Environ Monit Assess (2018) 190: 225
https://doi.org/10.1007/s10661-018-6601-y

A scientometric examination of the water quality research in India

P. Nishy · **Renuka Saroja**

Received: 5 April 2017 / Accepted: 7 March 2018 / Published online: 16 March 2018

Abstract Water quality has emerged as a fast-developing research area. Regular assessment of research activity is necessary for the successful R&D promotion. Water quality research work carried out in different countries increased over the years, and the USA ranked first in productivity while India stands in the seventh position in quantity and occupies the ninth position in quality of the research output. India observes a steady growth in the water quality research. Four thousand six hundred sixteen articles from India assessed from the aspect of citations received distributions of source countries, institutes, journals, impact factor, words in the title, author keywords. The qualitative and quantitative analysis identifies the contributions of the major institutions involved in research. Much of the country's water quality research is carried out by universities, public research institutions and science councils, whereas the contribution from Ministry of water resources not so significant. A considerable portion of Indian research is communicated through foreign journals, and the most active one is *Environmental Monitoring and Assessment* journal. Twenty-one percent of work is reported in journals published from India and around 7% ages in open access journals. The study highlights that international collaborative research resulted in high-quality papers. The authors meticulously analyse the published research works to gain a deeper understanding of focus areas through word cluster analyses on title words and keywords. When many papers deal with 'contamination', 'assessment' and 'treatment', enough studies done on 'water quality index', 'toxicity', considerable work is carried out in environmental, agricultural, industrial and health problems related to water quality. This detailed scientometric study from 1,09,766 research works from SCI-E during 1986–2015 plots the trends and identifies research hotspots for the benefit to scientists in the subject area. This study comprehends the magnitude of water quality research also establishes future research directions using various scientometric indicators.

Keywords Water quality · Water contamination · Water pollution · India · Scientometrics · Relative citation impact · Relative activity index · eXergy

P. Nishy (✉) · R. Saroja
CSIR National Institute for Interdisciplinary Science and Technology, Thiruvananthapuram 695 019 Kerala, India
e-mail: nishy@niist.res.in

R. Saroja
e-mail: renukasaroja@gmail.com

Introduction

Clean water is a basic necessity for a healthy and prosperous world. The general goal of water quality regulations is to protect and maintain thriving aquatic ecosystems and the resources in an economically and socially sound manner. The United Nations Millennium Development Goals (MDGs) considered the quality of drinking water as a major factor in achieving and ensuring the environmental sustainability. Protecting and managing this natural resource for the betterment of present life and conserving it for the benefit of future generations is a shared responsibility of all. The overall growth of humankind immensely depends on the quality of water and conservation of water resources as it adds to ecosystems, human health, socio-economic growth and sustainable development. Natural flowing water has an excellent property of sustaining different forms of life.

In India, the Ministry of Water Resources, River Development & Ganga Rejuvenation is the apex body for formulation and administration of rules, regulations and laws relating to the water resources. This ministry is formed in 1985 as the Ministry of Water Resources following the bifurcation of the Ministry of Irrigation and Power. In 2014, it was renamed as “Ministry of Water Resources, River Development & Ganga Rejuvenation”, with additional works related to National Mission for Clean Ganga. Presently, the Ministry has two attached offices—Central Water Commission and Central Soil & Materials Research Station. Additionally, there are many subordinate offices such as Central Ground Water Board, Central Water & Power Research Station, Bansagar Control Board, Sardar Sarovar Construction Advisory Committee, Ganga Flood Control Commission, Farakka Barrage Project and Upper Yamuna River Board. Narmada Control Authority, Tungabhadra Board, Betwa River Board, Brahmaputra Board, Godavari River Management Board, Krishna River Management Board are the Statutory Bodies of the Ministry. The Registered Societies, Autonomous bodies and public sector undertakings such as National Water Development Agency, National Institute of Hydrology, North Eastern Regional Institute of Water and Land Management (NERIWALM), National Projects Construction Corporation Limited, Water & Power Consultancy Services Limited (WAPCOS Ltd.) are also associated with the Ministry. These organisations are formed to promote integrated water management, which is vital for poverty reduction, environmental sustenance and sustainable economic development and management by using state-of-art technology, competency and by coordinating all stakeholders. National Water Policy envisages that the water resources of the country are developed and managed in an integrated manner (“Ministry of Water Resources, Government of India,” n.d.).

More than 80% of freshwater resources is consumed for agriculture in India. The roots of water pollution are many, but we have now come to a consensus that the anthropogenic input to the problem is of unprecedented nature. Whether it be sewage, mining, solid waste or natural disaster, water quality has been subject to much stress. According to statistics, in India, 19 states are affected by fluoride, seven states by arsenic, 16 states by nitrate, eight states by salinity ingress, and four states by inland salinity (TIFAC 2015). These issues can be understood and worked upon through a shared vision and integrated approach. ‘Technology Vision 2035’—a document released by TIFAC (Technology Information, Forecasting and Assessment Council, India), project water quality as a significant area and looking for technologies on water purification based on in-situ treatment, biomimetic, novel materials and ultra-sound. Other focus areas are recycling and reuse technologies for zero discharge, ground penetration radar to detect groundwater surface and water contamination. The document forecasts of the future area of research in water quality are the development of water positive materials for water purification, a new generation of RO membranes like graphene that works by chemical engineering and relies less on energy to push water molecules across them (TIFAC 2015).

Scientometrics is used to investigate qualitative and quantitative characteristics of published information to discover the development and progress of any research field. Scientometrics is the application of the bibliometric techniques to science and examining the development of the sciences (Diodato 1994). Bibliometric indicators attempt to measure the quantity and qualitative impact of scientific publications as a proxy for the published research based on a count of scientific papers and the citations they receive. Bibliometric indicators have been widely used to measure the scientific capacity and linkages to world science, both in developed and developing countries. The study represents the scientometric analysis to measure the qualitative and quantitative aspects of water quality research in India.

