Asian Journal of Chemistry and Pharmaceutical Sciences, *Vol 2(2), 2017, 1-16*

ISSN (Online) : 2456-6217
DOI:10.18311/ajcps/2017/20185

Assessment of Chemical Science Research Output Using Scientometric Indicators

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Abstract

The present paper deals with the chemical science research in India for the span of fifteen years based on web of science database. The main objective is to study a scientometric output of all chemical science scientists. In this we studied the growth of research output and citations, relative growth rate and doubling time, sub-discipline wise distribution of publications and citations, activity index, citation index, national and international collaboration, highly productive institutions, highly productive authors, highly preferred journals and highly cited publications. India has produced 1,31,212 papers, and received 12,70,317 citations during the period 2002-2016, in the same manner world has produced 24,04,444 publications in chemical science and had increased its publications from 1,14,912 in 2002 to 1,93,822 in 2016.

Keywords: Chemical Science, Growth of Publications, India, Relative Growth Rate and Doubling Time, Scientometric Indicators

1. Introduction

The 20th century may be described as the century of the development of metric sciences like librametrics, bibliometrics, scientometrics, cybermetrics or webometrics and lastly informatics. The objective is to use quantitative techniques and methods to assess the knowledge domain. Scientometrics has become prominent day by day because of the need to measure and evaluate the huge investments in Science and Technology (S&T) sectors, especially in research and development activities. Journals are the primary communication channel in disseminating research and scholarly information and publishing papers in high impact and good quality national as well as international journals is strongly related with gaining prestige, reputation and academic achievement in higher education environment[1].

The concept of indicators in itself is an interesting field of science. Some things are easy to measure directly, such as the mass or speed of objects. Sometimes it is very difficult, or perhaps impossible, to directly measuring a phenomenon, such as quality of life, happiness, and of course, innovation. Indicators are used to tell us about things that are difficult to measure[2]. The development of Science, Technology and Innovation (STI) indicators have grown substantially during the last twenty years across the globe. Scientometric Analysis is a well-established tool in information research. It is an application of quantitative methods to the history of science.

Scientometrics indicators can be classified to the number of scientometrics sets they represent and the application of reference standards[3]. Scientometrics indicators referring to the measure of a single Scientometrics aspect of Scientometrics system represented by a single Scientometrics set with a single hierarchical level are termed gross indicators. Those indicators which consist of several gross or complex indicators, preferably with weighting factors and each representing a special aspect of a Scientometrics system are composite or compound indexes.

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2. Objectives of the Study

The specific objectives:

- To examine the pattern of growth of the research publications output from India for the period 2002-2016.
- To examine the relative growth rate and doubling time of World and India
- To study the distribution of output and its impact in different sub-disciplines of chemical science.
- To identify the most prolific research institutions in the field of chemical science
- To identify the most commonly used journals
- To identify the most prolific Indian authors in chemical science.
- To examine the pattern of citations and identify the highly cited papers.

3. Methodology

For this study data were extracted by searching the Science Citation Index- Expanded (SCI-E) of Web of Science Database. The distribution of publications, source wise distribution, most prolific institutions, distribution of papers by leading research areas, prolific authors, highly cited papers, and international collaborators. The collected data were analysed using MS-Excel Spreadsheet and MS-Word.

4. Results and Discussion

4.1 Pattern of Growth of Publications Output in the Field Chemical Science (World and India)

Table 1 and Figure 1 reveals features of scientific literature in recent years has been its rate of growth. A number of growth models have been proposed regarding the rate of growth. Way back in 1965 Price[4] proposed an exponential rate of growth of scientific literature. He predicted a regular exponential growth with doubling period of ten to fifteen years.

India has produced 1,31,212 papers, and received 12,70,317 citations during the period 2002-2016, Average Citations per Paper is 9.68. As per the Web of Science data,

Table 1. Pattern of growth of publications output in the field Chemical Science (World and India)

	WORLD		INDIA				
Year	**TP**	**%**	**TP**	**TC**	**ACPP**	**H-index**	**TP Share**
2002	114912	4.78	4522	94726	20.95	105	3.94
2003	122020	5.08	4930	102072	20.7	113	4.04
2004	129479	5.39	5539	120603	21.77	114	4.28
2005	135085	5.62	5859	126800	21.64	122	4.34
2006	145318	6.04	6763	138815	20.53	127	4.65
2007	147836	6.15	7348	142009	19.33	119	4.97
2008	153488	6.38	7503	131716	17.56	112	4.89
2009	158723	6.60	8238	138103	16.76	110	5.19
2010	158913	6.61	8760	135258	15.44	109	5.51
2011	174805	7.27	9844	140215	14.24	100	5.63
2012	182690	7.60	10277	NA	NA	NA	5.63
2013	191773	7.98	11476	NA	NA	NA	5.98
2014	203848	8.48	13127	NA	NA	NA	6.44
2015	191732	7.97	13491	NA	NA	NA	7.04
2016	193822	8.06	13544	NA	NA	NA	6.99
2002-2006	**646814**	**26.90**	**27613**	**583016**	**21.11**	**NA**	**4.27**
2007-2011	**793765**	**33.01**	**41693**	**687301**	**16.48**	**NA**	**5.25**
2012-2016	**963865**	**40.09**	**61915**	**NA**	**NA**	**NA**	**6.42**
2002-2016	**2404444**		**131221**	**1270317**	**9.68**	**NA**	**5.46**

TP= Total Papers; ACPP=Average Citations per Paper

the cumulative publications growth of chemical science research output of India had increased from 27,613 publications during 2002-2006 to 41,693 publications during 2007-2011, and 61,915 publications during 2012-2016.

