

Mapping chemical science research in India: A bibliometric study

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Chemical sciences research in India has been mapped with data collected from the CD-ROM version of Chemistry Citation Index [publication year: 2002]. Roughly, 4.5% of the global R&D output in chemical sciences was contributed by Indian in 2002. Indian researchers published 6186 papers from 569 journals and 12 non-journal sources. More than 45% of these papers appeared in journals with an impact factor less than 1.000. Around 2% of the papers were either published in journals with no impact factor or not indexed in JCR 2003. The average impact factor for journal articles during this period is 1.359. While 26% of papers published by Indians were in US journals, the percentages for Indian and UK journals were 21 and 20%, respectively. Among Indian journals, the Asian Journal of Chemistry (IF 0.211) took the major chunk of 269 papers, while the Journal of Indian Chemical Society (IF 0.275) and the Indian Journal of Chemistry B (IF 0.492) carried 224 and 209 papers, respectively. In all, 563 institutions contributed 6199 papers in 2002. Of these papers, 68% were contributed by 10% of Indian institutions. The Indian Institute of Science, Bangalore ranks first with 345 papers. This is followed by the Indian Institute of Chemical Technology, Hyderabad with 263 papers. Bhabha Atomic Research Centre, Mumbai with 259 papers and the National Chemical Laboratory, Pune with 246 papers come in the third and fourth places, respectively. The largest contributions came from Mumbai, Bangalore, Hyderabad and Kolkata. In terms of states, Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh and West Bengal are major contributors. About 16% of the papers had international collaboration (with as many as 53 countries). Major collaborating countries in chemical sciences were the US, Germany, Japan and Great Britain.

Introduction

A studied definition of Chemistry goes like this: "Chemistry is one the oldest of the sciences, one of the newest of the sciences, without which modern life would not have been possible." The subject of Chemistry has grown from a study of some twenty-odd elements in the eighteenth century to a study of bonding between atoms in the 1950s (for which Linus Pauling received the Nobel Prize), and further on to investigations on structure, synthesis, dynamics, catalysis and supramolecular assemblies, and today to femtochemistry (study of reactions occurring in femtoseconds, 10^{-15} s). Today, major frontiers of Chemistry relate to Biology and Advanced Materials. Chemistry has overlap regions with several other disciplines, which make for diverse applications of science for humanity. The growth of Chemistry's territory has been phenomenal, and, to quote Prof. C.N.R. Rao, "... chemistry will continue to be dynamic in scope and will continue to provide us with many new frontiers to conquer in the years to come."¹

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Given the spectacular growth and impact of chemistry, it will be interesting to see how research in chemical sciences in India fares vis-à-vis the world scene. Rich countries invest more in resources and naturally reap more in scientific output, which is reflected in the larger number of quality publications. According to a UNESCO report², North America and Europe account for 36.6% and 37.5%, respectively, of the world's scientific publications.

Mapping of research in chemical science in India would help in assessing India's contribution to the world literature in chemical sciences. Such an exercise, based on published literature, has already been made by a number of groups in developed countries. However, such studies as applied to third world countries are rather limited³⁻⁵. Arunachalam *et al.* have mapped India's contribution to literature in mathematics⁶, materials science⁷, biology⁸, medicine⁹ and all of the sciences¹⁰ by using appropriate databases. More recently, Arunachalam and Gunasekaran have mapped such narrow fields as research in diabetes¹¹, tuberculosis¹²

and cardiovascular diseases¹³ as applied to India and China using multiple databases.

This study is an attempt to assess the volume of research performed by Indians in chemical sciences, their share of research to world literature in chemistry, journals in which they publish their results, impact of their publications in terms of journal impact factors, institutions involved in research in chemical sciences, extent of international collaboration, etc. Data for this study was culled from the CD-ROM version of *Chemistry Citation Index* [publication year: 2002]¹⁴.