Literature review

Wang, Li and Ho bibliometrically analysed the research articles reported water resources journals during 1993 to 2008 for many aspects, including countries, institutes and compared on H-index. Research trends investigated using words in the title of the research work, author keywords, and KeyWords Plus (the keywords assigned by the database Web of Science). They found that researchers paid most attention to quality parameters related to groundwater. Modelling and adsorption were the most popular techniques adopted in water resources research. India holds the eighth rank in terms of papers on water resource studies (Wang et al. 2011). Drinking water research during 1992–2011 studied by Fu, Wang and Ho and they realised that *Water Research*, *Environmental Science & Technology* and *Journal-American Water Works Association* were the three most common journals publishing research on drinking water. Disinfection process and consequent disinfection by-products attracted much attention related to drinking water, water treatment methods and water contaminants. Their analysis showed that ozonation and chlorination in disinfection and adsorption were the techniques discussed many times. The most concerned drinking water contaminants were arsenic, nitrate, fluoride, lead and cadmium. Their study could see that India is standing the sixth position among the most productive countries in the field of drinking water research (Fu et al. 2013).

Yuh-Shan Ho of Peking University analysed biosorption technology in water treatment research from 1991 to 2004 using bibliometric parameters. India occupied the third position among the most productive countries in water treatment research while the USA and Canada occupied the first and second position (Yuh-Shan 2008). In South Africa, much of the water research is carried out under the auspices of the Water Research Commission (WRC), a national public entity established by the Water Research Act (Act No. 34 of 1971). The study found that the water research and development community is small but highly productive. The analysis showed that the South African contribution to the global share of water-related papers in journals indexed by the ISI is more than three times the average for all disciplines in the country (Jacobs et al. 2014). The '*Journal of Chemical Technology and Biotechnology*' is identified as the leading journal followed by '*Journal of Hazardous Materials and Water Research*', in a bibliometric analysis of 24,447 industrial wastewater treatment research from 1991 to 2014. India and the Chinese Academy of Sciences were the most productive country and institution, respectively, while the USA was the most internationally collaborative country and had the highest h-index (82) of all nations (Zheng et al. 2015). Research of phosphorus in eutrophic lakes was assessed from the perspective of bibliometric analysis from 1900 to 2013 (Gao et al. 2015) mainly using frequency calculation, co-occurrence analysis, correlation analysis and spatial mapping and concluded that China has replaced the USA in terms of quantity of publications since 2011, whereas the USA ranks high while considering both quantity and quality together.

The patent activity in water pollution and water treatment of China (1985–2007) is compared with the patent data of South Korea, Brazil and India over the same periods (Yuan et al. 2010). China has had a remarkable period of rapid growth in patents filed on water pollution and treatment from this study of 169,312 patents collected from Derwent World Patents Index. China's local governments aim to improve their regional S&T capability and provide support to the National Water Pollution Control and Treatment Project in China. Another bibliometric study (Navaneethakrishnan and Sivakumar 2015) on the water research output of Sri Lanka based on SCOPUS database during the year 1972–2014 analysed 1026 publications contributed by 2254 authors. The study showed that the 50% of papers emerged during the period 1972–2006, whereas the most productive year was 2007 with 107 articles. Multiple-authored contributions hold the top position (87.3%) in quantity, and the average degree of collaboration was 0.83 during the study span.

We could not find any study analysing the output of water quality research done in India. This study is unique on the Indian research output related to water quality and treatment during the period 1986–2015.

Methodology

The core data collected for this study from Web of Science (WoS) Core Collection during 1986 to 2015. The following search query used for identifying the research papers on water quality, contamination and pollution.

TOPIC: (Water NEAR/3 (Quali OR Contam* OR Pollu*)) AND Timespan: (1986–2015)*

Indexes: SCI-EXPANDED, CPCI-S, CPCI-SSH, CCR-EXPANDED, IC.

The papers with at least one author from India are retrieved from the database on the below query:

TOPIC: (Water NEAR/3 (Quali OR Contam* OR Pollu*)) AND ADDRESS: India AND Timespan: (1986–2015)*

Indexes: SCI-EXPANDED, CPCI-S, CPCI-SSH, CCR-EXPANDED, IC.

Objectives of the study

1) To evaluate the water quality research happening on around the globe on quantity and quality parameters
2) To plot the trend of water quality research from India on quantity and quality parameters
3) To identify and compare the Indian research organisations engaged in water quality research
4) To study the collaborative research happening in the domain from India
5) To understand the research trends and the hotspot in water quality studies by Indian authors

Indicators used

When the quantity of research indicated as the number of papers published (P) and quality as the number of citations (C), the impact of research measured as citations received per paper ($i = C \div P$). Apart from these basic parameters, following four indicators are used to analyse the research output in the field of water quality research.

1) Relative activity index (RAI)

   The relative activity index indicates whether a unit is more or less active in a selected subdomain than the rest of the world. The number of a unit's publication in a particular subdomain is divided by the total number of publications from that unit. The whole worlds' publications in the same subdomain are divided by total publications of the world. The share of the unit's publications in the subdomain is divided by the share of the world's publications. The research activity on different time periods on different countries/institutions/ subjects can be normalised by using the methodology of Price and Schubert & Braun.

$$\mathrm{RAI}_{ift} = \frac{P_{ift}}{P_{it}} \Big/ \frac{P_{ft}}{P_t}$$

   where 'P' is the number of papers, 'i' is the data limited to the papers authored by that institution/ country, 'f' is the data for a particular field and 't' is the data for a particular year.

2) Relative citation impact (RCI)

   The citation impact for a unit is calculated by the number of citations per paper that unit has received over a certain period. The citation rates depend on the research fields and time periods. A relative citation impact can be calculated for any unit and compared to an appropriate baseline.

$$\mathrm{RCI}_{ift} = \frac{C_{ift}}{P_{ift}} \Big/ \frac{C_{ft}}{P_{ft}}$$

   where 'C' is the number of citations, and 'P' is the number of papers. 'i' is the data limited to the papers authored by that institution, 'f' is the data for a particular field and 't' is the data for a given year. The RCI for the world is always 1.00 for any field. The RCI value greater than 1.00 indicates performance above the world average and a value less than 1.00 shows poor performance compared to the world average for any unit for any field.