India has produced the highest publication i.e. 13,544 papers in 2016. The lowest publication is 4,522 in 2002. Chemical science publications are gradually increased year by year, the publications share of chemical science which has increased from 3.94% in 2002 to 6.99% in 2016. According to the research the trend line shows that there is a steady and significant increase in the publications in chemical science. India's research output in chemistry has been gradually increased year by year. The world's publications share of India during 2002-2016 was 5.46%, which has increased from 3.94 in 2002 to 6.99 in 2016.

Table 2 reveals the share of Indian research output and world's output in chemical science has increased from 1,14,912 in 2002 to 1,93,822 in 2016. World's publications had increased from 6, 46,814 publications during **2002-2006** to 7,93,765 publications during **2007-2011**, and 9,63,865 publications during **2012-2016**. In the same manner, the Indian research output in chemical science too has increased from 4,522 in 2002 to 13,544 by 2016.

Table 2. Share of Indian research output in chemical science

Year	TP	% of TP Share
2002	4522	3.94
2003	4930	4.04
2004	5539	4.28
2005	5859	4.34
2006	6763	4.65
2007	7348	4.97
2008	7503	4.89
2009	8238	5.19
2010	8760	5.51
2011	9844	5.63
2012	10277	5.63
2013	11476	5.98
2014	13127	6.44
2015	13491	7.04
2016	13544	6.99
2002-2006	27613	4.27
2007-2011	41693	5.25
2012-2016	61915	6.42
2002-2016	**131221**	**5.46**

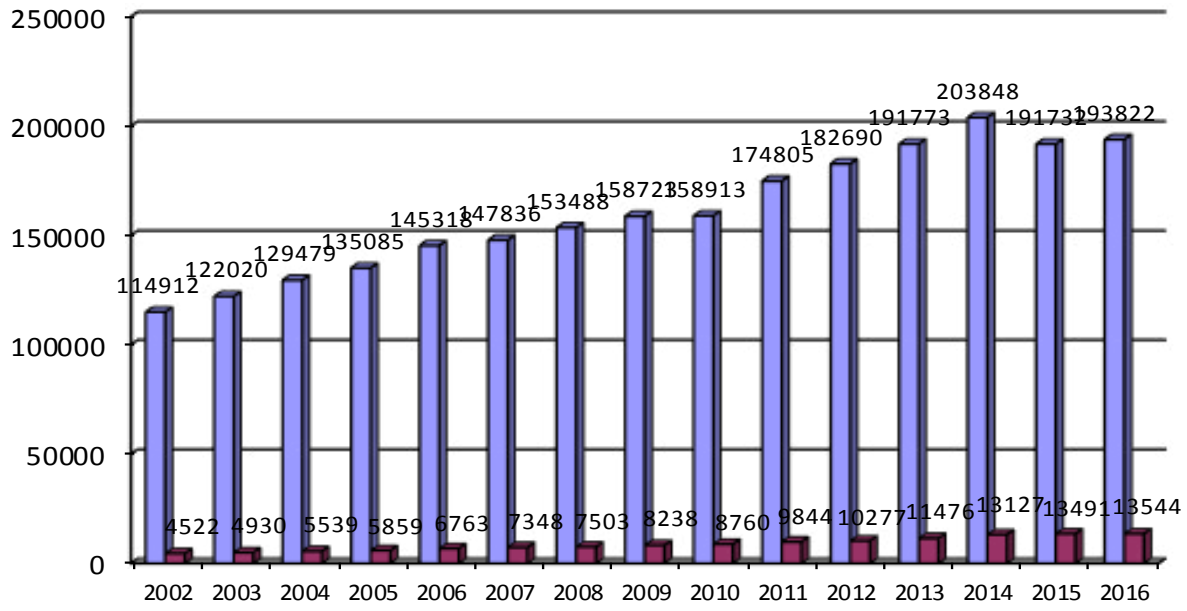

Figure 1. Status of World's Chemical Science Literature.

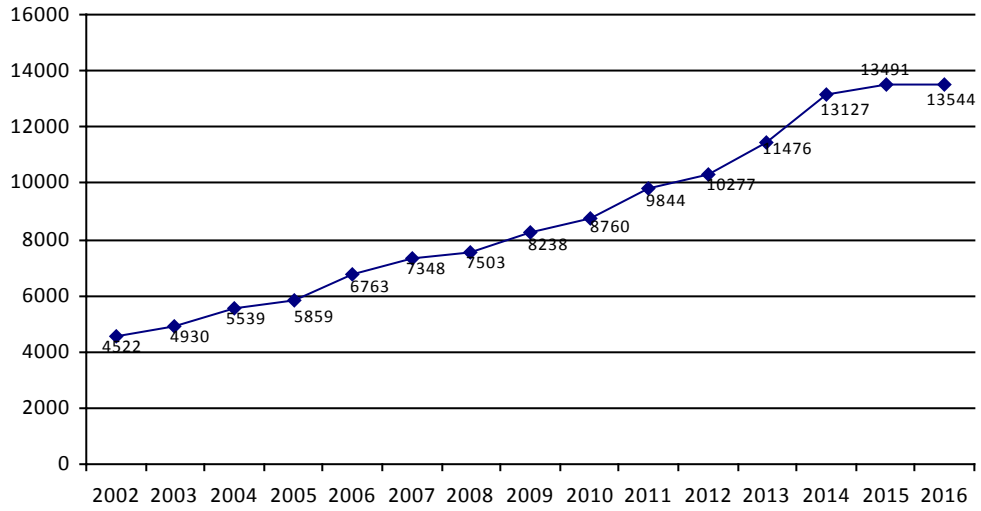

Figure 2. Share of Indian Research output in chemical science literature.

Figure 2 illustrates the study that the above point gets clarified when we analyse the percentage of India's papers compared to that of the world's papers. India's share of science and technology research output increased from 3.94% in 2002 to 6.99% in 2016. The plot shows a significant increase and the trend suggests a 5.30% average growth in the share per annum in the study period.

