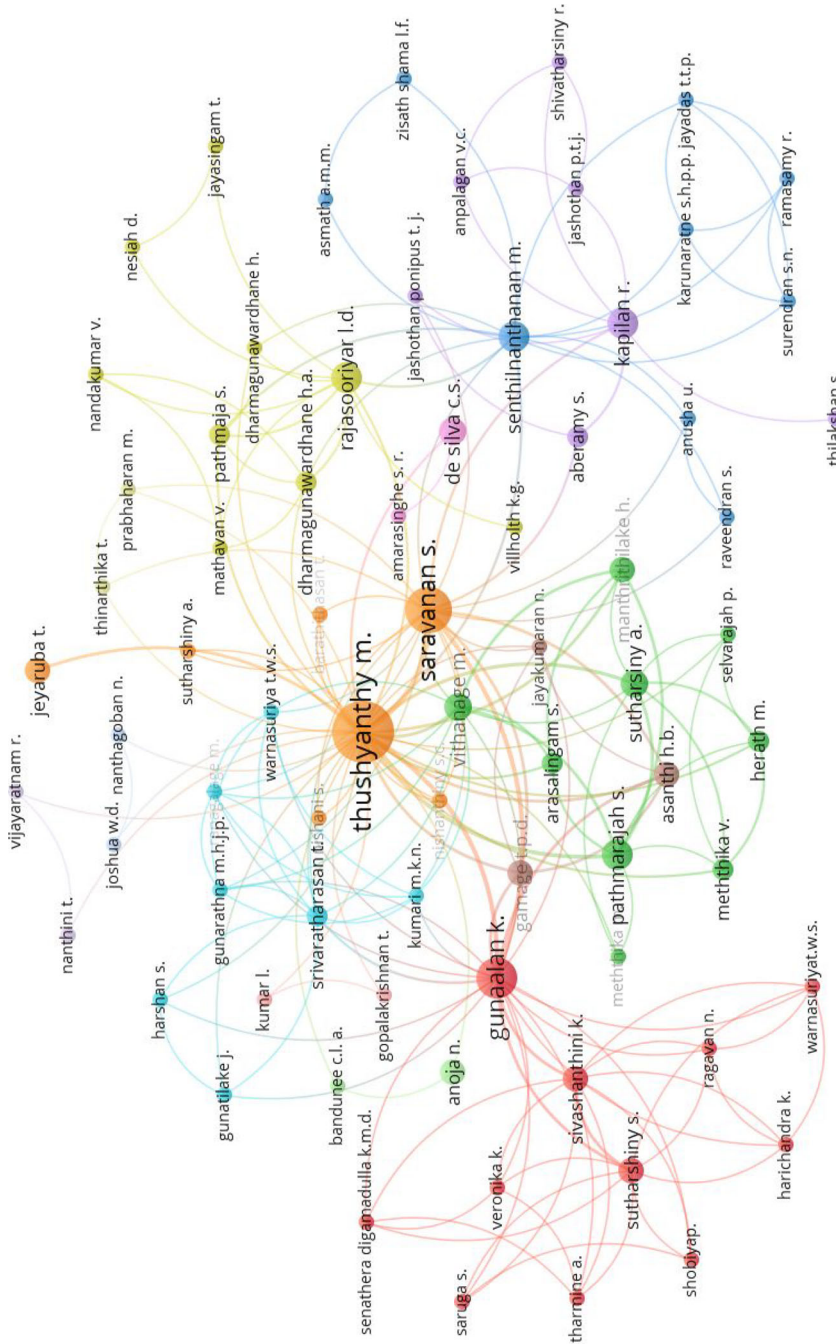


FIGURE 6 Collaborations network between authors in the collected publications through VOS viewer.

TABLE 4 Main Sri Lankan institutions, their contributions, and their links to other institutions.

Institution name	Article numbers	Links
University of Jaffna	82	30
University of Peradeniya	28	14
National Water Supply & Drainage Board	21	16
National Institute of Fundamental Studies	8	4
Open University of Sri Lanka	6	8
University of Ruhuna	6	7
International Water Management Institute	5	3
University of Sri Jayewardenepura	4	8

connected institutions. Node size of each institution represents the number of documents associated with authors from that specific institution.

