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A Scientometric Analysis of S&T Publications Output by India during 1985-2002

B.M. Gupta and S.M. Dhawan*

National Institute of Science, Technology & Development Studies
Dr K.S.Krishnan Marg, New Delhi-110 012
E-mail: bmgupta1@yahoo.com; bmgupta@nistads.res.in

**Library & Information Science Consultant*
114 Dayanand Vihar, New Delhi-110 092
E-mail: smdhawan@yahoo.com

ABSTRACT

The paper analyses India's publications output in three major international multidisciplinary databases, as indexed during 1981-2005. It reports on India's comparative strength in world science and technology (S&T) output, its growth and decline, its strong and weak subject areas of research, media of communication, its collaborative profile and quality of S&T output, institutional productivity and quality, and dynamics of Indian research at institutional and sectoral levels. The study also provides suggestions for improving the quantity and quality of research S&T in India.

Keywords: S&T analysis, India, research, institutional productivity.

1. INTRODUCTION

At the time of independence, the S&T base of the country was small. Today, it is much wider comprising more than 300 universities, 400 R&D institutions, 13 institutes of national importance, 1300 in-house industrial R&D units, and number of private and non-profitable organisations covering several disciplines. There has been steady rise in the government support to S&T from Rs 760.5 crore in 1980-81 to Rs 16, 361 crore in 2005-06. Despite its glorious record of achievements in several areas of S&T, the pace of growth of the scientific enterprise (particularly in terms of scientific output) in India has been slow compared to many other countries. Several past studies conform this finding.[1-12] There is an urgent need to relook at this issue in the context of recent publications data on India science.

2. OBJECTIVE

The main objective of this study is to ascertain India's status in S&T research by analysing its published research output as reported in journals. In particular, it seeks to understand its growth and decline in S&T research, its world share, its strong and weak subject areas of research, media of communication, its collaborative profile and quality of S&T output, institutional productivity and quality, and dynamics of Indian research at institutional and sectoral levels. Such a study is significant in providing the planners and policy makers quantitative data as required for microanalysis of current trends in S&T research and identifying thereby directions that the country should take to move ahead in S&T research as a global leader.

This article is based on the Report on Measurement of the Progress of Science in India: An Analysis of Publication Output in Science and Technology. New Delhi; Office of the Principal Scientific Adviser to the Government of India. http:// www.psa.gov.in

3. METHODOLOGY AND DATA SOURCE

The past scientometric studies that reported stagnation/decline in Indian science, were based mainly on *Science Citation Index* (SCI) database. The coverage of Indian journals in the *SCI* database is small, limited to select few journals, even though India publishes more than 1500 peer-reviewed journals. For better assessment of Indian science, SCIE Edition of *Web of Science* was used. It provides wider coverage of Indian journals and of journals from other developing countries. *Indian Science Abstracts* was deliberately not used for this study, though its coverage of Indian journals is much wider, for the reason that it does not provides citations on papers published. The citations data (as on February 2004) was used for undertaking qualitative analysis of India's publications output.

For studying shift in citations on time series basis, three publications data sets, i.e., 1985-1986, 1993-1994, and 2001-2002 were used. The time interval between the sets is eight years, and each set comprises publications data from two contiguous years, instead of one year, as has been the trend in the past for conducting such type of studies. The study examines publications period from 1985 to 2005 for studying growth trends. Besides, the study has looked at metrics on publications from India in *SCI* and *SCOPUS* databases for comparative analysis.

The study used both absolute and relative indices such as (i) average impact factor (IF) per paper, (ii) average citation per paper, (iii) share of collaborative and international collaborative papers, (iv) activity index, and (v) composite quality index (CQI). The *CQI* is an integrated measure of quality and is derived by averaging the summation of four relative indicators: (i) relative IF index, (ii) relative citation index, (iii) collaborative index, and (iv) international collaboration index. Specialisation index (SI) is a relative indicator which measures the extent to which institutional share in the given sub-field compares with the country share in the same sub-field, normalised between 1 and -1. Further, SI values above 0.5 indicate that the level of specialisation of the institution is high, whereas values between 0.2 and 0.5 and between -0.2 and 0.2 indicate that institutional specialisation is above average or just average, respectively.