4.2 Relative Growth Rate and Doubling Time

This study represents, the chronological distribution, Relative Growth Rate (RGR is the growth rate relative to the size of population or continuous growth rate with reference to scientific literature publication time, Relative Growth Rate (GR) is the increase in the number of publications per unit time) and doubling time, The doubling time (Dt) is the given period required for quantity to double in size or value) of world publications in the field of chemical science during the period 2002-2016.

One of the obvious features of scientific literature in recent years has been its rate of growth. A number of growth models have been proposed regarding the rate of growth. Price[4] proposed an exponential rate of growth of scientific literature. He predicted a regular exponential growth with doubling period of ten to fifteen years.

4.2.1 World and India

Table 3 and figure 3 shows the total output of world and India has been shown in Table 3 along with the RGR and Dt. The table shows that the relative growth rate of world output decreases gradually from 0.72 to 0.02 in fifteen year's period (2002-2016). The reason for this growth due to the information communication technology and World Wide Web. Figure 4 illustrates the doubling time (D_t) correspondingly increases from 0.96 to 8.25 in this period. The mean growth rate and doubling time for the world is **1.13** and **1.17** respectively.

Figure 5 and 6 reveals Indian output, as shown in Table 3, the growth rate decreases gradually from 0.74 to 0.11 during fifteen years period (2002-2016). This growth may be due to the establishment of major scientific institutions like DST, CSIR, NPL, NCL, etc., which resulted into more scientific research in chemical science. Correspondingly, the doubling time increases from 0.94 to 6.36 in the same period. The mean growth rate and doubling time for Indian output is **0.12** and **0.93**.

The year-wise analysis of RGR and Dt for world and India indicates a different finding. The growth rate of World is comparatively more than that of India. The average growth rate of world and India is 0.22 and 0.24 respectively. Correspondingly, the doubling time of world is 4.58 and India is 3.83 respectively.

Table 3. Relative growth rate and doubling time of world and India

Year	World Output	RGR	Dt	India Output	RGR	Dt
2002	114912			4522		
2003	122020	0.72	0.96	4930	0.74	0.94
2004	129479	0.44	1.59	5539	0.46	1.50
2005	135085	0.31	2.21	5859	0.33	2.10
2006	145318	0.25	2.72	6763	0.28	2.47
2007	147836	0.21	3.37	7348	0.24	2.94
2008	153488	0.18	3.92	7503	0.19	3.56
2009	158723	0.15	4.48	8238	0.18	3.91
2010	158913	0.13	5.17	8760	0.16	4.35
2011	174805	0.13	5.36	9844	0.15	4.52
2012	182690	0.12	5.80	10277	0.14	5.01
2013	191773	0.11	6.21	11476	0.13	5.14
2014	203848	0.11	6.51	13127	0.13	5.15
2015	191732	0.09	7.64	13491	0.12	5.69
2016	193822	0.08	8.25	13544	0.11	6.36
		Mean RGR 1.13	**Mean Dt 1.17**		**Mean RGR 0.12**	**Mean Dt 0.93**

RGR = Relative Growth Rate; Dt = Doubling Time

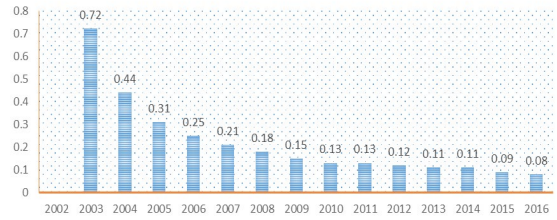

Figure 3. Relative Growth Rate (RGR) of world

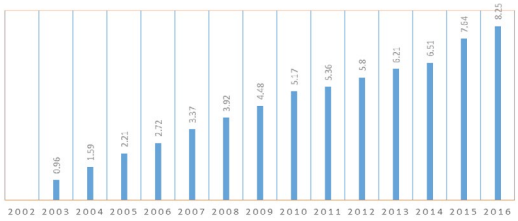

Figure 4. Doubling Time (DT) of World

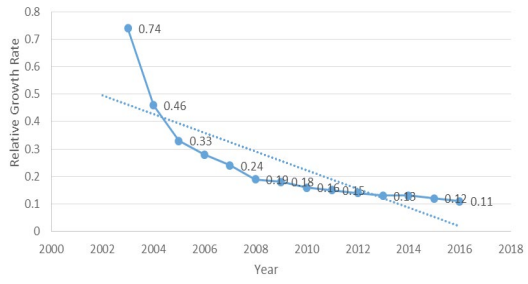

Figure 5. Relative Growth Rate (RGR) of India

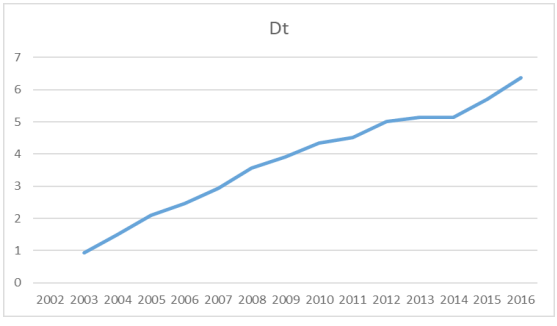

Figure 6. Doubling Time (Dt) of India

4.3 Most Productive Authors in Indian Chemical Science Research

The table 4 shows the highly productive authors from Indian chemical science research output during the study period. The top 25 authors having been identified as most productive authors in Indian chemical science research, the publications profile of these 25 authors along with their research output, citations received and h-index values are presented in Table 4. These 25 authors together contributed 21,257 papers with an average of 817.58 papers per author and account for 16.20% share in the cumulative Indian publications output during 2002-2016.