3) eXergy (X)

   Exergy, X, is the second-order energy-like term obtained from the product of impact (i = C/P, which is a quality term) and citations, C (a term that has both quality and quantity attributes). If P is the number of papers and C the number of citations, the eXergy value is computed as $X = (C/P) \times C$ and is arguably the best single scalar indicator of scientific effort (Prathap 2011).

4) Quartile ranking

   Based on impact factor (IF) data, the Journal Citation Reports provides yearly rankings of journals, in the subject categories relevant for the journal (in fact, there may be more than one). Quartile rankings derived for each journal in each of its subject categories according to which quartile of the IF distribution the journal occupies for that subject category. Quartiles are defined as the following:

X The journal rank in category according to Journal Impact Factor,
Y The number of journals in the category,
Z Percentile rank (X/Y).

Quartile score Q1: $0.0 < Z \leq 0.25$; Q2: $0.25 < Z \leq 0.5$; Q3: $0.5 < Z \leq 0.75$ and Q4: $0.75 < Z$.

Which means Q1 denotes the top 25% of the IF distribution, Q2 for the middle-high position (between top 50% and top 25%), Q3 middle-low position (top 75% to top 50%) and Q4 the lowest position (bottom 25% of IF distribution).("Rank," n.d.)

Results and discussions

World contribution on water quality research

During the study period, Science Citation Index–Expanded (SCI-E) reflects 109,766 papers from nearly 206 countries around the world on water quality research indicate the importance of this research field. Authors from the USA contributed 27.89% papers to receive 30.35% of citations, while the Peoples Republic of China stands the second position with 11.11% papers followed by Canada (5.27%), England (4.71%), Germany (4.41%), Australia (4.34%) and India (4.21%) (Table 1).

From the top ranked five countries namely the USA, Canada, England, Australia and Spain have higher research impact than the world average. Article from England shows highest quality with an average impact of 23.17 followed by Canada (20.49), the USA (20.36), Australia (20.03), Spain (18.86), France (18.5), Germany (18.1), Japan (12.71) and India (11.93). China stands at the bottom of the list in terms of quality with an average impact of 8.64. When we combine both the quantity (Papers) and quality (Impact) in eXergy term, the best-performed country is the USA followed by England, Canada, Australia, Germany, Spain, France, China, India and Japan.

Indian water quality research output in the global context

The first Indian water quality research reported in 1972 from College of Agriculture, Gwalior, on 'quality of well-waters of Northern Madhya Pradesh' (Somavanshi and Sinha 1972). The article published in 1980 in *Journal of the American Leather Chemists Association* on 'water pollution by tannery effluent' by authors from CSIR-CLRI can be considered as the first research paper on water pollution from Industry (Ramaswamy and Krishnamurthy 1980). Eighty-nine articles were published during 1972 to 1985 on contamination of irrigation water in reputed journals in the field of Agriculture, Soil Science, Plant Science, Agronomy, etc. Persistent growth of water quality research is noticed since 1986; hence, we are analysing publications from 1986 to comprehend the trends of 30 years of research happening in India on water quality.

Table 2 indicates that the yearly research productivity increased from 12 to 487 papers during 1986 to 2015 and the rapid increase is from the year 2001. Relative activity index of 1 indicates that the country's research activity in the given field corresponds to the world average; an indicator larger than 1 reflects higher emphasis than average in the field and vice versa. The RAI is higher than one in many years indicating higher performance of the country compared to the world average, while the average RCI is 0.63 during this period showing the quality of the Indian research is inferior to that of the world average. India adopted a 'National Water Policy' in 2002, which is revised and released as 'National Water Policy' -2012' during the India Water Week in 2013. The National Action Plan on Climate Change (NAPCC) launched in 2008 envisages the approach to be adopted to meet the challenges of the impact of climate change through eight national missions including National Water Mission (NWM) (Ministry of Water Resources 2012). We can surmise that these policies and missions have influenced

Table 1 World contribution on water quality research

Country	Papers P %	Citations C %	Impact $i = C \div P$	RCI	eXergy $X = i \times C$
1. USA	27.89	30.35	20.36	1.09	12,694,541
2. China	11.12	5.13	8.64	0.46	910,535
3. Canada	5.30	5.81	20.49	1.09	2,443,719
4. England	4.71	5.83	23.17	1.24	2,773,495
5. Germany	4.41	4.26	18.10	0.97	1,584,564
6. Australia	4.34	4.64	20.03	1.07	1,909,540
7. India	4.21	2.67	11.90	0.63	653,947
8. France	3.79	3.75	18.50	0.99	1,423,519
9. Spain	3.66	3.69	18.86	1.01	1,429,927
10. Japan	3.10	2.11	12.71	0.68	549,605
Others	44.39	31.67	28.81	0.71	18,743,497

Table 2 Growth of water quality research output from India during 1986–2015

Year	Papers *P* (%)	RAI	Authors per paper	References per paper	Citations per paper	RCI
1986 to 2000	652 (14.1)		2.95	18.57	14.31	1.20
2001	88 (1.90)	1.6	3.09	24.81	16.67	1.40
2002	86 (1.86)	1.41	3.42	24.31	22.07	1.85
2003	121 (2.62)	1.77	3.84	30.04	23.31	1.96
2004	118 (2.55)	1.59	3.18	27.28	26.81	2.25
2005	161 (3.48)	1.83	3.53	33.40	30.19	2.54
2006	204 (4.41)	1.94	3.44	33.71	27.21	2.29
2007	233 (5.04)	1.79	3.64	30.39	18.78	1.58
2008	280 (6.06)	1.8	3.48	34.37	15.55	1.31
2009	289 (6.26)	1.57	3.39	40.82	14.91	1.25
2010	333 (7.21)	1.74	3.58	37.83	10.54	0.89
2011	341 (7.38)	1.52	3.67	40.30	10.02	0.84
2012	372 (8.05)	1.48	3.73	42.42	6.89	0.58
2013	414 (8.96)	1.36	3.93	42.70	4.10	0.34
2014	437 (9.46)	1.36	4.10	47.37	2.89	0.24
2015	487 (10.55)	1.5	4.19	50.05	0.75	0.06
1986 to 2015	4616	1.62	3.62	36.58	11.90	0.63

the research in water quality positively resulted in a noticeable increase in publication numbers from 2003 onwards. During 2001to 2015, the RAI of Indian water quality research is 1.6, which shows that the country's research activity in water quality is very much higher than the world average. The 4616 papers on water quality research by Indian authors were communicated in different viewable forms such as research articles (86.3%), conference proceedings (9.21%), review articles (5.5%) and other documents like editorial materials, meeting abstracts, notes, letters, book chapters and news items.