Methodology

Bibliographic information such as author(s), title, source with year, volume, issue and page, author affiliation, language, and document type were downloaded from the CD-ROM version of *Chemistry Citation Index 2002*, in comma delimited format by giving India in the address field. CD-ROM disks of 2002 and 2003 were searched in order to collect papers with publication year 2002. The downloaded data in text format were converted into database file using Foxpro and analyzed with MS-Access. Only the first Indian address in the affiliation field was considered. Names of institutions as well of Indian towns and cities were standardized. For example, changes in names as from Madras to Chennai, Cochin to Kochi, Bombay to Mumbai, and Calcutta to Kolkata were also taken into consideration. *Journal Citation Reports 2003* was used for data on impact factors of journals. Furthermore, the change in the name of *J. Chem. Soc. Dalton Trans.* to *Dalton Trans.* from 2003 was also noted. Thus, the 2003 IF value of *Dalton Trans.*, which appeared in *Journal Citation Reports 2003* was assigned to that for *J. Chem. Soc. Dalton Trans.* for the year 2002. Countries that publish the journals were found from *Journal Citation Reports 2003*, and assigned two-letter codes as per ISO 3166.

Analysis

In terms of the number of annual publications (including articles, notes, letters, reviews, editorials, meeting abstracts, etc.) India ranked 9th with 3.42% in 1998 and 1999, and 3.41% in 2000; India climbed to the 8th position with 3.6% in 2001, continued to keep its place till 2004, when the percentage of its publications was 4.45%. As a comparison, the Peoples' Republic of China rose from the 7th place with 4.29% in 1998 to the 2nd

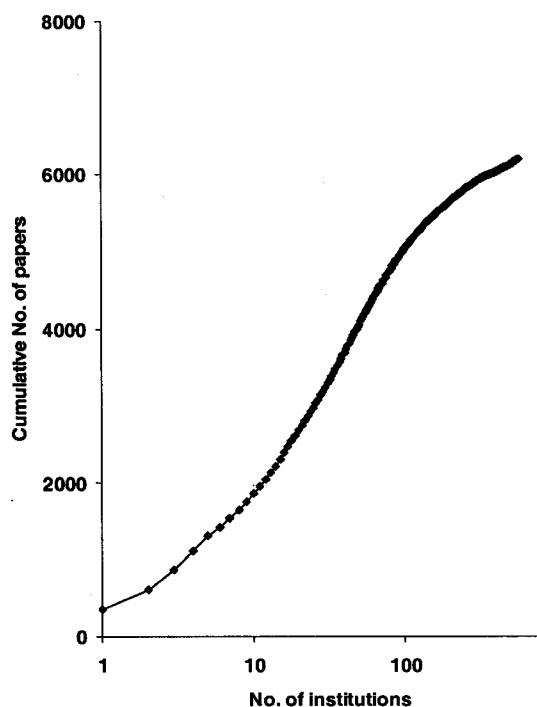


Figure 1- No. of journals vs. cumulative number of papers

place with 11.72% in 2004. Table 1 presents publication profiles in chemical sciences for selected countries from 1998 to 2004 (data derived from *Chemistry Citation Index* – disk years).

A similar trend can be seen in a recent release of statistical summary by the *Chemical Abstracts Services*. India's share to the world literature in chemistry increased from 2.3% in 1997 to 2.6% in 2004 while that of China increased from 6.8% in 1997 to 12% in 2004¹⁵. Incidentally, China's share is second only that of the world leader, the United States. The increase represents a tremendous growth in China's research during last decade.

Publications of Indian authors come in different document types such as articles, biographies, corrections, editorials, letters, meeting abstracts and reviews. In 2002, articles took a major chunk of over 95% of the papers (5933), with 2.7% appearing as reviews (141), 71 meeting abstracts, 19 corrections, 17 editorial materials, 15 letters and 3 biographies. Indian researchers published 6190 papers in English, 6 in Chinese, 2 in German and 1 in Polish.

Table 1 – Distribution of papers indexed in *CCI* [disk years] for selected countries