This, taken along with the visual indications of the links given in Figure 7, confirms that the degree of collaboration among these three institutions is stronger than their respective links to the remaining institutions in the map. This is particularly so between the Universities of Jaffna and Peradeniya reflected in the thickness of the line between the two institutions. We believe that well established links between individual researchers in these institutions through prior collaboration denoted the strength of these associations.

Figure 8 categorizes publications in terms of the countries from which authors and/or institutions came from. All but two of the 118 publications in the study were from Sri Lanka, with one each of the remaining two coming from Japan and the United Kingdom. Of the eight countries from which collaborating authors came from, Japan stands out accounting for a slightly higher number of papers ($n = 5$) than others with one or two publications derived from such international collaboration.

3.5 | Distribution into themes

As illustrated in Figure 9, when the collected publications were categorized according to the emphasis given in the study for the aspect of water quality examined, a significant 81% of the papers accounted for studies on water contamination compared with the three other themes related to water quality, namely, the treatment of water for supply purposes (8%), salination of groundwater (7%), and water and human health (4%). Publications within the dominant theme of water contamination in quality-related research consisted of papers on the physical, chemical, and biological parameters of the water.

3.6 | Keywords

VOS viewer software enables the mapping of authors' keywords in clusters of main topics researched within any one theme. When keywords are plotted across the entire range of publications being examined, their co-occurrence as a network, as shown in Figure 10, becomes an indication of relevant and popular issues being studied within a theme such as "groundwater" and "water quality" in this study. In terms of node size as an indication of the number of

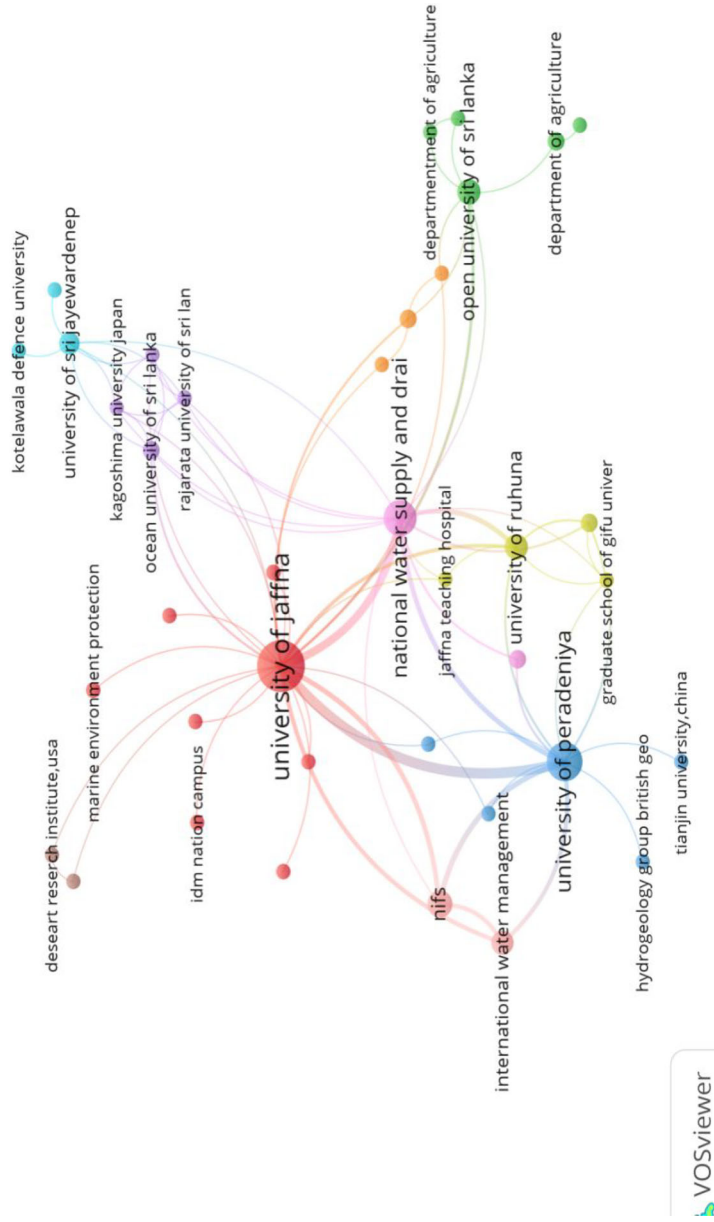


FIGURE 7 Network visualization map of research collaboration among the institutions using VOS viewer software.