Table 4. Most productive authors in Indian Chemical Science Research

Sl. No.	Authors	Affiliation	TP	% of 131221	TC	ACP	H-index
1	Kumar, A.	National University of Singapore, Department of Chemical & Bio molecular Engineering	2227	1.70	29647	13.31	65
2	Kumar, S.	Indian of Technology, Chemical Engineering, Gandhinagar	1674	1.28	19748	11.8	52
3	Ghosh, S.	Indian Institute Science, Bengaluru	1253	0.96	16984	13.55	51
4	Singh, S.	National Institute of Pharmaceutical Education and Research, Mohali	1121	0.85	12222	10.9	45
5	Kumar, R.	Guru Jambheshwar University, Haryana	1101	0.84	15068	13.69	51
6	Yadav, J. S.	Indian Institute of Chemical Technology, Hyderabad	914	0.70	17521	19.17	54
7	Das, S.	Indian Institute of Technology, Uttar Pradesh	897	0.68	11881	13.25	45
8	Singh, A. K.	Indian Institute of Technology, Uttar Pradesh	845	0.64	11457	13.56	46
9	Kumar, P.	Centre for Development of Advanced Computing, Pune	804	0.61	9524	11.85	41
10	Kumar, V.	Polymer Research Laboratory, Govt. Autonomous Science College, Jabalpur	760	0.58	9642	12.69	41
11	Sharma, S.	Indian Institute Science, Bengaluru	719	0.55	6784	9.44	33
12	Roy, S.	Indian Institute of Petroleum, Dehra Dun	698	0.53	8908	12.76	43
13	Kumar, M.	Gauhati University, Assam	677	0.52	9944	14.69	46
14	Sharma, A.	National Chemical Laboratory, Pune	663	0.51	8730	13.17	42
15	Singh, A.	Guru Nanak Dev University, Punjab	625	0.48	6058	9.69	28
16	Singh, P.	Indian Institute Technology, Kanpur	615	0.47	6995	11.37	35
17	Das, D.		594	0.45	8671	14.6	44
18	Ghosh, A.	Indian Institute Science, Bengaluru	585	0.45	9290	15.88	46
19	Reddy, B. V. S.		578	0.44	11101	19.21	49
20	Pal, S.	Indian Institute of Chemical Technology, Hyderabad	574	0.44	7444	12.97	36
21	Kumar, D.	Birla Institute Technology & Science, Pilani	573	0.44	6764	11.8	36
22	Singh, N.	Guru Nanak Dev University, Punjab	569	0.43	8975	15.77	45
22	Banerjee, S.	National Chemical Laboratory, Pune	569	0.43	8036	14.12	38
23	Singh, B.	Indian Institute of Technology, Kanpur	551	0.42	6146	11.15	38
24	Sarkar, S.	Centre for DNA Fingerprinting and Diagnostics, Hyderabad	537	0.41	6960	12.96	37
25	Bhattacharya, S.	Jadavpur University, Kolkata	534	0.41	8881	16.63	42

The top 25 scientists from Indian chemical science research listed for their highest productivity are shown in Table 4. These 25 scientists have together contributed 21,257 papers in India's total research output with an average of 817.58 papers per scientist. According to highest publications Kumar, A, occupies first rank with 2,227 articles (29,647 citations) with 13.31 of aveage citations per paper and his h-index is 65, followed by Kumar, S. published 1,674 papers and received 19,748 citations with an average of 11.8 and his h-index is 52, Ghosh, S. published 1,253 papers (16,984 citations), Singh, S. produced 1,121 papers and received 12,222 citations (h-index 45), Kumar, R. published 1,101 articles and received 15,068 citations. Yadav, J. S. has published 914 articles and received 17,521 citations with an average of 19.17 and his h-index is 54 and Das, S. published 897 articles.

4.4 Channels used for Communicating Cheimical Science Research

Table 5 illustrates the channels used for communicating of chemical science research include articles published in the scholarly journals, conference and seminars proceedings, reviews, editorial materials, corrections and book chapters. This study has observed a total of 1,31,221 publications in chemical science from India It has been observed from the table there are many communicating channels are used by scientists to publish their research articles in Indian chemical science literature. The majority of publications are published in Journals i.e., 1,22,712 (95.62), followed by Reviews 3,150 (2.40%) publications, 2,692 (2.05%) of papers published in Proceedings, 1,317 are as published as meeting abstracts and less than 1% of articles are published in other communication channels.

Table 5. Channels used for communicating cheimical science research

Sl. No.	Document Types	TP	% of 131221
1	Article	122712	95.62
2	Review	3150	2.40
3	Proceedings Paper	2692	2.05
4	Meeting Abstract	1317	1.00
5	Editorial Material	525	0.40
6	Correction	506	0.39
7	Letter	185	0.14
8	Book Chapter	47	0.04
9	Biographical Item	36	0.03
10	Retracted Publication	27	0.02
11	Software Review	11	0.01
12	News Item	7	0.01
13	Retraction	3	0.00
14	Reprint	2	0.00
15	Book Review	1	0.00

4.5 Language-Wise Distribution of Publications

Table 6 reveals the language-wise distribution of publications, the scientists researchers from Indian chemical science are published in different languages; English, Chinese, Japanese, German, Welsh, French, Estonian and Danish. It is observed that the majority (99.98%) of articles published in english language, 0.008% articles published in chinese language and very less number of articles are published in remaining languages.