4. GROWTH OF INDIAN S&T OUTPUT

The publications data in SCIE Edition of *Web of Science* revealed that the country had achieved annual average growth of 2.51 per cent in S&T during 1985-2002, 5.96 per cent during 1996-2005, and 10.5 per cent during 2000-05. India published 13,634 papers in S&T in 1985, which rose to 28,603 in 2005 (Fig. 1, Table 1).

The pace of country growth in S&T research publications is accelerating and its output is expected to touch 38,000 papers by 2010. Despite clocking faster publications growth rate in the later periods, India's world share did not show any significant change with time. Its world share marginally improved from 1.68 per cent to 1.77 per cent (as seen from *SCI* database) and from 2.03 per cent to 2.08 per cent (as seen from *SCIE* database) during 1993 to 2003 (Table 2).

India's growth rate as computed on publications data drawn from three different databases *SCI, SCIE* and *SCOPUS* has been found to differ. The five yearly average growth rate as computed on five yearly cumulative data was 6 per cent in *SCI*, and 8 per cent in *SCIE* during 1986-90 and 1991-95. It was 32 per cent and 33 per cent, respectively during 1991-95 to 2001-05. *SCOPUS* also showed 32 per cent growth rate during the same period (Table 3).

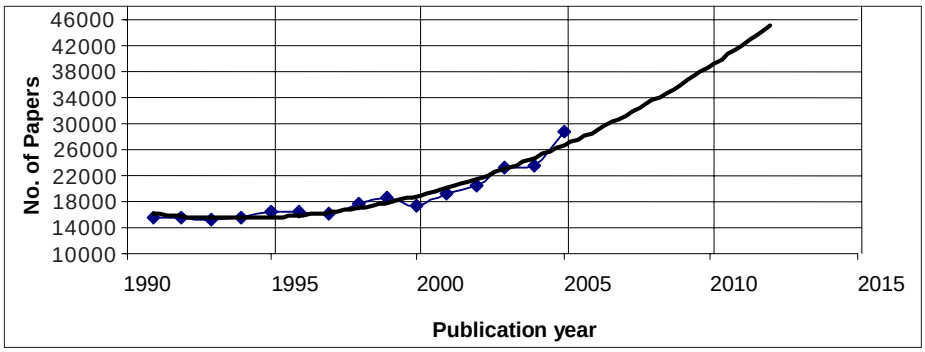

Figure 1. India's Publications Output in S&T Research during 1991-2005.

Table 1. India's research output in *SCI*, *Web of Science*, *SCOPUS* and *PASCAL*

Year	*SCI*	Web *SCIE*	Year	*SCI*	Web *SCIE*	Year	*SCI*	Web *SCIE*	*SCOPUS*	*PASCAL*
						1996	11177	16486	19609	7628
						1997	11067	16269	20197	9372
1981	13119	16064	1988	10208	14165	1998	12128	17740	20882	9543
1982	12124	14948	1989	10426	15180	1999	12521	18726	22255	9493
1983	12059	14325	1990	10103	14405	2000	12127	17501	22341	9674
1984	10600	14619	1991	10468	15532	2001	13425	19339	22879	9014
1985	11222	13634	1992	11160	15446	2002	14028	20405	24341	11239
1986	10854	14176	1993	10978	15340	2003	15699	23135	29067	10972
1987	10239	14321	1994	11319	15652	2004	16001	23336	31110	10890
1988	10208	14165	1995	11084	16373	2005	19448	28603	32474	10068

Table 2. India's world share in different multidisciplinary databases

Databases	Publications output by India			India's share in world publications output (%)		
	1993	1998	2003	1993	1998	2003
SCI	10978	12128	15699	1.68	1.57	1.77
Web *SCIE*	15340	17735	23138	2.03	1.85	2.08
PASCAL	NA	7628*	10068**		1.76*	2.11**

* 1996, ** 2005

Table 3. India's cumulative publications output in different multidisciplinary S&T databases

Period	Cumulative publications count				% Growth rate			
	Web *SCI*	*SCI*	*SCOPU*	*PASCAL*	Web	*SCI*	*SCOPUS*	*PASCAL*
1981-85	73590	59124						
1986-90	72247	51830			- 1.82	-12.33		
1991-95	78343	55009			+ 8.44	+6.13		
1996-00	86722	59020	105284	45710	+ 10.69	+7.29		
2001-05	114818	78601	139871	52183	+32.40	+33.17	+32.85	+14.16