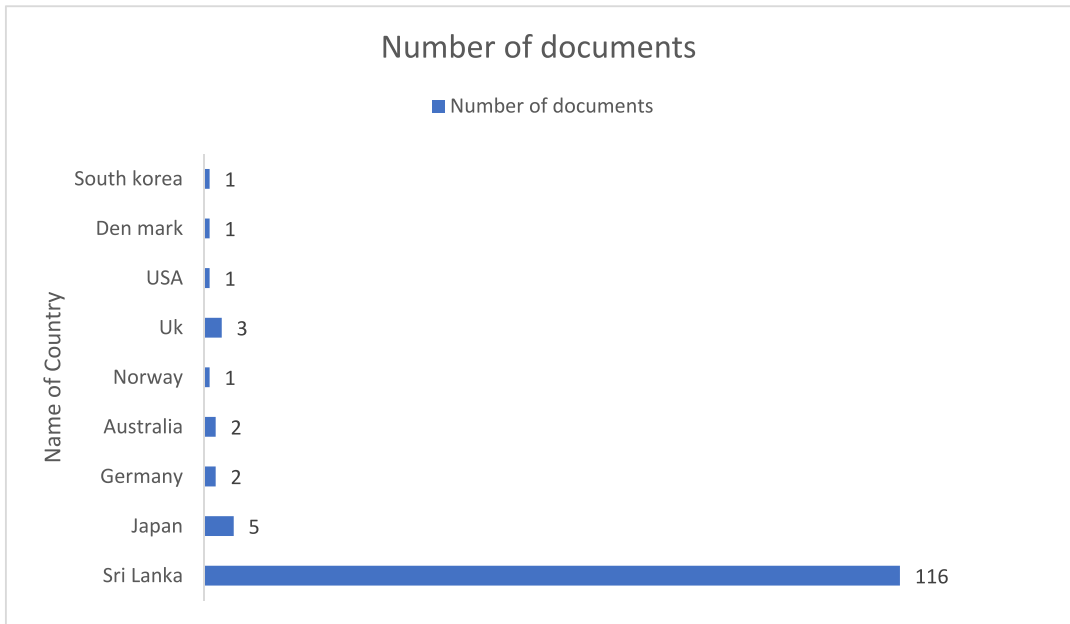


FIGURE 8 Countries contributing collected publications.

occurrences of a keyword, the two locational keywords, “Sri Lanka” and “Jaffna peninsula” gain prominence, along with two quality parameters “salinity” and “nitrate” as important keywords in the retrieved publications. The link strength between the keywords represents the co-occurrence of two key words in a same paper. The minimum number of occurrences was set to 2 to obtain relatively more precise visualization. Clearly, “groundwater” remains the central keyword in the literature examined here.

Figure 11 presents the authors’ keywords that occurred four or more times in the collected publications. Groundwater, Water Quality, Jaffna peninsula, Sri Lanka, Salinity, and Nitrate ranked as one group of keywords occurring in more than five documents, while pH, Water Quality Parameters, Jaffna Lagoon, Groundwater Quality, Electrical Conductivity, Jaffna, and Drinking Water are in a second group of keywords found fewer than five times.

4 | DISCUSSION

We begin this discussion by highlighting the limitations in the scope of this as a bibliometric study. The issue of a small number of papers ($n=22$) we were able to obtain initially from the three databases, Scopus, PubMed, and Web of Science, was overcome by going into Google Scholar. As a result, a significantly large number of additional publications ($n=96$) were gathered. For the reason that the number of publications drawn from indexed journals was so small, citations or impact analysis have not been pursued with this set of data as is commonly done in such a study.

The trend in scientific publishing in the NP, discussed in detail below, has been to publish widely including in conference proceedings rather than authors seeking out specialist journals of the indexed kind. In terms of our ambition of building a repository of all forms of

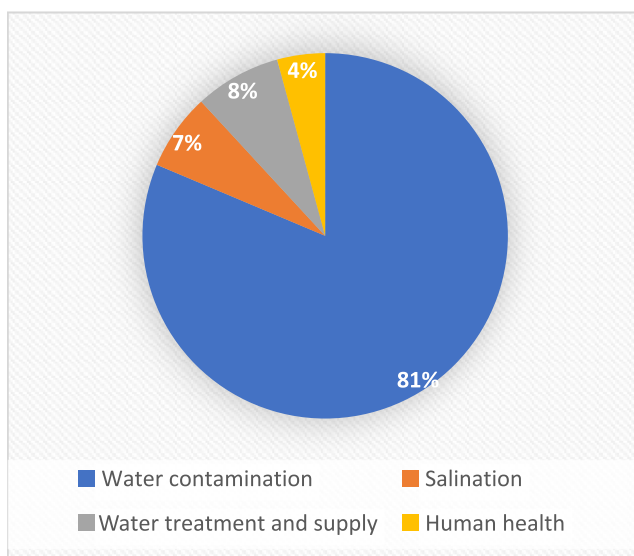


FIGURE 9 Distribution of themes.