Table 6. Language-wise distribution of publications

Sl. No.	Languages	Records	% of 131221
1	English	131202	99.987
2	Chinese	10	0.008
3	Japanese	3	0.002
4	German	2	0.002
5	Welsh	1	0.001
6	French	1	0.001
7	Estonian	1	0.001
8	Danish	1	0.001

4.6 Organizational/Institutional collaboration

Table 7 reveals the ranking list of top 25 highly productive Research Institutions in India based on their highest publications, citations, average citations per publication and h-index. According to the web of science database Indian Institute of Technology (IIT), Delhi contributed the highest publications to the field of engineering, i.e., 13,297 publications, followed by Bhabha Atomic Research Centre published 4.02% i.e., 5,273 articles and received 1,00,899 citations with an average (average citations per paper) 19.14 and h-index is 102, Indian Institute of Chemical Technology produced 5,078 papers and received 61,095 citations next to this Indian Institute of Science published 3.73% of papers (4,888 papers

and received 1,04,872 citations), National Chemical Laboratory published 3,992 papers University of Delhi produced 3,373 articles and received 63,109 citations and average citations per paper is 18.71, Banaras Hindu University produced 3,306 articles and received 61,905 citations and University of Hyderabad published 3,008 papers with 16.08 average citations per paper.

4.7 Subject-Wise Productivity of Indian Chemical Science Research

Table 8 indicate the subject-wise productivity of India in chemical science research. Materials Science, Biochemistry Molecular Biology, Science Technology Other Topics, Pharmacology Pharmacy, Engineering, Electrochemistry,

Table 7. Organizational/Institutional collaboration

Sl. No.	Organizations	TP	TC	ACP	H-index	%
1	Indian Institute of Technology	13297				10.13
2	Bhabha Atomic Research Centre	5273	100899	19.14	102	4.02
3	Indian Institute of Chemical Technology	5078	61095	12.03	79	3.87
4	Indian Institute of Science	4888	104872	21.45	113	3.73
5	National Chemical Laboratory	3992	85250	21.36	103	3.04
6	University of Delhi	3373	63109	18.71	88	2.57
7	Banaras Hindu University	3306	61905	18.73	88	2.52
8	University of Hyderabad	3008	48361	16.08	72	2.29
9	University of Calcutta	2845	50596	17.78	84	2.17
10	National Institute of Technology	2806	40332	14.37	71	2.14
11	Aligarh Muslim University	2697	48244	17.89	81	2.06
12	Anna University	2480	35230	14.21	70	1.89
13	Jawaharlal Nehru Centre for Advance Science Research	2423	38147	15.74	74	1.85
14	Guru Nanak Dev University	2132	26736	12.54	55	1.62
15	Panjab University	2127	44319	20.84	82	1.62
16	University of Rajasthan	1844	21229	11.51	55	1.41
17	University of Madras	1836	27524	14.99	64	1.40
18	Annamalai University	1603	50581	31.55	96	1.22
19	Shivaji University	1577	37419	23.73	90	1.20
20	University of Allahabad	1556	21176	13.61	59	1.19
21	Central Drug Research Institute	1461	15184	10.39	44	1.11
22	Institute of Chemical Technology	1440	19515	13.55	58	1.10
22	Indian Institute of Technology Guwahati	1342	23742	17.69	60	1.02
23	Osmania University	1280	18435	14.4	58	0.98
24	Sri Venkateswara University	1265	12981	10.26	39	0.96
25	University of Kalyani	1247	19268	15.45	58	0.95

Crystallography, Metallurgy Metallurgical Engineering, Polymer Science, Food Science Technology, Thermodynamics, Energy Fuels, Nuclear Science Technology, Biophysics, Instruments Instrumentation, Environmental Sciences Ecology were considered on the basis of the total number of publications.

4.8 International Collaboration

Due to the interdisciplinary growth of subject, the universe of knowledge is ever dynamic and is ever-growing. More and more specialization in the subjects is achieved by the scientists, which is a result of increased participation of group of researchers of different expertise. It has been found from earlier studies that collaboration in research varies from discipline to discipline and for the same discipline from time to time and from one country to another[5].

Collaborative research has become a well established feature in the field of chemical science. It is observed that there is a consistently increasing trend towards collaboration among various branches of chemical science which leads to collaborative authorship in literature.

Table 9 depicts the international collaborative papers of India with top with 25 countries during 2002-2016. The share of International collaborative publications in the Indian chemical science research output was 20.26% during 2002-2016. The largest number of collaborative publications (5,255) of India in chemical science research was with United States with 4.005% share, followed

Table 8. Subject-wise productivity of Indian chemical science research

Sl. No.	Research Areas	TP	% of 131221	TC	ACP	H-index
1	Materials Science	16316	12.434	---	---	---
2	Biochemistry Molecular Biology	6922	5.275	89357	12.91	92
3	Science Technology Other Topics	6891	5.251	121545	17.64	119
4	Pharmacology Pharmacy	5619	4.282	90529	16.11	97
5	Engineering	5593	4.262	69934	12.5	90
6	Electrochemistry	3888	2.963	74479	19.16	90
7	Crystallography	3623	2.761	54103	14.93	72
8	Metallurgy Metallurgical Engineering	2950	2.248	36214	12.28	57
9	Polymer Science	2791	2.127	48148	17.25	79
10	Food Science Technology	2750	2.096	42802	15.56	78
11	Thermodynamics	2429	1.851	25652	10.56	49
12	Energy Fuels	2160	1.646	41837	19.37	75
13	Nuclear Science Technology	1958	1.492	11682	5.97	32
14	Biophysics	1741	1.327	37336	21.45	73
15	Instruments Instrumentation	1396	1.064	27375	19.61	69
16	Environmental Sciences Ecology	1226	0.934	18645	15.21	62
17	Agriculture	1164	0.887	13693	11.76	48
18	Spectroscopy	922	0.703	7629	8.27	33
19	Nutrition Dietetics	761	0.58	20090	26.4	64
20	Computer Science	722	0.55	8002	11.08	36
21	Plant Sciences	680	0.518	4186	6.16	27
22	Biotechnology Applied Microbiology	655	0.499	15135	23.11	55
22	Mathematics	463	0.353	3750	8.1	25
23	Radiology Nuclear Medicine Medical Imaging	324	0.247	2321	7.16	21
24	Toxicology	310	0.236	2778	8.96	25
25	Acoustics	287	0.219	6561	22.86	43

by Germany contributed 2,597 papers with 1.979% of total share, South Korea published 2,461 papers, Japan produced 2,062 papers, England published 1,549 articles, France contributes 1,484 papers, Spain published 1,224 papers and Saudi Arabia has contributed with India in chemical science research i.e. 1,188 papers. Many countries are contributed with below 1% share with India in chemical science research during 2002 to 2016.