No.	Country	1998		1999		2000		2001		2002		2003		2004	
		No. of papers	% share	No. of papers	% share	No. of papers	% share	No. of papers	% share	No. of papers	% share	No. of papers	% share	No. of papers	% share
	World	144384		149548		143055		157424		152742		151341		166146	
1	USA	37916	26.26	38394	25.67	34941	24.42	43317	27.52	38658	25.31	31552	20.85	42225	25.41
2	Japan	17295	11.98	17805	11.91	17046	11.92	17102	10.86	16748	10.96	17626	11.65	16681	10.04
3	Germany	14232	9.86	13896	9.29	13228	9.25	13558	8.61	12882	8.43	13080	8.64	13342	8.03
4	France	9847	6.82	9803	6.56	9137	6.39	9628	6.12	9209	6.03	9646	6.37	8948	5.39
5	UK	9170	6.35	9675	6.47	8858	6.19	9464	6.01	8803	5.76	8801	5.82	8826	5.31
6	Russia	7868	5.45	8456	5.65	7811	5.46	7860	4.99	7780	5.09	7769	5.13	7636	4.60
7	Peoples' R China	6194	4.29	8543	5.71	10154	7.10	11636	7.39	13639	8.93	15727	10.39	19476	11.72
8	Italy	5131	3.55	5411	3.62	5181	3.62	5580	3.54	5535	3.62	6143	4.06	5985	3.60
9	India	4945	3.42	5111	3.42	4875	3.41	5664	3.60	6301	4.13	6632	4.38	7387	4.45
10	Spain	4751	3.29	5019	3.36	5123	3.58	5433	3.45	5538	3.63	5605	3.70	5850	3.52
11	Canada	3991	2.76	4090	2.73	3966	2.77	4074	2.59	3861	2.53	4100	2.71	4278	2.57
12	Poland	3148	2.18	3364	2.25	3265	2.28	3839	2.44	3723	2.44	3911	2.58	4514	2.72
13	South Korea	2801	1.94	3168	2.12	3567	2.49	4161	2.64	4515	2.96	4611	3.05	5004	3.01
14	Netherlands	2505	1.73	2595	1.74	2328	1.63	2778	1.76	2531	1.66	2487	1.64	2656	1.60
15	Switzerland	2299	1.59	2499	1.67	2281	1.59	2391	1.52	2207	1.44	2414	1.60	2575	1.55
16	Australia	2232	1.55	2158	1.44	2073	1.45	2169	1.38	2116	1.39	2477	1.64	2308	1.39
17	Sweden	2120	1.47	2023	1.35	2046	1.43	2227	1.41	2154	1.41	2130	1.41	2228	1.34
18	Taiwan	1766	1.22	1963	1.31	1966	1.37	2202	1.40	2323	1.52	2495	1.65	2668	1.61
19	Belgium	1666	1.15	1706	1.14	1596	1.12	1694	1.08	1639	1.07	1847	1.22	1811	1.09
20	Brazil	1549	1.07	1815	1.21	1946	1.36	2410	1.53	2503	1.64	2467	1.63	2598	1.56

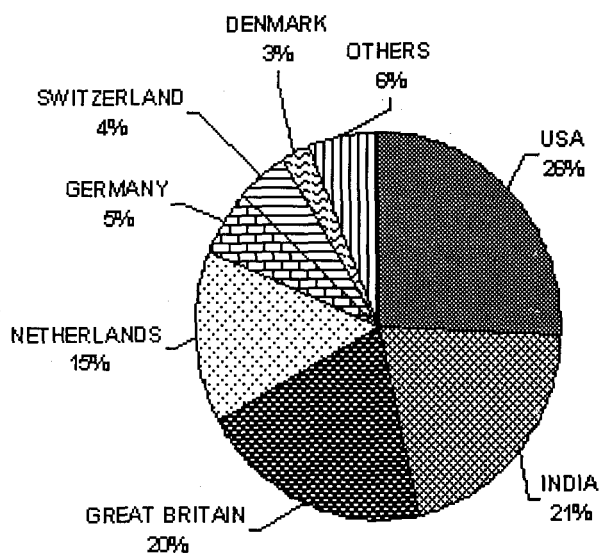


Figure 2- Distribution of papers by country of publication of journals

Indian researchers published 6186 papers from 569 journals shown in Table 2. The top three journals used by Indians were published from India: 269 papers in *Asian Journal of Chemistry* (IF 0.211), 224 papers in *Journal of Indian Chemical Society* (IF 0.275) and 209 papers in *Indian Journal of Chemistry Section B* (IF 0.492). There were 23 Indian journals carrying 1288 papers. Among the Indian journals, 2 papers were published in the *Indian Journal of Microbiology* not indexed in the *JCR 2003*. A plot of the number of journals vs. cumulative number of papers is shown in Figure 1. Apart from journal papers, 13 papers were published in 12 non-journal sources. Among these 6 were articles and 7 were reviews. Non-journal items mainly comprised book series and monographs.