5. ANALYSES AND RESULTS

5.1 Broad Publications Characteristics

India published 27,810 papers from 1734 institutions during 1985-1986; 30,992 papers during 1993-1994 from 2223 institutions; and 39,744 papers during 2001-2002 from 3443 institutions. Only 10 per cent institutions, which comes to 181 institutions during 1985-86, 215 during 1993-94, and 310 during 200-02 account for about 80 per cent of the country's S&T output.

It shows that majority are low productivity institutions and high productivity research seems to be confined to few selected institutions only. India's S&T output appearing in foreign journals far exceeds the output that appeared in Indian journals. For example, output was reported in only 26 Indian journals during 1985-86 out of a total of 2113 journals, 44 during 1993-94 out of a total of 2558 journals, and 49 during 2001-02 out of a total of 3359 journals (Table 4).

India is spreading out its research papers in far too many journals: 2113 during 1985-86; 2558 during 1993-94; and 3359 during 2001-02, respectively. This leads to low visibility of Indian research output in some of the journals. The presence of Indian papers in 90 per cent journals has been found to

Table 4. Indian and foreign journals reporting India's research output

Journal category	Type	Period		
		85-86	93-94	01-02
Indian	No. of journals	26	44	49
	No. of papers	6586	6724	7582
	Average IF per paper	0.15	0.12	0.12
	Average citations per paper	2.06	1.65	0.58
Foreign	No. of journals	2085	2514	3309
	No. of papers	16567	20364	27560
	Average IF per paper*	0.62	1.03	1.25
	Average citations per paper	6.35	6.45	2.58
Total Data	No. of journals	2111	2258	3358
	No. of papers	23153	27088	35142
	Average IF per paper	0.748	0.806	1.229
	Average Citations per paper	4.92	5.26	2.15

* *Average impact factor per paper has been computed on journal impact factor. It is an indicator devised to understand change in the quality of journals that authors used to publish their papers over different periods.*

be low varying (per journal) between 1 and 10 in two publications years. Such a low visibility of Indian papers in journals hardly helps authors to receive high citations, even if such papers were published in high impact journals (Table 5).

5.2 Publications Output by S&T Sector

The institutions pursuing S&T research in India are categorised broadly as Institutes of National Importance (INI), Universities and Colleges, Mission-oriented R&D, Industry and others. The institutions under the universities and colleges include universities, deemed universities, inter-university centres, general colleges, medical colleges, and special institutions.

Those under the mission-oriented R&D sector fall under the administrative and financial control of R&D agencies/departments as well as socio-economic ministries/departments of Central/State governments. The institutions under the industry sector include both private and public enterprises. Institutions classed as others derive their funds from international, private and non-profitable sources (Table 6).

The universities and colleges sector institutions contributed the largest but declining share (from 52.2 per cent to 46.6 per cent) during 1985-86 and 2001-02. In contrast, mission-oriented R&D sector showed rise in its publications share from 28.37 per cent to 37.93 per cent, followed by INI from

Table 5. Productivity range of journals covering Indian S&T output

No. of papers	Number of journals			No. of papers	Number of journals		
	85-86	93-94	01-02		85-86	93-94	01-02
1	625	729	929	9	49	63	82
2	309	388	506	10	41	49	52
3	187	253	345	11-15	138	159	230
4	158	166	174	16-20	75	87	120
5	101	145	174	21-40	109	141	191
6	113	96	142	41-60	35	47	51
7	58	91	102	> 60	55	76	99
8	60	68	82	Total	2113	2558	3359

Table 6. Distribution of publications output by sector

Type of S&T institution	Publications output			% share of output			% growth rate over 16 years
	85-86	94-95	01-02	85-86	94-95	01-02	85-86 & 01-02
Univ. & colleges	12095	12324	16403	52.24	45.50	46.68	35.62
INI	3990	4978	7175	17.23	18.38	20.42	79.82
R&D	6569	9218	13329	28.37	34.03	37.93	102.91
Industry	411	496	708	1.78	1.83	2.01	72.26
Others	235	562	1237	1.01	2.07	3.52	426.38
Total	23153	27088	35142	100.00	100.00	100.00	51.78

17.23 per cent to 20.42 per cent, and industry from 1.78 per cent to 2.01 per cent during the corresponding period. The universities and colleges sector is the largest in terms of size of institutional participation (accounting for 48-50 per cent share), followed by mission-oriented R&D institutions (22-30 per cent), industry (14-20 per cent), and INI (less than 1 per cent) during 1985-86 and 2001-02 (Table 7).