Table 9. International collaboration

Sl. No.	Countries	TP	% of 131221
1	USA	5255	4.005
2	Germany	2597	1.979
3	South Korea	2461	1.875
4	Japan	2062	1.571
5	England	1549	1.18
6	France	1484	1.131
7	Spain	1224	0.933
8	Saudi Arabia	1188	0.905
9	Italy	1040	0.793
10	Taiwan	1028	0.783
11	Canada	777	0.592
12	Peoples R China	699	0.533
13	Australia	691	0.527
14	Malaysia	663	0.505
15	South Africa	545	0.415
16	Switzerland	433	0.33
17	Singapore	400	0.305
18	Portugal	396	0.302
19	Poland	342	0.261
20	Belgium	322	0.245
21	Czech Republic	302	0.23
22	Sweden	301	0.229
23	Iran	276	0.21
24	Israel	275	0.21
25	Scotland	274	0.209

4.9 Publication Efficiency Index (PEI)

To examine the impact of research papers produced by a given country is significantly related to the research effort. Chen and Guan[6] propose Publication Efficiency Index (PEI). If PEI >1(greater than), this indicates that the impact of publications in a given field by a particular country is more than the research effort devoted to it during the period considered. The same formula is employed to calculate the Publication Efficiency Index (PEI) of the Indian chemical scienceliterature during the period 2002 to 2011. Table 10 shows the PEI scores for India.

The study demonstrates that PEI score is not greater than one for all the years. This means that for all the years the indian chemical research performance is not more than the research effort devoted to it during 2002-2011. All the researchers are active in the chemical science research publications during 2002 to 2011 (except during 2002 to 2007 in these years the PEI score is less than one). It is observed that the highest PEI is 1.29 in Indian chemical science research in the year.

Table 10. Publication Efficiency Index (PEI)

Year	TC	PEI
2002	4522	0.87
2003	4930	0.89
2004	5539	0.84
2005	5859	0.85
2006	6763	0.89
2007	7348	0.95
2008	7503	1.04
2009	8238	1.09
2010	8760	1.19
2011	9844	1.29
	69306	1
		Mean 0.99

4.10 Relative Citation Impact (RCI)

The indicator was developed by Institute of Scientific Information (now Thomson Reuters, USA) to calculate science and engineering indicators. RCI measures both the influence and visibility of a nation's research in global perspective. Table 11 indicates the RCI is a ratio of a country's share of world citations (percent citations) to country's share of world publications (percent publications). RCI = 1 indicates that country's citation rate is equal to world citation rate; RCI > 1 indicates that country's citation rate is higher than world's citation rate and RCI < 1 indicate that country's citation rate is less than world's citation rate[7].

Table 11. Relative Citation Index (RCI) of Indian Chemical Science Research

Year	TNP	TNC	ACP	RCI
2002	4522	94726	20.95	1.14
2003	4930	102072	20.70	1.13
2004	5539	120603	21.77	1.19
2005	5859	126800	21.64	1.18
2006	6763	138815	20.53	1.12
2007	7348	142009	19.33	1.05
2008	7503	131716	17.56	0.96
2009	8238	138103	16.76	0.91
2010	8760	135258	15.44	0.84
2011	9844	140215	14.24	0.78
	69306	1270317	18.33	1

Note: TNP= Total No. of Publications, TNC=Total No. of Citations, ACP=Average Citations per Paper, RCI=Relative Citation Index

4.11 Activity Index

In the present study, the Activity Index (AI) has been calculated for different years to see how India's performance gradually changed during different years. For this the author has used the Activity Index 2002-2016. The Activity Index was first suggested by Frame[8] and used among others by Schubert and Braun[9]; Nagpaul[10]; Karki and Garg[11]. The Activity Index (AI) characterizes the relative research effort of a country for a given subjects. It is defined as;

$$AI = \frac{\textit{given field's share in the country's publication output}}{\textit{given field's share in the world's publication output}}$$

$$\text{Mathematically AI} = \frac{\text{nij/nio}}{\text{noj/noo}} * 100$$

Where:

nij - Indian output of papers in particular field
nio - Total Indian output on all subjects
noj - World output of papers in particular field
noo - Total World output on all subjects

The table 12 shows that the highest Activity Index in various subject categories in different years were: Pharmacology Pharmacy the highest activity index i.e., 127.32 in 2012, Electrochemistry 113.96 (2016), Energy Fuels 149.98 (2002), Crystallography 129.32 (2014), Polymer Science 145.56 (2015), Thermodynamics 143.03 (2012), Spectroscopy 152.91 (2014), Instruments Instrumentation 127.49 (2013), Nuclear Science Technology 154.43 (2014) and Toxicology 166.48 in 2014.

It is observed from the data that the Toxicology subject scored highest Activity Index (166.48), followed by Nuclear Science Technology (154.43), Spectroscopy (152.91), Energy Fuels (149.98), Polymer Science (145.56) etc., in fifteen years period. It indicates India's research efforts in these subjects correspond to the world's average.