Use of letters journals

Over 14% of Indian papers appeared in Letters Journals. Indian authors published 883 papers in 43 Letters/Communications journals. Of these, 603 papers appeared in 26 letter journals and 280 papers appeared in 17 communication journals. All journals with the "Letters" or "Communication" tag in their titles were considered. Journals such as *Biochem. Biophys. Res. Commun.* (Impact factor 2.836), *Collect. Czech. Chem. Commun.* (Impact factor 1.041) and *Phys. Rep-Rev. Sect. Phys. Lett.* (Impact factor 11.980) were not considered as they

publish regular articles and reviews. Major Letters/Communications journals of relevance were *Tetrahedron Letters* (198 papers), *Materials Letters* (117 papers) and *Synthetic Communications* (105 papers). Indian chemistry researchers published less number of papers in Letters journals as compared to their counterparts in physics¹⁶.

Distribution by journal publishing country

Figure 2 depicts the distribution of the country of origin of journals used by Indian chemical sciences researchers to publish their articles. It can be seen from the table 3, that Indian publications appeared in journals published from 34 countries. Unlike Indian publications in the life sciences, where 55.4% (4630 papers) appeared in 75 Indian journals¹⁷, a majority of Indian papers in chemical sciences appeared in US journals. Thus, 26% (1591 papers) appeared in 169 US-based journals, as against 10.1% (844 papers) in biological sciences that appeared in 294 US journals. About 21% (1288 papers) papers were published in 23 Indian journals. The shares in journals from other countries are as follows: 20% (1267 papers) in 130 British journals; 14.5% (897 papers) in 95 Dutch journals; 5.4% (337 papers) in 48 German journals; and 4.2% (260 papers) in 20 Swiss journals.

Distribution by journal impact factor

Table 4 shows the range of impact factors of journals used by Indian researchers in chemical sciences. Indian researchers and scientists published 6186 papers in 569 journals in 2002. More than 45% of these papers appeared in 229 journals with impact factor less than 1.000. Around 2% of their publications appeared in journals that had no impact factor or are not indexed in *Journal Citation Reports 2003*. About 45% of the papers were published in 270 journals with impact factors between 1.000 and 3.000. Significantly, 336 papers appeared in 36 journals with impact factors between 3.000 and 5.000. More importantly, 51 papers appeared in 14 journals with impact factors between 5.000 and 8.000, and 24 in 8 journals with impact factors greater than 8.000. Of the latter 24 papers, 13 were articles, 8 reviews, 2 editorials and an erratum. Figure 3 illustrates the number of papers and impact factor range of journals used by Indian researchers. Large number of papers appeared in low impact factor range of journals.

Table 2 - Distribution of journals used by Indian researchers in Chemistry in 2002

No.	Journal	Impact factor JCR 2003	Country	No. of papers
1	<i>Asian J Chem</i>	0.211	IN	269
2	<i>J Indian Chem Soc</i>	0.275	IN	224
3	<i>Indian J Chem Sect B</i>	0.492	IN	209
4	<i>Tetrahedron Lett</i>	2.326	GB	198
5	<i>Indian J Chem Sect A</i>	0.489	IN	194
6	<i>J Appl Polym Sci</i>	1.017	US	130
7	<i>Mater Lett</i>	0.774	NL	117
8	<i>Acta Crystallogr E-Struct Rep</i>	0.453	DK	106
9	<i>Syn Commun</i>	0.853	US	105
10	<i>Indian J Heterocycl Chem</i>	0.247	IN	96
11	<i>Tetrahedron</i>	2.641	GB	78
12	<i>J Chem Phys</i>	2.950	US	70
13	<i>Abstr Pap Amer Chem Soc</i>	0.000	US	69
14	<i>Chem Phys Lett</i>	2.438	NL	62
15	<i>Proc Indian Acad Sci-Chem Sci</i>	0.649	IN	60
16	<i>J Mol Catal A-Chem</i>	2.264	NL	58
17	<i>Transit Metal Chem</i>	0.840	NL	56
18	<i>J Radioanal Nucl Chem</i>	0.472	HU	54
19	<i>Bull Electrochem</i>	0.241	IN	53
20	<i>Chem Commun</i>	4.031	GB	52
21	<i>J Phys-Condens Matter</i>	1.757	GB	51
22	<i>Syn Reactiv Inorg Metal-Org C</i>	0.472	US	50
	547 Other Journals			825
	Non-Journal Items			13
	Total			6199