Mission-oriented R&D sector showed the fastest growth in publications output in 16 years (102.9 per cent), followed by INI (79.8 per cent), and Industry (72.2 per cent). The growth in universities and colleges sector (accounting for the largest institutional participation) showed the slowest growth (35.6 per cent) and well below the country average growth of 51.7 per cent (Table 6).

5.3 Growth in Collaborative Research

S&T research in the country is fast emerging as a network activity with institutions from various sectors collaborating at national and international level. The country witnessed significant rise in collaborative research (from 1700 to 14,104 papers during 1985-86 and 2001-02). Collaborative share of the country output rose from 7.34 per cent to 45.10 per cent during the corresponding period. Among the sectors, collaborative share was (14.8 per cent during 1985-86 and 61.1 per cent during 2001-02) highest in the industry sector, followed by INI (12.4 per cent during 1985-86 and 50 per cent during 2001-02), mission-oriented R&D (8.51 per cent during 1985-86 and 46.8 per cent during 2001-02), and universities and colleges (7.4 per cent during 1985-86 and 45.1 per cent during 2001-02) are the lowest (Tables 8 and 9).

Collaborative research has shown faster growth rate (729.6 per cent) than the country growth rate in S&T publications (51.78 per cent). Mission-oriented R&D sector has shown the fastest growth rate in collaborative research output (1017 per cent) compared to 102.9 per cent in total papers over 16 years, followed by universities and colleges (726 per cent compared to 35.6 per cent), INI (620 per cent, 79.8 per cent), respectively during the corresponding periods (Tables 8 and 9).

Collaborative research at national level is greater than that at international level as seen from publications count (Table 10). It implies that attention in collaborative research at national level is greater than at international level. India's partnership with other countries for collaborative research had increased with time (from 70 to 96 and to 113 countries during 1985-86, 1993-94 and 2001-02, respectively). These countries include the USA and Canada (in North America), Germany, the UK, France, Italy, the Netherlands, Switzerland,

Table 7. Distribution of institutions in S&T by sector

Type of S&T institution	Number of institution			% share of the total institutions			% growth rate over 16 years
	85-86	94-95	01-02	85-86	94-95	01-02	85-86 to 01-02
Univ. & Colleges	882	1001	1672	50.87	45.03	48.56	89.57
INI	12	12	13	0.69	0.54	0.38	8.33
R&D	525	676	785	30.28	30.41	22.80	49.52
Industry	156	197	345	11.36	8.86	10.02	121.15
Others	159	337	628	9.17	15.16	18.24	294.97
Total	1734	2223	3443	100.0	100.0	100.00	98.56

Table 8. Collaborative papers as a share of country output by sector

Sector	Total papers			Total collaborative papers (TCP)			% TCP		
	85-86	93-94	01-02	85-86	93-94	01-02	85-86	93-94	01-02
Univ. & Colleges	12095	12324	16403	895	1816	7397	7.40	14.74	45.10
INI	3990	4978	7175	498	999	3588	12.48	20.07	50.01
R&D	6569	9218	13329	559	1500	6245	8.51	16.27	46.85
Industry	411	496	708	61	128	433	14.84	25.80	61.16
Others	235	562	1237	33	142	642	14.04	25.27	51.90
Total	23153	27088	35142	1700	3691	14104	7.34	13.63	40.13