The number of authors increased during the study period. One fourth of research papers reported as collaborative work of two authors and an equal amount is the outcome of research from three authors. Though the average number of authors is 3.6, about 90 papers are having more than ten authors and one review article on 'GCIP water and energy budget synthesis (WEBS)'(Roads et al. 2003) is contributed by 32 authors. The references cited per article are increased from an average of 6 to 50 from the year 1986 to 2015. The review articles have an average of 141 references while others have an average of 30 references.

During the period, 5.86% (6438) water quality research communicated in open access (OA) journals from around the globe while the percentage contribution of Indian researchers is little higher than seven. First Indian research communicated through OA journals is a study note on 'Enhanced reproductive potential of neochetina-bruchi hostache fed on water hyacinth plants from polluted water bodies' by researchers from CSIR-IICT appeared 1988 in *Current Science* journal (Jamil and Jyothi 1988). After 2 years, a full article from Pt. Ravishankar Shukla University on 'Alum plant waste-application in treatment of Fluoride polluted water' published in journal *Fluoride* (Nair et al. 1990). By 2015, a total of 338 (7.32%) research works were disseminated through open access journals. It is observed that the significant share open access articles are communicated in *Currrent Science*, followed by *E-Journal of Chemistry, Journal of Earth System Science, Indian Journal of Medical Research and African Journal of Biotechnology.* It is interesting to note that the impact of research published in open access journals is 9.55, vis-a-vis to the overall impact of 11.9.

Water quality research reported in a wide range of 920 journals and more than 80% of them hold only five or less articles each. Table 3 shows the top 15 productive journals, accounting for approximately 30% of the research output. It is found that the *Journal Environmental Monitoring and*

Table 3 Journal-wise distribution of publications related to Indian water quality research

Journal	Impact factor	Quartile ranking	Papers P (%)	Impact $i = C \div P$
1. Environmental Monitoring and Assessment	1.633	Q2	6.96	8.68
2. Environmental Earth Sciences	1.765	Q1	3.57	10.26
3. Journal of Environmental Biology	0.529	Q3	3.36	4.78
4. Current Science	0.967	Q1	2.23	11.02
5. Journal of Hazardous Materials	4.836	Q1	1.86	37.80
6. Asian Journal of Chemistry	0.355	Q4	1.83	0.69
7. Journal of the Geological Society of India	0.547	Q3	1.53	4.63
8. Desalination	4.412	Q1	1.13	14.50
9. Water Science and Technology	1.064	Q2	1.11	5.70
10. Environmental Science and Pollution Research	2.76	Q1	1.08	5.11
11. Indian Journal of Marine Sciences	0.294	Q4	1.08	4.83
12. Science of the Total Environment	3.976	Q1	1.01	16.74
13. Water Air and Soil Pollution	1.551	Q2	0.96	12.02
14. Journal of the Indian Chemical Society	0.145	Q4	0.94	1.05
15. Arabian Journal f Geosciences	1.224	Q2	0.89	4.53

Assessment published the highest number of papers (295), *Environmental Earth Sciences* ranked second with 152 articles (3.57%) while *Journal of Environmental Biology* occupies the third position with 142 articles (3.35%). When quartile ranking of these journals considered, we could see that more than 42% journals are in the Q1 category, 31.63% in Q2, 16% in Q3 and less than 10% of the Q4 category. Indian authors published in high-quality journals in the field, i.e. more than 38% of the papers published in Q1 journals, 32% in Q2 journals, 16% in Q3 journals and only 8% articles are in Q4 category journals. One article on 'Role of metal-reducing bacteria in arsenic release from Bengal delta sediments?' published in the high impact factor journal, *Nature* and the paper cited 517 times (Islam et al. 2004). Some other top impact factor journals preferred by Indian authors are *PLOS Medicine, Trends in Biotechnology* and *Hepatology*. All of the papers published in top impact factor journals are on health hazards due to contamination of drinking water, and these well-cited works are the outcome of international collaboration work. Nine percentage researches are disseminated through journals having no impact factor, and these works received an average of 2.83 citations.

Around 21% of the papers from Indian authors are in Indian journals; the average impact of these papers reported in Indian Journals (3.87) is less compared to that of papers in foreign journals (14) similar to the trend observed in chemistry field (Nishy et al. 2011). The Indian journals published water quality research are *Journal of Environmental Biology*, *Current Science*, *Asian Journal of Chemistry*, *Journal of the Geological Society of India*, *Indian Journal of Marine Sciences*, *Journal of the Indian Chemical Society*, *Journal of Scientific & Industrial Research*, *Indian Journal of Fisheries*, *E-Journal of Chemistry*, *Research Journal of Chemistry and Environment*, *Indian Journal of Agricultural Sciences*, *National Academy Science Letters-India* and the *Indian Journal of Chemical Technology*.

International collaboration

From multi-authored papers, collaboration countries were estimated by the affiliation of each author. Papers with authors from different countries are considered as the output of international collaboration. Collaborative research is more effective than the single country's research based on the knowledge of the country and the available infrastructure, etc. India is collaborating with more than 85 countries for 791 international collaborative papers. Out of these, 366 papers are with first or corresponding authors from India, which can be considered as the research originated from India. The foremost research collaborators are from the USA (23%), Germany (9.5%), South Korea (8.3%), England (8.3%), Japan (6.7%) and Australia (6%). Although single-country articles still dominate in the water quality research, international collaboration is becoming increasingly popular (Table 4). The internationally collaborative works on are getting more citations and the average impact of such papers is 17.32, whereas the average impact of papers without collaboration is 10.81 only.