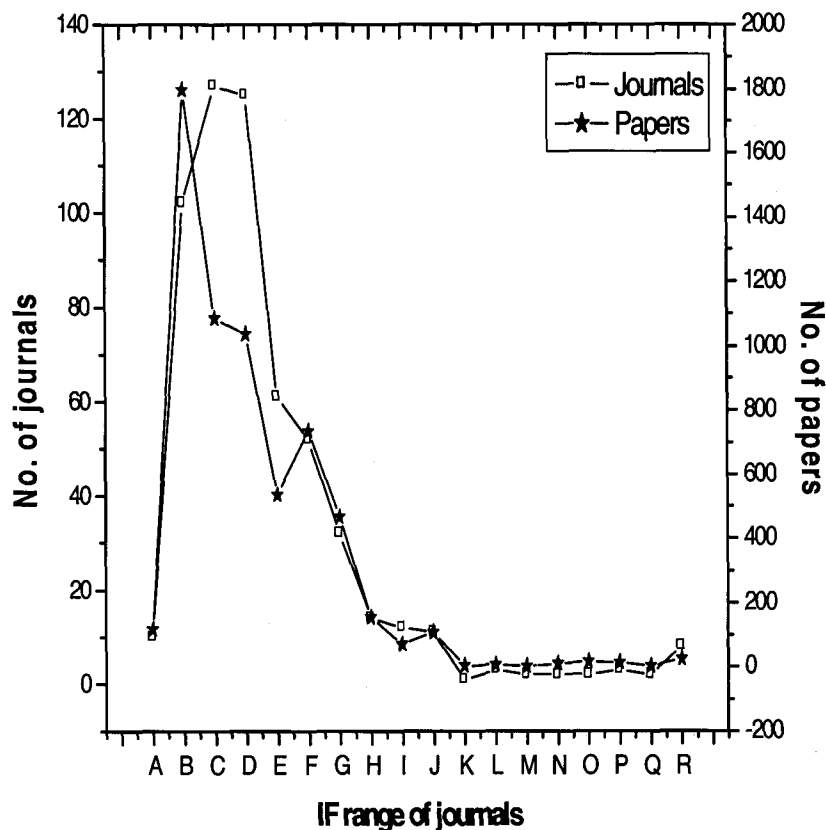


Figure 3 — Number of papers with impact factor range of

Impact factor range

A = 0.000	E = 1.500 – 1.999	I = 3.500 – 3.999	M = 5.500 – 5.999	Q = 7.500 – 7.999
B = 0.000 – 0.499	F = 2.000 – 2.499	J = 4.000 – 4.499	N = 6.000 – 6.499	R = 8.000 <
C = 0.500 – 0.999	G = 2.500 – 2.999	K = 4.500 – 4.999	O = 6.500 – 6.999	
D = 1.000 – 1.499	H = 3.000 – 3.499	L = 5.000 – 5.499	P = 7.000 – 7.499	

Distribution by institution

Institution-wise contribution of Indian researchers in chemical sciences during the year 2002 is given in Table 5. As mentioned above, 6199 papers were published in 2002. These came from 563 institutions. More than a hundred papers originated from ten research institutions (including one university). The most prolific publishing institutions were the Indian Institute of Science, Bangalore; Indian Institute of Chemical Technology, Hyderabad; Bhabha Atomic Research Centre, Mumbai; and National Chemical Laboratory, Pune. A plot of the number of institutions vs. cumulative number of papers is given in Figure 4. Top 20 institutions published papers in high-impact journals. Publications of various

institutions sorted in terms of the impact factor ranges of the journals is provided in Table 6. It can be seen that most of the papers appeared in journals with impact factor between 0.500 and 1.500.