Table 9. Growth rate in collaborative research by sector

Sector	Total papers			Total collaborative papers (TCP)			% Growth over 16 years 85-86 to 01-02	
	85-86	93-94	01-02	85-86	93-94	01-02	Country	TCP
Univ. & Colleges	12095	12324	16403	895	1816	7397	35.62	726.48
INI	3990	4978	7175	498	999	3588	79.82	620.48
R&D	6569	9218	13329	559	1500	6245	102.91	1017.17
Industry	411	496	708	61	128	433	72.26	609.84
Others	235	562	1237	33	142	642	426.38	1845.45
Total	23153	27088	35142	1700	3691	14104	51.78	729.65

Table 10. Share of national and international collaborative publications

Period	TP	TCP	TNCP	TICP	% TCP/TP	% TNCP/TP	% TICP/TP
85-86	23153	1700	996	704	7.34	4.30	3.04
93-94	27088	3691	2168	1523	13.63	8.00	5.62
01-02	35142	14104	8109	5995	40.13	23.07	17.06

TP = Total papers; TCP = Total collaborative papers; TNCP = Total nationally collaborative papers; TICP = Total internationally collaborative papers

Spain, Sweden, Belgium, Russia, Denmark, Poland, Hungary, Norway, and Finland (in Europe), Japan, Taiwan, China, South Korea, Singapore, Malaysia, Bangladesh, Israel, Thailand and Iran (in Asia), Australia and New Zealand (in Oceania), Brazil and Mexico (in South America), and South Africa. Collaborative research at international level has increased significantly.

It was the largest with North America (increased from 373 to 2379 papers), followed by the Europe (from 292 to 2,763 papers), Asia (from 77 to 1,381 papers), Oceania (from 11 to 177 papers), Africa (from 19 to 145 papers), and South America (6 to 147 papers) during 1985-86 to 2001-02. Despite absolute increase in collaborative papers at international level, India's collaborative share with the USA had declined from 43.8 per cent to 35.1 per cent, and with Canada from 9.52 per cent to 4.91 per cent during 1985-86 to 2001-02. On the other hand, its collaborative share with the European countries had been on rise (Table 11).

At subject level, collaborative share was the largest in chemistry, followed by clinical medicine, physics, biomedical science, basic life sciences, and engineering during 1985-86 to 2001-02. Collaborative share of publications showed rise in physics (from 16 per cent to 26.1 per cent) and in engineering (from 10 per cent to 20.7 per cent) in contrast to decline in biomedical sciences (from 15.3 per cent to 8.97 per cent) and clinical medicine (from 19.4 per cent to 13.5 per cent) during 1985-86 to 2001-02.

Table 11. India's collaborative S&T output with partner countries

Country	Co-authored papers by India with partner countries			Country	Co-authored papers by India with partner countries		
	85-86	93-94	01-02		85-86	93-94	01-02
USA	309	634	2107	Brazil	5	20	85
Germany	71	162	866	Singapore	2	5	83
UK	99	174	703	Russia	22	61	77
Japan	44	120	608	Malaysia	3	6	77
France	30	109	433	Denmark	3	11	63
Canada	67	96	294	Poland	8	18	63
Italy	33	82	235	Bangladesh	1	12	58
Australia	11	55	159	Israel	2	9	57
Taiwan	0	3	158	Mexico	6	14	51
China	2	39	151	South Africa	1	8	48
Netherlands	9	46	133	Thailand	3	10	45
Switzerland	22	19	118	Hungary	8	9	42
Spain	3	19	118	Norway	1	8	38
South Korea	0	6	106	Finland	2	8	37
Sweden	16	25	101	Austria	16	18	36
Belgium	10	21	88	Iran	1	1	33

5.4. Impact of Research Output

A significant share of India's research output in S&T (75 per cent to 80 per cent) is published in low impact journals (IF between 0.01 and 1.99), and 8 per cent to 15 per cent in medium impact journals (IF between 2 and 3.99) and 0.96 per cent to 5.12 per cent in high impact journals (IF 4 and above). In addition, India published 3.5 per cent to 10.8 per cent of its output in zero impact journals. The marginal rise in country share in medium and high impact journals coupled with corresponding decline in its share in zero and low impact journals is indicative of rising trend in the quality of India's overall research output, even though the rise so discovered is still not significant (Tables 12 and 13). The mission-oriented R&D sector showed the highest average IF per paper (1.454), followed by INI (1.37), universities and colleges (0.975), and industry (0.945)