Institutions engaged in water quality research

Research institutions under various ministries and universities are involved in water quality research in India (Table 5). More than half of the published research is from various universities in India. Institutions under CSIR contributed about 14.44% and around the same amount of papers are from higher educational institutions of national importance like IITs, NITs and IISc. When ICAR institutes contributed around 6.79%, the institutes under the Ministry of Water Resources (MoWR) added only 3.10% of the total output. Though universities posted the highest number of research papers, ICMR institutes and IITs are having the highest impact and papers from CSIR and IISc also shows higher impact than that of university papers. The papers from institutions under MoWR are of inferior quality than the country average with RCI of 0.63. Similar is the situation of water quality publications from the institutes under Ministry of Environment & Forest (MoEF), Ministry of Earth Sciences (MoES) and Department of Atomic Energy (DAE).

Research areas, trends and hotspots in water quality research

Indian water quality research papers appeared in various disciplines such as chemistry (17.76%), engineering (14.10%), physics (13.30%) and a few studies are on water resources (0.92%). The OECD Category Classification of the Frascati Manual which first published in 2002 and revised in 2007 (van Steen 2007area, especially about emerging technology fields such as ICT, biotechnology and nanotechnology. The OECD classification hierarchy is broken up into two levels with six major codes and 42 minor codes. The Web of Science scheme comprises approximately 250 subject areas are represented and mapped to one OECD minor category. In OECD classification, data on research performance in a superordinate (major) field incorporate data on research performance insubordinate (minor) areas, however, because of journals overlap between Web of Science (WoS) categories; the figures for the superordinate category of OECD will not necessarily equal to the sum of the subordinate fields. The impact of water quality research during the period 1986–2015 under OECD Categories is given in Table 6.

The 4616 papers from India are distributed in Earth & related environmental sciences (55.3%), chemical sciences (14%), biological sciences (12.5%) and environmental engineering (13.9%). The other main research fields are in health science, agriculture, forestry and fisheries. The impact of the research papers is more in environmental biotechnology (26), civil engineering (20), environmental engineering (19), chemical engineering (18), basic medicine and health science having the same impact (16).

Table 4 International collaborative papers during 1986 to 2015

Period	International collaborative papers		
	Papers P (%)	Citations C (%)	RCI
Upto 2000	41 (6.52)	2271 (24.45)	3.75
2001–05	78 (13.71)	3545 (24.95)	1.82
2006–10	210 (15.72)	4620 (20.91)	1.33
2011–15	462 (22.57)	3268 (35.12)	1.56

Table 5 Indian organisations engaged in water quality research

Organisations	Papers (P)	Citations (C)	Impact $I = C/P$	RCI
1. UNIVs	2472	27,985	11.32	0.95
2. CSIR	665	10,123	15.22	1.28
3. IITs	471	8652	18.37	1.54
4. ICAR	313	2166	6.92	0.58
5. MoWR	143	1119	7.83	0.66
6. NITs	138	837	6.07	0.51
7. ICMR	135	2540	18.81	1.58
8. DAE	98	741	7.56	0.63
9. IISc	68	999	14.69	1.23
10. MoES	67	426	6.36	0.53
11. MoEF	55	431	7.84	0.66
12. DRDO	52	713	13.71	1.15
13. DST	45	449	9.98	0.84
Total	4604	54,905	11.93	

Table 6 Indian water quality research in different disciplines of S & T

Discipline	Papers, P (%)	Citation (C)	Impact $i = C \div P$	eXergy $X = i \times C$
Earth and related environmental sciences	2560 (55.3%)	30,256	12	357,588
Environmental engineering	643 (13.9)	11,930	19	221,345
Environmental biotechnology	205 (4.4)	5387	26	141,560
Chemical sciences	648 (14)	8613	13	114,481
Civil engineering	274 (5.9)	5348	20	104,384
Chemical engineering	294 (6.4)	5292	18	95,256
Basic medicine	286 (6.2)	4703	16	77,336
Biological sciences	578 (12.5)	6357	11	69,916
Health sciences	175 (3.8)	2779	16	44,131
Agriculture, forestry and fisheries	305 (6.6)	2467	8	19,954

Authors express the subject focus of the research through the title of the article briefly to the readers. Further, the authors give appropriate keywords to elaborate the subject of study. Hence an attempt is made to statistically analyse the words from the title of the articles and author-keywords by grouping similar terms representing the same idea to understand the emphasis of water quality research happening in India. The RCI and eXergy of papers calculated for understanding the predominant area. The synthesised analysis of words in titles and keywords has proved to be a helpful method for revealing the research hotspots and discovering scientific research trends (Fu et al. 2013; Chiu and Ho 2007; Xie et al. 2008). In Table 7, the words are ordered and grouped to represent the central theme for easy understanding of the concept. The rankings of these words within the cluster is according to their eXergy were considered for providing valuable clues for the characteristics of hot issues.

The Safe Drinking Water Act (SDWA) defines 'contaminant' as any physical, chemical, biological or radiological substance or matter in water. Drinking water may reasonably be expected to contain at least small amounts of some contaminants. Some contaminants may be harmful if consumed at certain levels in drinking water. The presence of contaminants does not necessarily indicate that the water poses a health risk (US EPA 2004). From the analysis, it is seen that more than 33% of the research dealt with the contamination of water, and such papers got an average impact of 13.69. A review article in this category on 'Chromium toxicity in plants' reported in *Environment International* in 2005 by the collaborative efforts of researchers from Tamil Nadu Agricultural University, Universidad Michoacana and Universidad Nacional Autónoma de México have received more than 525 citations (Shanker et al. 2005). When 'contamination assessment' is addressed by 15.38% of papers, 'contamination removal' is discussed in 8. 12%. However, the papers on contamination removal got more citations (21.07) than that of assessment (9.50). Another collaborative research from University of the UAE, the University of Ulster and CCS Haryana Agricultural University (Banat et al. 1996) on 'Microbial decolourization of textile-dye-containing effluents: A review' published in *Bioresource Technology* in 1996 received 844 citations.