Distribution by city and state

A profile of the number of papers published from various cities and states of India is given in Table 7. Indian publications came from 236 cities, a fact suggesting a wide distribution of talent across the country. Mumbai accounted for the largest number of papers (587), followed by Bangalore (507), Hyderabad (483) and Kolkata (418). As for the states, Maharashtra, Tamil Nadu and Karnataka were the states that accounted for

Table 3 – Distribution of papers by journal publishing country

No.	Journal PublishingCountry	Country Code	No. of journals	No. of papers
1	United States	US	169	1591
2	India	IN	23	1288
3	Great Britain	GB	130	1267
4	Netherlands	NL	95	897
5	Germany	DE	48	337
6	Switzerland	CH	20	268
7	Denmark	DK	7	168
8	Hungary	HU	4	88
9	Japan	JP	12	68
10	France	FR	6	33
11	Bulgaria	BG	1	29
12	Poland	PL	6	18
13	Russia	RU	7	12
14	Canada	CA	4	12
15	Taiwan	TW	3	12
16	Singapore	SG	3	11
17	Peoples R China	CN	7	11
18	Yugoslavia	YU	1	11
19	Turkey	TR	1	11
20	Austria	AT	2	10
21	Italy	IT	2	10
22	Iran	IR	2	8
23	Czech Republic	CZ	2	5
24	South Korea	KR	3	5
25	Spain	ES	2	4
26	Sweden	SE	1	2
27	Latvia	LV	1	2
28	Saudi Arabia	SA	1	2
29	Slovakia	SK	1	1
30	Australia	AU	1	1
31	Croatia	HR	1	1
32	Chile	CL	1	1
33	Slovenia	SI	1	1
34	Romania	RO	1	1
	Non-Journals		12	13
	Total		581	6199

Table 4 – Distribution of papers by impact factor range of journals

Journal impact factor range (JCR 2003)	No. of journals	No. of papers
0.000	10	117
0.000 - 0.499	102	1797
0.500 - 0.999	127	1086
1.000 - 1.499	125	1037
1.500 - 1.999	61	536
2.000 - 2.499	52	736
2.500 - 2.999	32	466
3.000 - 3.499	14	154
3.500 - 3.999	12	70
4.000 - 4.499	11	108
4.500 - 4.999	1	4
5.000 - 5.499	3	6
5.500 - 5.999	2	2
6.000 - 6.499	2	10
6.500 - 6.999	2	16
7.000 - 7.499	3	14
7.500 - 7.999	2	3
8.000 <	8	24
Total	569	6186

Note: Only publications in journals were considered. The figures in this table exclude non-journal items. Table 5- Distribution of papers by institution

Table 5 — Distribution of papers by institution

No.	Institution	No. of papers
1	Indian Inst Sci, Bangalore	345
2	Indian Inst Chem Technol, Hyderabad	263
3	Bhabha Atom Res Ctr, Mumbai	259
4	Natl Chem Lab, Pune	246
5	Indian Assoc Cultivat Sci, Kolkata	190
6	Indian Inst Technol, Kanpur	118
7	Indian Inst Technol, Kharagpur	112
8	Indian Inst Technol, Mumbai	108
9	Univ Hyderabad, Hyderabad	107
10	Indian Inst Technol, New Delhi	104
11	Mumbai Univ Inst Chem Technol Muict, Mumbai	96
12	Univ Rajasthan, Jaipur	91
13	Indian Inst Technol, Chennai	89
14	Univ Mysore, Mysore	88
15	Anna Univ, Chennai	87
16	Univ Madras, Chennai	84
17	Banaras Hindu Univ, Varanasi	80
18	Jadavpur Univ, Kolkata	71
19	Jawaharlal Nehru Ctr Adv Sci Res, Bangalore	71
20	Cent Leather Res Inst, Chennai	67
21	Reg Res Lab, Thiruvananthapuram	65
22	Madurai Kamaraj Univ, Madurai	61
23	Univ Delhi, Delhi	60
	540 Other Institutions	3337
	Total	6199

the largest number of papers. Top 11 states produced over 92% of the papers while the top 11 cities accounted for 56% of the papers.

Collaboration

The year 2002 had 2338 collaborative papers. Domestic collaboration resulted in 1348 papers, while international collaboration yielded 990 papers. About 16% of these

papers came from international collaboration in chemistry alone. Table 8 shows details of national and international collaboration. The number of countries with which Indian chemical sciences researchers collaborated was 53, although a majority of the collaborative projects were with the USA, Germany and Japan (Table 9). It is pertinent to note that the UK, which was a major destination for Indian students and a major collaborator in the yesteryears has been relegated to 4th place. UK's

Table 6- Distribution of papers by institutions vs. impact factor range of journals