Table 12. Average impact per paper

Type of S&T institution	85-86	93-94	2001-02	% rise
Universities	0.631	0.660	0.975	54.52
INI	0.910	0.906	1.370	50.55
R&D	0.869	0.944	1.454	67.32
Industry	0.644	0.647	0.945	46.74
Others	0.621	1.041	1.691	172.30
Total	0.748	0.806	1.229	64.30

Note: Per cent rise refers to change from 85-86 to 2001-02 over 16 years

Table 13. Per cent share of country output by journal IF

JI IF Range	85-86	93-94	2001-02
0.000–0.000	10.88	4.84	3.53
0.001–1.999	80.01	84.42	76.29
2.000–3.999	8.13	8.9	15.06
4 and more	0.96	1.83	5.12
	99.98	99.99	100

sectors in 2001-02. All the S&T sectors have shown rise in their average impact factor per paper during 1985-86 to 2001-02, the highest being in mission-oriented R&D sector (67.3 per cent), followed by universities and colleges (54.5 per cent), and INI (50.5 per cent) and Industry (46.7 per cent) sectors. It shows that the R&D sector has made relatively significant progress in its average IF by switching to higher IF journals for publishing its research papers.

India's share of high-cited papers (those receiving 20 or more citations per paper) is around 4.8 per cent to 5.45 per cent, and of medium cited papers (receiving 5 to 19 citations per paper) it is moderate (24.4 per cent to 26.8 per cent). A major share of the country's output (28 per cent to 30 per cent) failed to receive any citation since their publication in 1985-86 and 1993-94 (Table 14). In this study, only cumulated citations received by papers since their publications in 1985-86 and 1993-94 (till February 2004) were considered for analysis.

Table 14. Country output distributed by citations received per paper

Citations range	85-86 %	93-94 %	2001-02 %
0–0	30.08	28.09	44.28
1–4	40.68	39.68	42.44
5–19	24.44	26.83	12.31
20 and more	4.8	5.4	0.97

5.5 Institutional Productivity and their Ranking

The numerical strength of high productivity institutions in S&T in the country is very low. In all, only 24 institutions had been successful in publishing 300 or more papers each during the three study periods 1985-86, 1993-94, or 2001-02. Their publications activity showed rise over time. During 1985-86 to 2001-02, it was fastest in Anna University (ANNAUM), Chennai; and Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Bangalore; followed by Indian Institute of Chemical Technology (IICT), Hyderabad; Saha Institute of Nuclear Physics (SINP), Kolkata; All India Institute of Medical Sciences (AIIMS), New Delhi; and Bombay University (BOMBUB), Mumbai. There was no change in the activity index of publications in case of Bhabha Atomic Research Centre (BARC), Mumbai, whereas institutions like Indian Institute of Technology (IIT), Delhi; IIT, Chennai; Punjab University (PANJUC), Chandigarh; and Banaras Hindu University (BANAUV), Varanasi showed decline in their activity index during the corresponding period (Table 15).

The institutions were compared on selective line indicators of performance. In terms of research impact per paper, four institutions namely JNCASR, Bangalore; TIFR, Mumbai; HYDEUH, Hyderabad; and SINP, Kolkata topped the list (IF per paper of 2 and above). Five institutions namely Indian Institute of Science (IISc), Bangalore; National Chemical Laboratory (NCL), Pune; AIIMS, New Delhi; IICT, Hyderabad; and Indian Association for Cultivation of Science (IACS), Kolkata showed medium IF (1.5 to 1.99) during 2001-02. The maximum rise in IF per paper from 1985-86 to 2001-02 was observed in JNCASR, Bangalore followed by NCL, Pune; IICT, Hyderabad; IISc, Bangalore; AIIMS, New Delhi; BOMBUB, Mumbai; and IIT, Mumbai (Table 16).