publications on water in the NP, we acknowledged this trend and, therefore, included publications gathered from all four databases, indexed and nonindexed. While the repository will continue to gather material well beyond texts of a scientific kind, this study becomes the first bibliometric examination of what has been obtained in the first search just concluded of scientific publications on water quality. Nishy and Saroja (2018) refer to their analysis of water quality and treatment research output in India as the first of its kind for India. Interestingly, they found that 33% or a third of the 4,616 papers on water quality research in India was dealing with contamination in water. The comparable figure in our study in the NP is substantially higher at 81% reflecting the high degree of concern in the North of Sri Lanka about rising levels of salinity in groundwater and anthropogenic contamination of the same groundwater resource.

4.1 | Growth of publications

As discussed in Section 3.1 above, there are two phases noted in the pattern of growth in publications on water quality, a sluggish 30-year first phase with an average of less than one publication per year (0.3 per year) and a 22-year-long second phase of rapid growth in number of publications until 2020 when publication rate rose to 12 articles per year, an average of approximately 5 published per year and an acceleration rate of 0.5 per year² (2000–2021) as shown in Figure 2. This observation can easily be correlated with the initial phase of war and disruption experienced in the wider society, followed by a phase of relative stability favorable to scientific endeavors following the ceasefire in 2002. A similar increase in research activity seen in India was shown to be the outcome of a single policy intervention in the form of National Water Policy introduced in 2002 (Nishy & Saroja, 2018).

During the 10-year block of 1969–1979, only three publications related to water quality appeared. Two of these reported variation in salinity levels in the Jaffna lagoon