No.	Institution	No. of papers	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	Non-JrIs.
1	Indian Inst Sci, Bangalore	345	4	27	35	72	35	57	65	7	10	18		3		2	3	2		5	
2	Indian Inst Chem Technol, Hyderabad	263	13	19	42	10	24	88	41	8	6	8	1			2					1
3	Bhabha Atom Res Ctr, Mumbai	259		51	53	53	24	31	37	2	5			1		2					
4	Natl Chem Lab, Pune	246	10	12	17	30	35	57	39	17	7	13				1	3		2	1	2
5	Indian Assoc Cultivat Sci, Kolkata	190	1	16	24	35	31	32	29	15	4	1								1	1
6	Indian Inst Technol, Kanpur	118	1	9	14	15	13	18	11	21	1	9			1		2	1		2	
7	Indian Inst Technol, Kharagpur	112	1	20	31	34	4	12	2	5		2								1	
8	Indian Inst Technol, Mumbai	108	1	8	7	21	18	21	17	6	2	6								1	
9	Univ Hyderabad, Hyderabad	107	2	4	18	11	9	10	21	9	2	9	1			4	1	1		4	1
10	Indian Inst Technol, New Delhi	104	4	11	24	24	11	19	8	1							1				1
11	Mumbai Univ Inst Chem Technol Muict, Mumbai	96	1	22	25	19	10	11	5	2			1								
12	Univ Rajasthan, Jaipur	91		57	18	4	4	4	3	1											
13	Indian Inst Technol, Chennai	89	3	9	14	15	8	21	9	4	5	1									
14	Univ Mysore, Mysore	88	4	37	15	20	4	7	1												
15	Anna Univ, Chennai	87		6	25	39	5	8	1	1		2									
16	Univ Madras, Chennai	84		28	24	8	9	10	5												
17	Banaras Hindu Univ, Varanasi	80		26	12	22	13	6		1											
18	Jadavpur Univ, Kolkata	71		13	16	10	9	8	8	6	1										
19	Jawaharlal Nehru Ctr Adv Sci Res, Bangalore	71		3	3	21	4	9	13	3	2	4					3			6	
20	Cent Leather Res Inst, Chennai	67	2	5	20	17	4	4	7	3	2	2		1							
21	Reg Res Lab, Thiruvananthapuram	65		4	10	8	10	10	8	3	3	7				1				1	
22	Madurai Kamaraj Univ, Madurai	61	1	31	6	11	4	2	4	2											
23	Univ Delhi, Delhi	60	2	17	9	12	9	7	2			2									
	540 Other Institutions	3337	67	1362	624	526	239	284	130	37	20	24	1	1	1	2	3	6	1	2	7
	Total	6199	117	1797	1086	1037	536	736	466	154	70	108	4	6	2	10	16	14	3	24	13

Impact factor range

A = 0.000	E = 1.500 - 1.999	I = 3.500 - 3.999	M = 5.500 - 5.999	Q = 7.500 - 7.999
B = 0.000 - 0.499	F = 2.000 - 2.499	J = 4.000 - 4.499	N = 6.000 - 6.499	R = 8.000 <
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D = 1.000 - 1.499	H = 3.000 - 3.499	L = 5.000 - 5.499	P = 7.000 - 7.499	

Table 7- Distribution of papers by Indian cities and states

No.	City	No. of papers	State	No. of papers
1	Mumbai	587	Maharashtra	1092
2	Bangalore	508	Tamil Nadu	770
3	Hyderabad	483	Karnataka	754
4	Kolkata	418	Andhra Pradesh	698
5	Chennai	368	West Bengal	671
6	Pune	319	Uttar Pradesh	598
7	Delhi	318	Delhi	318
8	Kanpur	162	Kerala	236
9	Kharagpur	115	Gujarat	208
10	Mysore	113	Madhya Pradesh	185
11	Thiruvananthapuram	105	Rajasthan	161
	225 Other Cities	2703	15 Other States	508
	Total	6199	Total	6199

position has been usurped by such countries as Germany, Japan, etc. It is against this backdrop that the British Government has come forward with a 10 million pound programme for forging scientific ties with India (*The Hindu*, August 28, 2005¹⁸). Internationalization index was calculated in Table 8 as suggested by Frame and Carpenter¹⁹, according to which the value for the international link is equal to the number of countries with which a given country is collaborating.

$$\text{Internationalization index} = \frac{100 \times \text{number of international links}}{\text{total number of papers from the country}}$$