JNCASR, Bangalore; TIFR, Mumbai; NCL, Pune; HYDEUH, Hyderabad; IISc, Bangalore; and IACS, Kolkata topped the list in terms of high citations per paper (9 or more citations per paper published during 1993-94). NCL, Pune; ANNAUM, Chennai; SINP, Kolkata; PGIMER, Chandigarh; DELHUD, Delhi; BARC, Mumbai; and IIT, Mumbai registered high rise in citations received per paper published in 1993-94 over papers published in 1985-86 (Table 16). CQI has been devised as a relative measure for computing quality of institutional performance in research output. CQI is a composite indicator computed on IF per paper, citations per paper, overall collaborative share and share of internationally collaborative papers of institutions. As per CQI the top 10 institutions were: JNCASR, Bangalore; TIFR, Mumbai; HYDEUH, Hyderabad; IISc, Bangalore; SINP, Kolkata; MADRUM, Chennai; IIT, Mumbai; IACS, Kolkata; IIT, Kanpur; and ISI, Kolkata (Table 16).

5.6 Growth in Publications Output by Subject

Chemistry, physics, and engineering have been the leading areas of research in India and have shown consistent rising trend in publications output. Chemistry, however, was an exception, since it showed a small dip in 1993-94. India's combined publications share in these disciplines has increased from 56.5 per cent to 63.9 per cent over 16 years from 1985-86 to 2001-02 (Table 17).

The national growth rate in these disciplines during the same period of 16 years has been (69.08 per cent, 68.4 per cent and, 77.7 per cent, respectively) above the country's average of 51.8 per cent.

Agriculture, biology, basic life sciences, clinical medicine, biomedical sciences and earth and environmental sciences have been the medium productivity areas of research in Indian science. Mathematics and computer science have been its low productivity areas. Over a period of 16 years, the publication growth was fastest in clinical medicine (141.6 per cent), followed by basic life sciences (81.6 per cent), and biomedical sciences (76.4 per cent) during 1985-86 to 2001-02. In contrast, the country witnessed slower growth in biology (-32.9 per cent), agriculture (18.3 per cent), and earth and environmental sciences (51.1 per cent). Mathematics also witnessed slower growth rate. Computer science, though, witnessed high growth (118.5 per cent) but its national share is still very small (1.3 per cent and 1.8 per cent) during 1985-86 and 2001-02. Since the government had been providing substantial support to universities and R&D agencies for research in computer science, its low share in the country's output is a matter of concern (Table 17). The decline in the publications share of agriculture in the national output may be attributed to the inadequate coverage of agricultural journals in the *Web of Science*. The national share in earth and environmental sciences remained stagnant. This discipline needs greater attention in view of

Table 15. Top high productivity institutions of S&T in India

Inst. Code	Total Papers				Activity Index		
	85-86	93-94	01-02	Total	85-86	93-94	01-02
ANNAUM	37	63	311	411	0.33	0.48	1.84
JNCASR	0	146	363	509	0.0	0.9	1.73
IICT	98	292	562	952	0.38	0.97	1.43
SINP	126	138	316	580	0.80	0.75	1.32
AIIMS	350	428	902	1680	0.77	0.8	1.3
BOMBUB	191	221	423	835	0.84	0.83	1.23
IIT, MUMBAI	353	401	699	1453	0.90	0.87	1.17
ISI, KOLKATTA	168	212	344	724	0.86	0.92	1.15
MADRUM	155	188	301	644	0.89	0.92	1.14
TIFR	388	551	803	1742	0.82	1.00	1.12
NCL	348	428	658	1434	0.89	0.94	1.11
IACS	219	367	481	1067	0.76	1.08	1.10
IIS, BANG	886	1226	1719	3831	0.85	1.01	1.09
PGIMER	255	331	473	1059	0.89	0.99	1.09
IIT, KANP	427	460	667	1554	1.01	0.93	1.04
JADAUC	284	396	513	1193	0.88	1.05	1.04
DELHI UNIV	421	381	577	1379	1.13	0.87	1.02
BARC	716	832	1076	2624	1.01	1.00	1.00
HYDEUH	180	307	337	824	0.81	1.17	0.99
IIT, KHAR	430	589	688	1707	0.93	1.09	0.98
PANJUC	299	238	345	882	1.25	0.85	0.95
IIT, CHENNAI	453	511	575	1539	1.09	1.05	0.91
IIT, DELHI	611	567	690	1868	1.21	0.96	0.90
BANAUV	531	440	402	1373	1.43	1.01	0.71

the challenges thrown by Tsunami, green house effect and other environmental changes taking place the world over. The decline and slow growth of publications in biology and mathematics, in spite of well-established departments and faculties (comparable to physics and chemistry) in large number of universities is a matter of concern. There is an urgent need to improve course contents and focus in research in both the fields. For example, changes in curriculum from traditional to modern biology, and from traditional mathematics to computational and applied mathematics may attract more research funds, and make this research more relevant to Indian biotechnology and computer industry and may help the students engaged in research in these fields in getting employment in India.