More than 7% of papers studied the environmental issues to receive an average impact of 8.95, whereas the average impact of 5% industrial water quality papers is 7.95. The 9% papers dealt with the water quality issues related to Agriculture received an average impact of 11.24. While 19% are research conducted on various water bodies, most studies were done on rivers (10.85%) wherein 2.95% were on river Ganga.

Research conducted on the effect of water pollution on human health (6.87%) could make an impact of 18.56 when studies on various diseases (4.16%) received the highest impact (20.68). The 2% papers relevant to food received citations to make an average impact of 10.74. Specific research on water pollution health effects on human organs such as the liver, the kidney, the bladder and the lung made the highest impact (29.02). Implications of oxidative stress caused by chronic exposure to excessive levels of arsenic toxicity in drinking water initially discussed in 2005 (Das et al. 2005); thereafter, research on this problem (2.6%) conducted intensely to make an average impact of 22.21.

Table 7 Research topics of Indian authors on water quality research

Keywords	Papers P %	Impact $i = C \div P$	Exergy $X = i \times C$
Contamination	33.69	13.69	291,488
Removal/reduce	11.66	19.16	197,232
Assessment/evaluation/measurement	15.38	9.50	64,097
Agriculture	9.47	11.24	55,235
Environmental	7.19	8.95	26,623
Industrial	4.64	7.95	13,521
Health	6.87	18.56	109,142
Diseases	4.16	20.68	82,088
Food	1.88	10.74	10,027
Water quality index	21.34	15.41	233,757
Organic chemicals	3.12	19.50	54,756
Total hardness	2.34	11.90	15,289
Disinfectants	1.88	12.37	13,308
Total solids	3.18	7.34	7920
Total coliform	2.17	7.31	5344
Biochemical oxygen demand/chemical oxygen demand (BOD-COD)	1.41	7.68	3831
Dissolved oxygen	0.58	8.22	1825
Radionuclides	0.76	6.51	1485
Water bodies	18.87	8.88	68,691
Rivers	10.85	11.27	63,627
Ganga	2.95	10.63	15,374
Yamuna	0.97	5.93	1584
Sea/ocean	1.88	8.76	6674
Estuary	1.82	8.06	5456
Lake	2.84	5.98	4692
Well	1.26	6.78	2663
Pond	1.58	3.97	1152
Stream	0.95	4.45	873
Toxic heavy metals	22.31	20.60	437,091
Toxicity	24.78	19.52	435,903
Arsenic	7.69	25.75	235,323
Chromium	2.08	26.58	67,841
Mercury	1.19	23.56	30,538
Lead	1.58	14.11	14,533
Cadmium	1.52	12.49	10,913
Nickel	0.54	9.00	2025
Treatment method	12.74	18.14	193,512
Adsorption	6.35	23.45	161,128
Chlorination	0.56	15.85	6529

The Heavy Metal Pollution Index (HPI) has been studied to assess the extent of pollution and portability of water during pre- and post-rainy seasons in almost all rivers of the country independently by various researchers. These scientific investigations paid more attention to toxicity (24.78%), toxic heavy metals (22.31%) and contaminants including arsenic (7.69%), chromium (2.08%), mercury (1.19%), lead (1.58%),

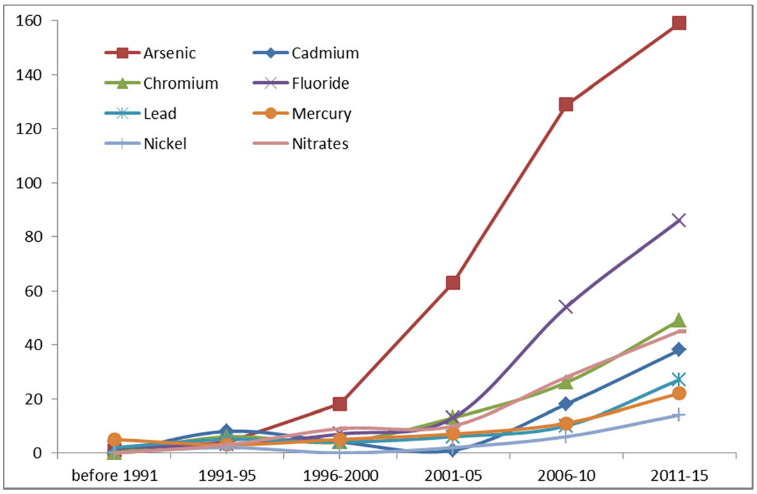

Fig. 1 Toxicity in water as seen in research papers from India

cadmium (1.52%) and nickel (0.54%). These works discussed profoundly among researchers to get an average impact of 20.60. The first Indian study on toxic metal lead communicated in 1987 (Haque, 1987) and a paper on mercury in 1980 (Mahajan & Juneja, 1980), whereas the first paper on arsenic appeared in 1990 (Cherian et al. 1990). The first research on cadmium published in 1992 (Iyer and Sarin 1992) and on nickel in 1993 (Srikanth et al. 1993) only. The research papers on these issues are constantly increased from one paper in 1987 to 120 papers in 2015. The spectrophotometric extraction method for the determining of arsenic in water is discussed in 1990 (Cherian et al. 1990). Arsenic contamination in West Bengal region, effects of arsenic-contaminated water on health issues like arsenicosis, skin lesions, kala-azar and methods of removing arsenic are the topics that are mostly discussed by Indian researchers. Studies conducted in Agra, Allahabad, Tamil Nadu West Bengal region on fluoride contamination; researchers concentrated on determination and defluoridation methods too. Lead and cadmium determination and removal method are studies on wastewater. A large number of papers discussed the effects of mercury contamination in aqua plants and animals (Fig. 1).