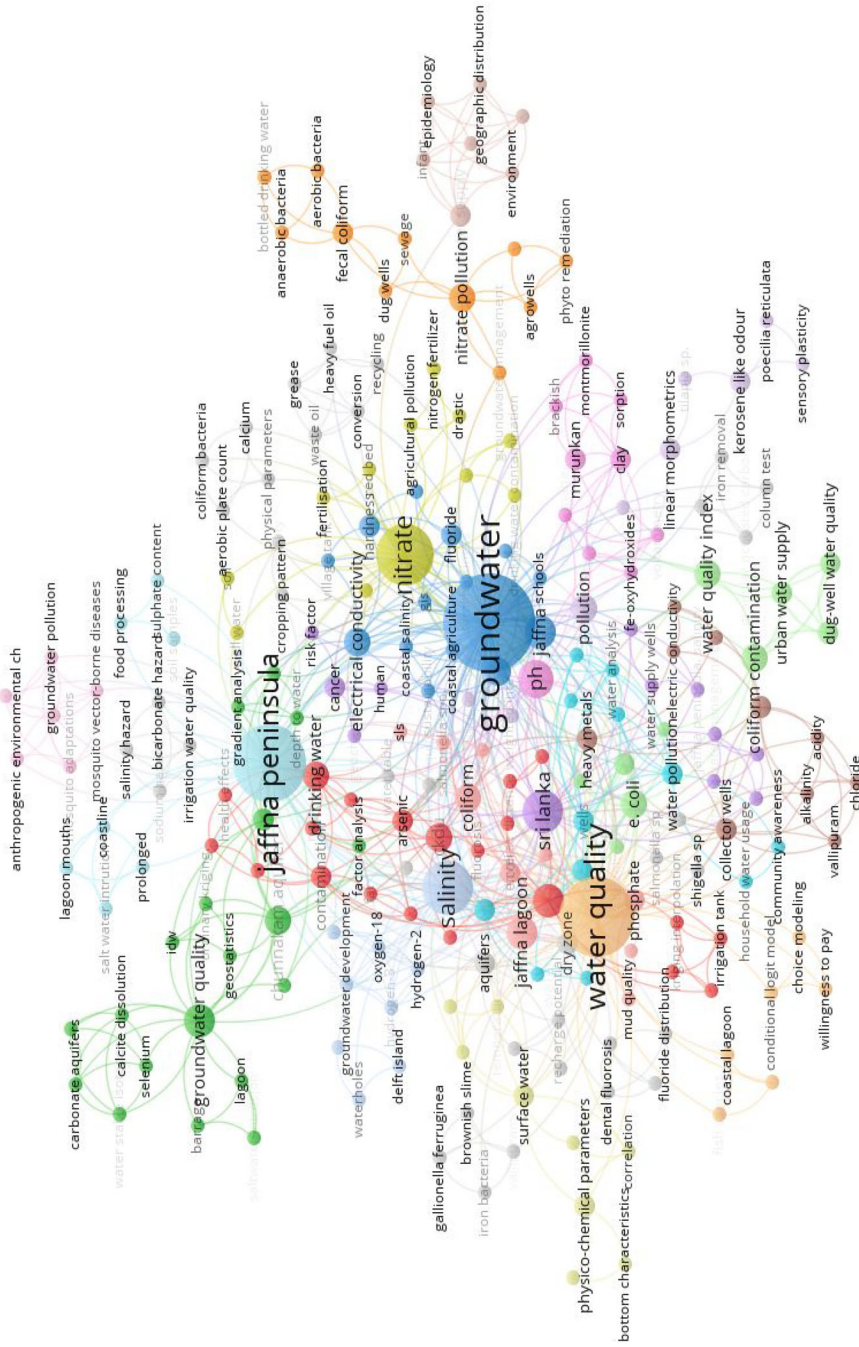


FIGURE 10 Co-occurrence network of authors' keywords in the collected publications on water quality.

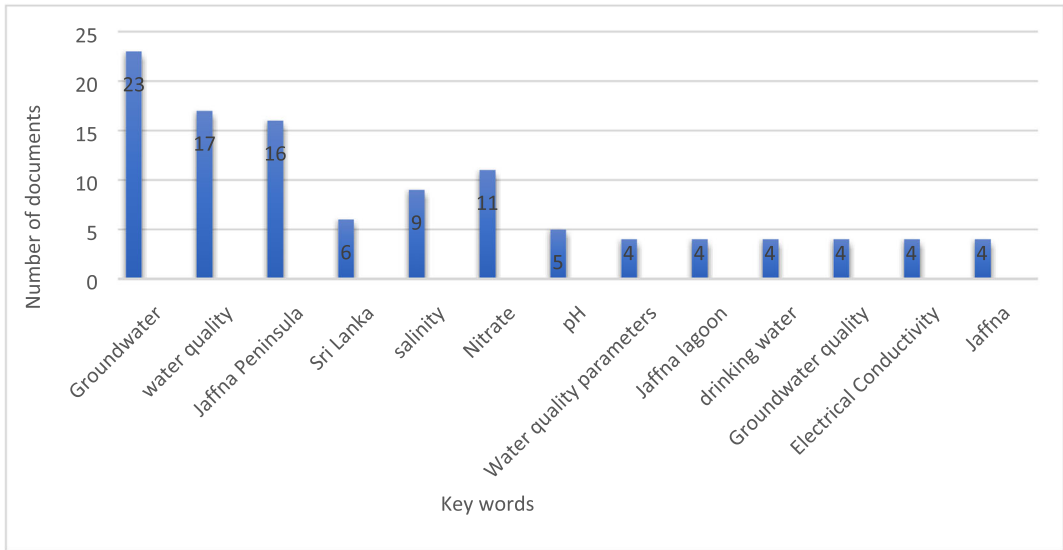


FIGURE 11 Authors' keywords ranked according to occurrence.

(Arulpragasam, 1974; Sachithanathan, 1969) while the third published in the *Ceylon Medical Journal* reported on the 1974 Cholera outbreak (Mendis et al., 1977).

The second 10-year block from 1980 to 1989 saw six papers being published and in the third decade (1990–1999) only one paper was published. This was a conference paper on water problems in Jaffna peninsula by Navaratnarajah (1994).

4.2 | Publication types and authorship

In terms of publication types discussed in Section 3.2, journal publications seem to outnumber conference papers at an approximate ratio of 2:1 with a tendency in recent years for this ratio to move to 3:1. It appears that 65% of all the journal articles published have been in international journals with only 35% published in national journals. However, the observation that up to 48 articles were published in 41 different international journals during the study period indicates that researchers seek a wide range of less known journals primarily because these journals were simply presenting an “international” face. This tendency has implications for the scientific output in terms of its quality, the peer review process, and in turn also for the usefulness of the work for practical application in the local context and in policy making.