4.12 Highly Cited Papers in the Field Indian Chemical Science

Table 13 shows characteristics of selected highly cited papers of India in chemical science were also evaluated in this section and the list of such high – cited papers is presented based on publication output of India in this area, 25 papers are identified as highly cited ones, who have received citations from 743 to 2,132 during 2002 to 2016 of these 25 papers, These 25 high cited papers were published in 13 journals including 6 papers in *Chemical Reviews*, 2 in *Angewandte Chemie-International Edition,* 2 in *Advanced Materials* and remaining papers are published 1 each. Citations received by these top 25 cited papers accumulated to 27,445 (2.16%) of all citations. Most of the papers are having multiple authors (Three or more authors), two papers are single author and seven papers are having two authors. The top cited paper was 'Graphene: The New Two-Dimensional Nanomaterial', authored by Rao, CNR; Sood, AK; Subrahmanyam, KS; and Govindaraj, A. it is published in *Angewandte Chemie-International Edition* in the year 2009 and this paper has received 2132 citations, followed by 'Metal carboxylates with open architectures', authored by Rao, CNR; Natarajan, S; Vaidhyanathan, R. published in *Angewandte Chemie-International* in the year 2004, and this paper received 1754 citations, 'Hydrogen bridges in crystal engineering: Interactions without borders' authored by Desiraju, GR. published in *Accounts of Chemical Research* in the year 2002 and this paper received 1512 citations, 'Recent advances in the Baylis-Hillman reaction and applications' authored by Basavaiah, D; Rao, A J; Satyanarayana, T. published in *Chemical Reviews* in the year 2003 this paper received 1438. 'Chitosan chemistry and pharmaceutical

Table 12. Activity Index

Year	Pharmacology Pharmacy	Electrochemistry	Energy Fuels	Crystallography	Polymer Science	Thermodynamics	Spectroscopy	Instruments Instrumentation	Nuclear Science Technology	Toxicology
2002	76.37	110.17	**149.98**	78.86	66.36	52.03	19.38	78.66	90.58	45.25
2003	80.49	57.85	60.52	83.70	64.67	72.84	49.40	59.30	70.70	63.72
2004	96.22	107.08	85.37	74.90	52.25	83.34	52.26	59.91	50.83	49.06
2005	90.60	78.43	116.33	83.08	77.87	65.51	75.68	68.46	72.75	58.89
2006	75.53	91.37	109.37	114.04	82.70	80.36	74.76	107.66	95.44	127.96
2007	87.46	105.24	110.32	105.19	66.59	61.07	77.30	114.02	84.41	46.77
2008	92.86	99.84	113.52	92.81	55.92	81.30	77.17	101.06	64.50	78.52
2009	108.62	93.51	99.59	80.67	61.18	103.73	51.43	88.83	61.87	83.16
2010	114.30	85.96	88.77	83.66	68.57	126.11	107.22	85.16	106.87	123.77
2011	111.38	98.35	96.56	93.72	87.27	105.75	151.06	95.89	143.28	118.88
2012	**127.32**	98.10	103.38	101.40	96.13	**143.03**	125.69	100.93	137.86	97.85
2013	89.84	96.35	92.97	113.72	112.08	141.88	123.97	**127.49**	111.09	134.54
2014	118.71	108.48	103.02	**129.32**	131.91	113.12	**152.91**	119.67	**154.43**	**166.48**
2015	108.01	109.20	92.65	115.22	**145.56**	107.32	115.84	104.29	101.79	147.44
2016	112.03	**113.96**	104.92	106.03	144.34	96.83	131.32	100.23	109.07	140.49

Table 13. Highly cited papers in the field Indian chemical science

Sl. No	Citations Received	Title of the Article	Authors	Source	Year of Publication
1	2132	Graphene: The New Two-Dimensional Nanomaterial	Rao, CNR; Sood, AK; Subrahmanyam, KS; Govindaraj, A	*Angewandte Chemie-International Edition*, *48*(42), 7752-7777	2009
2	1754	Metal carboxylates with open architectures	Rao, CNR; Natarajan, S; Vaidhyanathan, R	*Angewandte Chemie-International Edition*, *43*(12), 1466-1496	2004
3	1512	Hydrogen bridges in crystal engineering: Interactions without borders	Desiraju, GR	*Accounts of Chemical Research*, *35*(7), 565-573	2002
4	1438	Recent advances in the Baylis-Hillman reaction and applications	Basavaiah, D; Rao, AJ; Satyanarayana, T	*Chemical Reviews, 103(*3), 811-891	2003
5	1391	Chitosan chemistry and pharmaceutical perspectives	Kumar, MNVR; Muzzarelli, RAA; Muzzarelli, C; Sashiwa, H; Domb, AJ	*Chemical Reviews*, *104*(12), 6017-6084	2004
6	1381	Recent applications of the Suzuki-Miyaura cross-coupling reaction in organic synthesis	Kotha, S; Lahiri, K; Kashinath, D	*Tetrahedron*, *58*(48), 9633-9695	2002
7	1262	Interparticle coupling effect on the surface plasmon resonance of gold nanoparticles: From theory to applications	Ghosh, SK; Pal, T	*Chemical Reviews*, *107*(11), 4797-4862	2007
8	1225	Supramolecular gels: Functions and uses	Sangeetha, NM; Maitra, U	*Chemical Society Reviews, 34*(10), 821-836	2005
9	1186	Recent advances on chitosan-based micro- and nanoparticles in drug delivery	Agnihotri, SA; Mallikarjuna, NN; Aminabhavi, TM	*Journal of Controlled Release, 100*(1), 5-28	2004
10	1116	Supramolecular Coordination: Self-Assembly of Finite Two- and Three-Dimensional Ensembles	Chakrabarty, R; Mukherjee, PS; Stang, PJ	*Chemical Reviews, 111*(11), 6810-6918	2011
11	1050	Biodegradable polymeric nanoparticles based drug delivery systems	Kumari, A; Yadav, SK; Yadav, SC	*Colloids and Surfaces B-Biointerfaces, 75*(1), 1-18	2010
12	1015	Controlling the aspect ratio of inorganic nanorods and nanowires	Murphy, CJ; Jana, NR	*Advanced Materials, 14*(1), 80-82	2002
13	988	Recent developments in ring opening polymerization of lactones for biomedical applications	Albertsson, AC; Varma, IK	*Biomacromolecules*, *4*(6), 1466-1486	2003
14	956	Recent advances in transition metal catalyzed oxidation of organic substrates with molecular oxygen	Punniyamurthy, T; Velusamy, S; Iqbal, J	Chemical Reviews, 105(6), 2329-2363	2005