Many papers examined the effects of these toxic elements and other contaminants on food and health. Moreover, health issues have been discussed in 6.87% of papers while 4.16% papers discussed various diseases related to water quality and such papers have an average impact more than 20. The 'water quality index' based on contaminants addressed in 21% of research works and these works examined organic chemicals, total hardness, total solids, total coliform, biochemical oxygen

Table 8 Abbreviations used

Abbreviation	Expansion
c	Number of citations received for a publications
CCR	Current Chemical Reactions
CPCI	Conference Proceedings Citation Index
CPCI-SSH	Conference Proceedings Citation Index- Social Science & Humanities
CSIR	The Council of Scientific and Industrial Research, India
DAE	The Department of Atomic Energy, India
DRDO	The Defence Research and Development Organisation, India
DST	Department of Science and Technology, India
i	Impact, i.e. citations received per paper
IC	Index Chemicus
ICAR	The Indian Council of Agricultural Research
ICMR	The Indian Council of Medical Research
IISc	Indian Institute of Science
IITs	The Indian Institutes of Technology
MoEF	Ministry of Environment, Forest and Climate Change, India
MoES	Ministry of Earth Sciences, India
MoWR	The Ministry of Water Resources, India
NITs	The National Institutes of Technology, India
OA	Open access
P	Papers published
RAI	Relative activity index
RCI	Relative citation impact
SCI	Science Citation Index
UNIVs	Indian universities
WoS	Web of Science
X	eXergy

demand, chemical oxygen demand, dissolved oxygen, radionuclides, etc. to captivate a good number of citations with an average impact of 15.41.

Conclusion

Millions of people are suffering from waterborne diseases caused by drinking contaminated, dirty water every year. The scarcity of potable water will affect more people unless we efficiently use this limited resource. Hence, research on water quality is essential and vital for the survival of mankind. We have seen researchers from all parts of the world are engaged in water quality research; the USA, Peoples R China and Canada are the three most important countries reported the highest number of papers when India occupies the seventh position. Research works by authors from the USA, Canada, England, Australia and Spain are of higher impact than the world average whereas papers by Indian authors could make a lesser impact than the global average (RCI 0.63). The research activity in water quality increased in India after adopting National Water Policy in 2002; the RAI in Indian water quality research reached 1.6 during 2001–2015 indicating a much higher activity than the world average. More than half of the papers are from various universities in India; however, these papers could not attract many citations from researchers in the field. Institutions under CSIR published 14.44% and around the same amount of papers are from higher educational institutions of national importance like IITs, NITs and IISc. When ICAR institutes contributed around 6.79%, the institutes under Ministry of water resources produced only 3.10% papers. The highly cited papers are from ICMR institutes, and IITs and publications from CSIR and IISc also show higher impacts than that of University publications. The papers from institutes under MoWR received lesser citations than the country average with an RCI of only 0.63. Similarly, research published by the institutes under MoEF, MoES and MoAE could not make much impact in the field of water quality.

The majority (88%) of water quality research from Indian institutes are communicated through journals published from outside India. Indian authors published more than seven percentage papers in open access journals. India researchers published a few international collaborative articles (17%); however, these collaborative research papers received more citations to make an average impact of 17.32 vis-a-vis to average impact of 10.81 for non-collaborative papers. The USA, Germany, South Korea, England, Japan and Australia are the major collaborating countries in water quality research. A study from Ulster University North Ireland and Haryana Agricultural university India on ‘Microbial decolorization of textile-dye-containing effluents’ reported in *Bioresource Technology* (Banat et al. 1996) is the highest cited one followed by an article on ‘Role of metal-reducing bacteria in arsenic release from Bengal delta sediments’ from Univ Manchester England, SERC Daresbury Lab England and Univ Kalyani India (Islam et al. 2004).

Water quality researches conducted were in fields of environmental biotechnology, civil engineering, environmental engineering and chemical engineering. Papers discussed the issues related to basic medicine, and health sciences made the highest quality impact. Indian researchers published more on chemical indicators, water pollution and heavy metals. Papers on oxidative stress, toxicity, adsorption, factor analysis, arsenic and purification were very impactful. Studies on these toxic contaminations sharply increased since 2000, and it continues to be a favourite research topic. Good quality research papers published on health issues and the influence of contaminated water on various human organs (average impact of 29.02). Problems like food contamination, oxidative stress caused by chronic exposure to excessive levels of arsenic toxicity in drinking water were studied to produce high-quality research papers.

The present study sketched the trends, presented the highlights and identified issues of water quality research from research papers from India. It also provided indicators helpful to researchers as well as policymakers for research assessment and identifying challenges in the subject area (Table 8).

References

Banat, I. M., Nigam, P., Singh, D., & Marchant, R. (1996). Microbial decolorization of textile-dyecontaining effluents: a review. *Bioresource Technology, 58*(3), 217–227. https://doi.org/10.1016/S0960-8524(96)00113-7.

C. G. van Steen, J. (2007). Revised fields of science and technology (FOS) in the Frascati Manual. *Ocde*, (2006), 12. Retrieved from http://www.oecd.org/sti/inno/38235147.pdf

Cherian, L., Raju, J., & Gupta, V. K. (1990). A simple extraction spectrophotometric method for the determination of arsenic in water and environmental-samples. *Journal of the Indian Chemical Society, 67*(6), 500–502.

Chiu, W. T., & Ho, Y. S. (2007). Bibliometric analysis of tsunami research. *Scientometrics, 73*(1), 3–17. https://doi.org/10.1007/s11192-005-1523-1.

Das, S., Santra, A., Lahiri, S., & Mazumder, D. N. G. (2005). Implications of oxidative stress and hepatic cytokine (TNF-alpha and IL-6) response in the pathogenesis of hepatic collagenesis in chronic arsenic toxicity. *Toxicology and Applied Pharmacology, 204*(1), 18–26. https://doi.org/10.1016/j.taap.2004.08.010.

Diodato, V. (1994). *Dictionary of bibliometrics* (2012th edn.). Binghamton: The Haworth Press, Inc.