The dramatic growth in the number of journals pertaining to water research in the global arena since 2000 has been noted, with the total number now approaching 2,100 journals (Mehmood, 2019). Despite such massive expansion in the opportunities to publish internationally, and in view of the emerging pattern of publications indicated in this study, the need for outcomes of scientific research on critical local water issues to be deliberated locally, and the place for one or two quality local journals could not be emphasized more.

There is clear evidence of an increase in the number of multi-authored publications, such collaboration among authors picking up from the 2006–10 period. In fact, this trend continues to date, so much so that while single-authored papers went up from a total of 5 (4% of the total)

in the study period prior to 2005 to 11 in the period after 2005 (9% of the total) while the corresponding rise in multiauthored papers was from 8 to 94 or 7% to 80% of the total number. This tenfold increase corresponds to an average of six multiauthored publications per year and with an average of 3.5 authors per paper over the past 15 years (Figure 12).

Though we are unable to explain this phenomenon in full based on the data available, indications are that a combination of factors contributes to this trend of increasing proportion of multiauthored publications. Some of the key factors include the prioritization of research and scholarly writing by academics as university policy, emphasis given to projects undertaken by postgraduate and senior undergraduate candidates and their publications, multiple supervisors involved in these studies, sometime across departments and disciplines, and finally, an increasing number of graduate candidates attached to water authorities in the public sector conducting projects worthy of scientific writing and publications. Availability of funds for research, established teams of researchers from across disciplines at the University of Jaffna taking advantage of this, and of course an increase in the number of subject specific symposia and conferences in the country also appear to have supported this trend. The same sequence of events affecting the publication trend in water research observed at a global level has been commented on by Mehmood (2019) in The Global Snapshot Report of the UN University.

4.3 | Institutional affiliation

In terms of authors' affiliations, public universities ranked high followed by water-related government agencies and then the occasional international universities and research institutes. This corresponds well with the observation that out of the grand total of 221 authors identified in the study, 43% were academics followed by another 30% who were their collaborators, most likely their student researchers and others, 14% from government agencies, and the remaining 13% representing international collaborators and institutions such as the National Institute of Fundamental Studies (NIFS) and the International Water Management Institute (IWMI).

Among the universities, University of Jaffna remained as the largest contributor of publications on water quality in the NP. These publications appear to be the outcome of extensive collaboration internally among 10 different departments situated in five different faculties of University of Jaffna, namely, Science, Arts, Agriculture, Applied Sciences, and Engineering. It is to be noted that such an attitude of interdisciplinary collaboration already existing at the University of Jaffna clearly enabled the formulation of a transdisciplinary action research project such as WASPAR to eventuate.

A further reflection of the role of the University of Jaffna as a key site of water research in the NP and a venue for research by graduate students is in the node size of researcher, Thushyanthy, M., and the link strength she demonstrates across a number of preferred collaborators including graduate students and their respective institutions.

It would have been interesting to establish the impact of publications arising from the work of university researchers if citation as a factor of analysis had been completed. Evidence from comparable research in India shows that although university research accounted for more than half of the published research on water quality, some of the public research institutions and IITs of India ranked higher in terms of impact of their papers than universities and their publications (Nishy & Saroja, 2018).

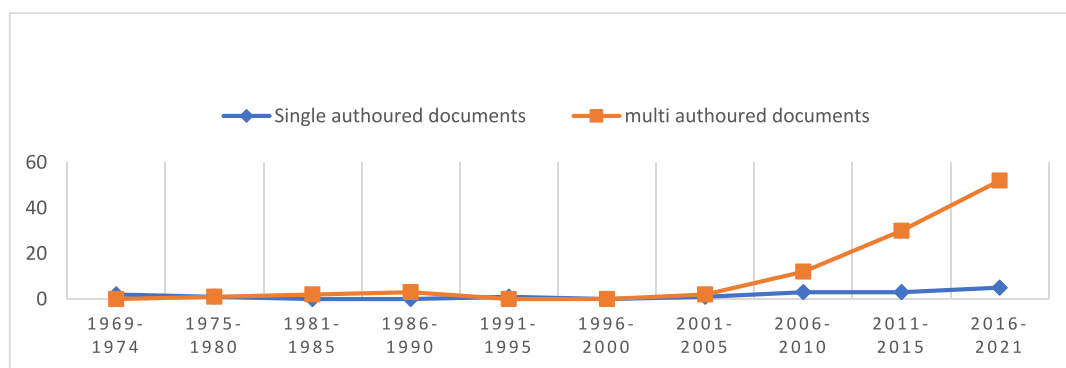


FIGURE 12 Progression of authors' collaboration.