15	910	Application of conducting polymers to biosensors	Gerard, M; Chaubey, A; Malhotra, BD	*Biosensors & Bioelectronics, 17*(5), 345-359	2002
16	906	Rapid synthesis of Au, Ag, and bimetallic Au core-Ag shell nanoparticles using Neem (Azadirachta indica) leaf broth	Shankar, S. S., Rai, ,A., Ahmad, A., & Sastry, M.	*Journal of Colloid and Interface Science, 275*(2), 496-502	2004
17	897	Biological synthesis of triangular gold nanoprisms	Shankar, SS; Rai, A; Ankamwar, B; Singh, A; Ahmad, A; Sastry, M	*Nature Materials, 3*(7), 482-488	2004
18	845	Structure, and Properties of Boron- and Nitrogen-Doped Graphene	Panchokarla, LS; Subrahmanyam, KS; Saha, SK; Govindaraj, A; Krishnamurthy, HR; Waghmare, UV; Rao, CNR	*Advanced Materials, 21*(46), 4726-+	2009
19	813	Biocompatibility of gold nanoparticles and their endocytotic fate inside the cellular compartment: A microscopic overview	Shukla, R; Bansal, V; Chaudhary, M; Basu, A; Bhonde, R); Sastry, M	*Langmuir, 21*(23), 10644-10654	2005
20	804	Core/Shell Nanoparticles: Classes, Properties, Synthesis Mechanisms, Characterization, and Applications	Chaudhuri, RG; Paria, S	*Chemical Reviews, 112*(4), 2373-2433	2012
21	797	Graphene Quantum Dots Derived from Carbon Fibers	Peng, J; Gao, W; Gupta, BK; Liu, Z; Romero-Aburto, R; Ge, LH; Song, L; Alemany, LB; Zhan, XB; Gao, GH; Vithayathil, SA; Kaipparettu, BA; Marti, AA; Hayashi, T; Zhu, JJ; Ajayan, PM	*Nano Letters, 12*(2), 844-849	2012
22	793	Crystal engineering: A holistic view	Desiraju, GR	Angewandte Chemie-International Edition, 46(44), 8342-8356.	2007
23	775	Polyionic hydrocolloids for the intestinal delivery of protein drugs: Alginate and chitosan - a review	George, M; Abraham, TE	Journal of Controlled Release,114(1), 1-14	2006
24	756	Removal of Congo Red from water by adsorption onto activated carbon prepared from coir pith, an agricultural solid waste	Namasivayam, C; Kavitha, D	Dyes and Pigments, 54(1), 47-58	2002
25	743	Structural diversity and chemical trends in hybrid inorganic-organic framework materials	Cheetham, AK; Rao, CNR; Feller, RK	Chemical Communications, 46, 4780-4795	2006

perspectives', authored by Kumar, MNVR; Muzzarelli, RAA; Muzzarelli, C; Sashiwa, H; Domb, AJ, published in *Chemical Reviews* and received 1391 citations. 'Recent applications of the Suzuki-Miyaura cross-coupling reaction in organic synthesis', authored by Kotha, S; Lahiri, K;

Kashinath, D. published in *Tetrahedron* in the year 2002, and this paper received 1381 citations, 'Interparticle coupling effect on the surface plasmon resonance of gold nanoparticles: From theory to applications' authored by Ghosh, SK; Pal, T. published in *Chemical Reviews* in the year 2007 this paper received 1262. 'Supramolecular gels: Functions and uses' authored by Sangeetha, NM; Maitra, U. published in *Chemical Society Reviews* in the year 2005 and this paper received 1225 citations, this shows that more research activities are being carried on in newly developing field

5. Conclusion

The present study analyses India's publication activity in terms of global share, share of international collaborative publications, and visibility and citation impact for the period 2002-2016. It explores how far the trends in Indian chemical science output mirror those of the other upcoming countries and what the main differences among those countries. It discusses the findings in the light of the above-mentioned ongoing discussion on decline or emergence of chemical science literature. It provides opportunity to the planners and policy makers in both the countries to use the findings in assessing the R&D initiatives in India.

The study reveals that India has produced 1,31,212 papers, and received 12,70,317 citations during the period 2002-2016, in the same manner world has produced 24,04,444 publications in chemical science and had increased its publications from 1,14,912 in 2002 to 1,93,822 in 2016. The study has identified most active institutions engaged in chemical research, areas of research in chemical science, journals used for communication and the impact of the highly cited papers in chemical science research output. The findings of the present study will be beneficial for the scholars and scientists who are engaged in research of various disciplines of chemical science as well as policy makers in the field.

At the national level there is a need to increase the evolving research strategies and delineating specific directions to investigate the recent trends. There is also need to increase international collaboration, which will increase both quality and quantity of research in chemical science literature.

6. Conflict of Interest Statement

We declare that we have no conflict of interest.

7. Acknowledgement

The authors thank to the Head of the Department of Library & Information Science, Karnataka University, Dharwad and Dr. Vitthal Bagalkoti, Library and Information Officer, CMR University, Bangalore for providing necessary facilities and resources for completing this article. This research received no specific grant from any funding agency.

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