Fu, H.-Z., Wang, M.-H., & Ho, Y.-S. (2013). Mapping of drinking water research: a bibliometric analysis of research output during 1992-2011. *Science of the Total Environment, 443*, 757–765. https://doi.org/10.1016/j.scitotenv.2012.11.061.

Gao, W., Chen, Y., Liu, Y., & Guo, H. c. (2015). Scientometric analysis of phosphorus research in eutrophic lakes. *Scientometrics, 102*(3), 1951–1964. https://doi.org/10.1007/s11192-014-1500-7.

Haque, M. A. (1987). Contamination of soil, water and vegetation by copper, lead and zinc ore mining and smelting at Khetri and Zawar (India). *Journal of the Geological Society of India, 30*(5), 451–458.

Islam, F., Gault, A., Boothman, C., PIslam, F., Gault, A., Boothman, C., et al. (2004). Role of metal-reducing bacteria in arsenic release from Bengal delta sediments. *Nature, 430*(6995), 68–71.

Iyer, V. N., & Sarin, R. (1992). Chemical speciation and bioavailability of lead and cadmium in an aquatic system polluted by sewage discharges. *Chemical Speciation and Bioavailability, 4*(4), 135–142.

Jacobs, I., Pouris, A., & Naidoo, D. (2014). A scientometric examination of the performance of water research in South Africa. *Water SA, 40*(4), 631–637.

Jamil, K., & Jyothi, K. (1988). Enhanced reproductive potential of neochetina-bruchi hostache fed on water hyacinth plants from polluted water bodies. *Current Scciencce, 57*(4), 195–197 Retrieved from https://apps.webofknowledge.com/full_record.do?product=WOS&search_mode=GeneralSearch&qid=1&SID=E5NvdpqDqiPKHbaMVpJ&page=1&doc=1.

Mahajan, C. J., & Juneja, C. L. (1980). Combined effect of simultaneous mercury pollution of diet and water on the fish Channa - (-ophiocephalus)-punctatus. *Current Science, 49*(18), 715–717.

Ministry of Water Resources, G. of I. (2012). National Water Policy (2012). New Delhi.

Nair, S., Jallan, G., & Pandey, G. (1990). Alum plant waste-application in treatment of Fluoride polluted water. Fluoride, 23(1), 35–236. Retrieved from https://apps.webofknowledge.com/full_record.do?product=WOS&search_mode=GeneralSearch&qid=4&SID=E5NvdpqDqiPKHbaMVpJ&page=1&doc=1

Navaneethakrishnan, S., & Sivakumar, S.. (2015). Bibliometric-analysis-of-water-resource-development-and-utilization-based-research-studies-in-Sri-Lanka. *International Journal of Scientific & Engineering Research*, 6(8), 1432–1439.

Nishy, P., Parvatharajan, P., & Prathap, G. (2011). Where do Indian chemists publish their best research ? *Current Science, 100*(11), 10–11.

Prathap, G. (2011). The Energy–Exergy–Entropy (or EEE) sequences in bibliometric assessment. *Scientometrics, 87*(3), 515–524. https://doi.org/10.1007/s11192-011-0367-0.

Ramaswamy, P., & Krishnamurthy, V. (1980). Water pollution by tannery effluent. *Journal of the American Leather Chemists Association, 75*(6), 200–210.

Rank. (n.d.). Retrieved February 5, 2017, from http://ipscience-help.thomsonreuters.com/incitesLiveJCR/Jallan,GJCRGroup/jcrJournalProfile/jcrJournalProfileRank.html

Roads, J., Lawford, R., Bainto, E., Berbery, E., Chen, S., Fekete, B., et al. (2003). GCIP water and energy budget synthesis (WEBS). *Journal of Geophysical Research -Atmospheres, 108*(D16). https://doi.org/10.1029/2002JD002583.

Shanker, A. K., Cervantes, C., Loza-Tavera, H., & Avudainayagam, S. (2005). Chromium toxicity in plants. *Environment International, 31*(5), 739–753. https://doi.org/10.1016/j.envint.2005.02.003.

Somavanshi, R., & Sinha, S. (1972). Quality of well waters of northern Madhya Pradesh. *Indian Journal of Agricultural Sciences, 42*(11), 1007–1010.

Srikanth, R., Rao, A. M., Kumar, C. S., & Khanum, A. (1993). Lead, cadmium, nickel, and zinc contamination of groundwater around Hussain Sagar lake, Hyderabad, India. *Bulletin of Environmental Contamination and Toxicology, 50*(1), 138–143.

TIFAC. (2015). Technology Vision 2035, 120. doi:https://doi.org/10.1179/0267084411Z.0000000007

US EPA. (2004). Understanding the Safe Drinking Water Act—Role and responsibilities, 4. Retrieved from https://www.epa.gov/sites/production/files/2015-04/documents/epa816f04030.pdf

Wang, M.-H., Li, J., & Ho, Y.-S. (2011). Research articles published in water resources journals: a bibliometric analysis. *Desalination and Water Treatment, 28*(1–3), 353–365 https://doi.org/10/5004/dwt.2011.2412.

Xie, S., Zhang, J., & Ho, Y. S. (2008). Assessment of world aerosol research trends by bibliometric analysis. *Scientometrics, 77*(1), 113–130. https://doi.org/10.1007/s11192-007-1928-0.

Yuan, J. P., Yue, W. P., Su, C., Wu, Z., Ma, Z., Pan, Y. T., … Wu, Y. S. (2010). Patent activity on water pollution and treatment in China-a scientometric perspective. Scientometrics, 83(3), 639–651. doi:https://doi.org/10.1007/s11192-009-0126-7.

Yuh-Shan, Ho. (2008). Bibliometric analysis of biosorption technology in water treatment research from 1991 to 2004. *International Journal of Environment & Pollution*, 34(1–4), 1–13. doi:https://doi.org/10.1504/IJEP.2008.020778.

Zheng, T., Wang, J., Wang, Q., Nie, C., Smale, N., Shi, Z., & Wang, X. (2015). A bibliometric analysis of industrial wastewater research: current trends and future prospects. *Scientometrics, 105*(2), 863–882. https://doi.org/10.1007/s11192-015-1736-x.