4.4 | Effective use of keywords

Taking keywords as a unit of analysis revealed that salinity, nitrate, and pH were the three authors' keywords associated with water quality in a specific sense among the publications in the study (Figures 10 and 11). Water quality, water quality parameters, and water quality index are three other quality-related keywords used in a generic sense.

Keywords that co-occurred in Figure 10 were groundwater as the main one along with salinity, nitrate, coliforms as the usual contaminants, and Chunnakam aquifer and arsenic as less prominent but critical factors in the contamination narrative pertaining to the North. Chunnakam refers to the most prominent of the three aquifers noted to be present in the Jaffna peninsula and one that experienced a noticeable level of waste oil contamination in 2015 creating controversy in the province. Despite minimal attention the case received from the research community, it entered the keywords list to be noted for its co-occurrence in this study.

A synthesis of what is presented in Figures 10 and 11 along with the next set of keywords not expressed in Figure 11 showed that contamination of water arising from sources external to the aquifers particularly through human activities has been the dominant theme of majority of research conducted in the NP. This corresponds well with evidence from water quality research in India reported by Nishy and Saroja (2018).

Keywords Plus as an improved and a more efficient way to study literature has been in use in recent times. Zhang et al. (2016) referred to Keywords Plus as a pioneering option for making greater use of cited references in bibliographic records. These words are inherently generic and useful across disciplines.

We chose to examine the author's keywords and Keywords Plus generated keywords in the 22 indexed articles in our total collection of the 118 articles gathered. This revealed 62 author's keywords as opposed to 289 Keywords Plus. A close examination of the two sets of keywords indicates that authors tend to be parsimonious and perhaps inconsistent when choosing keywords.

The usefulness of Keywords Plus in this kind of research remains to be explored. If undertaking a systematic review of literature is one of the objectives of developing a repository as in our case, it is clear that more publications should aspire to enter the indexed journal category of publications and Keywords Plus would be a widely useful way to scan publications than relying solely on authors' selection of keywords. It should be mentioned here that as many as 32 of the 118 publications included in this study did not carry any author's keywords at all.

In order to position water-related publications arising from research carried out in the NP in relation to water research publications from the whole of Sri Lanka, we reached out the records from two global sources, namely, UNU-INWEH Report (Mehmood, 2019) and SCImago Journal and Country Rank portal. These are summarized in Table 5. While the present study restricted itself to publications on water quality and pertaining to the NP alone, the two global studies considered here claim to have included all water research, through adopting the words “water science and technology” in the case of SCImago Journal and Country Rank portal, and the words “water research” in the case of UNU-INWEH Report. Though both global studies have drawn Sri Lankan publications from the same Scopus database, the corresponding numbers for Sri Lankan water publications in the 2012–2017 period appear substantially different from each other. Despite these differences, the publication trend for Sri Lanka shows consistent growth while water quality research published in NP stays stable and accounting for only a small fraction of Sri Lanka’s total water-related publications.

Further, two different studies from Sri Lanka, one examining “water research in Sri Lanka” over a period of 52 years (1972–2014) and the other covering “water resource management research” over the 29 years (1990–2019), were published by Navaneethakrishnan and Sivakumar (2015) and Janen and Sivakumar (2020), respectively. Both articles make the observation that a significant number of papers in their studies has been published in the journal titled “Agriculture Water Management.” But we hasten to note that the publications examined in these two analyses would not always be works pertaining to Sri Lanka but included also research carried out in other countries and published by researchers with affiliation to Sri Lankan institutions.

4.5 | Hotspots, gaps, and barriers

Despite a brief period of withdrawal of nitrogenous fertilizer for agricultural production in Sri Lanka during the 2020–2022 growing seasons, accompanied by a general shortage of other agro-chemicals due to the financial crisis, no dramatic change is expected in the levels of chemical use in farming practice. Therefore, the possibility of prolonged agrochemical contamination, nitrate in drinking water in particular, would likely remain as a hotspot in water research in the feature. Likewise, rising concerns for salinity in drinking water, particularly in coastal areas, sewerage-derived microbial contamination of groundwater and the impact of both on human health will also continue to be research hotspots in the NP (Karthiga et al., 2023).