Collaborative research between developed and developing nations is increasing steadily in recent years²⁰ in all areas of science and technology as can be deciphered from the annual editions of the *Science Citation Index*. India accounts for 17.6% of internationally co-authored papers²¹. Patterns of

Table 8 — Distribution of papers by number of nations collaborating with Indian scientists

No. of Nations	No. of papers
Two	874
Three	103
Four	11
Seven	2
Total papers	6199
Collaborative papers	2338
Domestic collaboration	1348
International collaboration	990
% Internationally collaborated papers	15.97
No. of international links	1125
Internationalization Index	18.14

Table 9 - Nations collaborating with India in chemical research

No.	Nations	No. of papers
1	USA	231
2	Germany	171
3	Japan	114
4	Great Britain	90
5	France	78
6	Taiwan	61
7	Italy	40
8	Canada	37
9	South-Korea	31
10	Spain	28
11	Malaysia	26
12	Netherlands	21
13	Peoples-R-China	21
14	Switzerland	16
15	Australia	15
16	Mexico	13
17	Poland	12
18	Denmark	10
19	Belgium	9
20	Finland	9
21	Russia	9
22	Singapore	9
23	Portugal	6
24	Sweden	6
25	Hungary	5
26	Israel	5
27	Norway	5
28	Austria	4
29	Czech-Republic	4
30	Iran	3
31	Ireland	3
32	New-Zealand	3
33	South-Africa	3
34	Thailand	3
35	Argentina	2
36	Brazil	2
37	Chile	2
38	Egypt	2
39	Tunisia	2
40	Algeria	1
41	Bangladesh	1
42	Bhutan	1
43	Ethiopia	1
44	Greece	1
45	Macedonia	1
46	Nepal	1
47	Nigeria	1
48	Oman	1
49	Romania	1
50	Slovenia	1
51	Turkey	1
52	Ukraine	1
53	Yugoslavia	1
	Total	1125

domestic and international collaborative research in various main and subfields can be seen in earlier publications ²².

Outlook

Going by the number of publications, chemical research in India accounted for 2.6% of the world output in 2004. This is meager compared to 12% for China, which ranks next to the world leader, the USA. The recent past has witnessed a giant leap in China's research profile. It would be both ideal and educative to juxtapose input indicators when measuring the output. The share of national resources spent on R&D in India declined from a peak of 0.98% in 1988 to 0.66% in 1997, and recovered slightly to 0.8% in 2000 ²³. There is a need for strengthening research in chemical sciences in India in order to tackle the crucial problems such as energy production and environment conservation in the country. Although this study is limited to chemical sciences research in India, it could provide useful indicators for policy makers, scientists and science administrators to reorient research priorities. A study such as this would be more meaningful if it is extended to an analysis of publication patterns of Indian chemical scientists over a longer period.

Accessing information plays a vital role in the production of scientific knowledge. Unlike the past, the present era of information and communication technologies has opened up opportunities for researchers around the world. Even though many STM journals come in electronic version for free or paid access, the fledgling concept of open access publishing has already made a great impact on research communities. The Open Archives Initiative is a boon to researchers in developing countries, especially to publicize their findings in their own institutional archives. It is time that Indian institutions set up institutional archives to publicize their research. An encouraging development here is that several commercial and society-based publishers today allow authors to include their research publications in their own institutional self archives. Suber²⁴, Chan²⁵, and Arunachalam²⁶ stress the importance of open access and how it benefits developing countries to overcome barriers to accessing research information. It is noteworthy that the universities in the UK have joined calls for open access to publicly-funded research through the Internet ²⁷.

Conclusions

An analysis of the 2002 *Chemistry Citation Index* shows that chemical sciences research in India is carried out in 563 institutions. Top 10 institutions—including the Indian Institute of Science and four Indian Institutes of Technology—published more than a hundred papers in 2002. A value of 15.9% for the extent of international collaboration in chemical sciences fades in comparison with a value of 17.6% for all the sciences¹⁸. Around 50% of papers appeared in journals with medium impact factor, between 1.000 and 5.000. Furthermore, it is necessary to look into citation counts for each paper to assess its real value. The study is also limited in the sense that the results and conclusion are drawn based only on papers published by Indian researchers in journals indexed in the *Chemistry Citation Index*. Moreover, a subfield analysis would provide a more comprehensive picture of India's research output. It is also necessary to classify the category of fields by viewing the subject contents.

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