The need for knowledge on new and emerging contaminants such as pharmaceuticals, pesticides and other persistent organic pollutants or POPs is among the new trends in water quality research globally but likely to remain as a gap in the immediate future in the NP. Another gap at present relates to the alarming situation with regard to chronic kidney disease of unknown etiology (CKDu) in the NP. The very large body of literature on CKDu, especially in North Central Sri Lanka, includes significant amount of research seeking causative factors in groundwater. There is only one publication on this topic arising from NP (Gobalarajah et al., 2020). A multidisciplinary approach to research for clues about this disease, specifically connected to water quality in the NP, has to be given high priority in the feature.

In addition to research on water purification undertaken by National Water Supply and Drainage Board at the provincial level, especially in the assessment of filtration systems and quality of prefiltration and postfiltration (Anoja, 2022, 2022a, 2022b), wastewater treatments and recycling research utilizing biological and physical means including the use of biochar are

trends in recent research and development (R&D) at the University of Jaffna (Kannan et al., 2021; Thinojah et al., 2020).

With recent development in the supply side of water and the arrival of new filtration technology, enrollment of new and reliable supply wells for regional provision of water, and the availability of desalinated water under the Jaffna and Kilinochhi Water Supply Scheme, the need for more research on water quality of a monitoring and quality assurance kind is undeniable. Existing form of collaboration between the University of Jaffna and the R&D divisions of the two national Boards responsible for water has resulted in thesis research by undergraduate and graduate students.

While the Water Boards have free access to their comprehensive sets of data, manpower available for them to work with such data is likely to limit their research output in quantity and quality. The practice of charging a fee for access to the data and the lack of flexible funds within the university to pay for the purchase of that data is beginning to appear as a serious barrier to conducting applied and policy-relevant research of significant quality and quantity from university–government collaboration. Some possible ways forward to how these dilemmas could be overcome are taken up in the next section along with some concluding remarks.

5 | CONCLUSIONS

The present study has provided a baseline set of indicators useful for current and future researchers in the NP, thereby contributing to a quantitative narrative on the streams of water quality research in the manner described by Leong (2021). To what extent can the patterns in past research revealed in this study be utilized within the ambitions of a future-oriented project such as WASPAR is an important question for us. If, for example, the water quality research of recent decades discussed here and its systematic review would lead to a narrative that is clear enough and helps reduce uncertainty in the community, then the democratic institutional spaces opened up by a project such as WASPAR would lead to effective water management decisions and the needed water security through human behavior change. However, the evidence from this study so far, and indeed from global reviews, point to the opposite.

When research on water contamination and salination is dominated by too many unconnected, single projects addressing narrow questions and leading to publications addressing discreet research questions, knowledge from such research without any synthesis leads not only to wasteful repetition but also towards a narrative of fear. The UN University's Report on global water research refers to the disconnect between the rising number of water publications and impact of those publications measured via citations (Mehmood, 2019). The report attributes the lack of cross citations of this increasing number of works to their generally low quality or

TABLE 5 Water research documents reported for Sri Lanka and its NP (2012–2017).

Source	Number of documents					
	2012	2013	2014	2015	2016	2017
Global snapshot	130	137	168	170	196	200
SCImago	38	40	50	52	61	53
Water quality studies for NP	9	6	4	9	11	11

narrow focus, which in turn was seen as a reflection of the pressure on researchers to publish a certain number of papers each year with an emphasis on quantity rather than the quality of the research output.

Therefore, what is called for here in the NP, following this bibliometric study, is an extension of the goodwill and collaboration evident among researchers, towards the conduct of more thematic and transdisciplinary water research programs with a long time horizon, held together by a systemic water governance approach to address region's water issues, coordinated at provincial level and supported by appropriate national and international funding. Researchers should seek publication in established, better known, and index journals dedicated to the water theme and pay more attention to choice of keywords both of which would intern lead to greater impacts from their publications. What has been demonstrated via the WASPAR project to date is the role universities of the region have in leading the way in such research programs while being "honest brokers" bridging the multiple institutions and engaging a concerned public.

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