6. FINDINGS

India achieved 5.96 per cent average annual growth in S&T publications during 1996-2005, and its pace of growth is accelerating. As seen from *Web of Science,* it was 2.51 per cent during last eighteen years (1985-2002), 5.96 per cent during

Table 16. IF, citations/paper and CQI of top high productivity institutions of S&T in India

Inst. Code	TPIF			TPTC			CQI		
	85-86	93-94	01-02	85-86	93-94	01-02	85-86	93-94	01-02
IIS, BANG	1.221	1.234	1.871	8.704	9.267	3.513	1.87	1.78	1.43
BARC	0.963	0.983	1.328	5.021	6.537	2.940	0.77	0.94	1.03
AIIMS	1.146	1.6	1.723	6.663	7.201	2.078	1.40	1.87	1.04
TIFR	1.945	1.597	2.231	10.492	11.210	4.230	2.58	2.07	1.73
IIT,BOMB	0.699	0.918	1.216	4.04	5.506	2.575	0.90	1.26	1.30
IIT, DELH	0.700	0.640	0.936	5.414	4.783	1.812	0.75	0.98	0.98
IIT, KHAR	0.694	0.594	0.96	4.977	5.138	1.737	1.54	0.85	1.04
IIT, KANP	0.981	0.811	1.315	6.431	7.033	2.813	1.08	1.31	1.24
NCL	0.806	1.334	1.784	6.491	10.100	4.070	0.80	1.19	1.05
DELHI UNIV	0.751	0.965	1.241	3.931	5.714	2.166	1.10	1.26	1.20
IIT, CHENNAI	0.798	0.58	0.955	4.442	3.861	1.55	1.80	0.74	1.05
IICT	0.844	0.992	1.686	7.520	7.281	4.210	1.19	0.81	0.98
JADAUC	0.914	0.736	1.24	4.905	4.808	2.347	1.09	0.93	1.18
IACS	1.424	1.059	1.596	10.612	9.082	3.291	1.45	1.07	1.27
PGIMER	0.942	0.884	1.337	4.529	6.601	1.516	2.05	1.58	0.82
BOMBUB	0.472	0.658	1.031	5.068	5.579	2.054	0.83	0.91	0.71
BANAUV	0.808	0.715	1.04	10.823	4.818	3.095	1.49	1.04	1.07
JNCASR	0.000	1.686	2.690	0.000	11.692	7.375	0.00	2.65	1.76
PANJUC	0.800	0.687	1.268	4.970	4.987	3.125	1.63	1.60	1.23
ISI, CALC	0.655	0.48	0.94	4.869	5.575	1.977	1.37	1.49	1.24
SINP	1.617	1.492	2.100	4.968	7.145	3.411	0.97	1.26	1.35
HYDEUH	1.739	1.46	2.14	13.283	9.762	4.932	2.29	1.80	1.70
ANNAUM	0.783	0.95	0.86	3.486	6.73	1.9	0.85	1.65	1.16
MADRUM	0.836	0.70	0.98	4.284	4.229	2.272	1.42	1.01	1.32

TPIF = Impact factor per paper; TPTC = Citations received per paper; CQI = Composite quality index

last ten years (1996-2005), and 10.5 per cent in the recent five years (2000-05). Compared to other developing countries like China, Brazil and South Korea, India's world share in S&T publications is still very low. If India has to catch up with these countries, it has to evolve strong and effective strategies aiming at still higher publications growth rate.

Among the various sectors, universities and colleges sector is the largest in the country in terms of publications output and institutional participation in S&T research. Mission-oriented R&D sector ranks second followed by INI, and industry sector. Despite its largest institutional participation and publications share, universities and colleges sector growth rate in publications output (35.7 per cent) has been below the country average (51.7 per cent), and secondly its publications share has been declining. In contrast, all other S&T sectors showed consistent rise in their publications share. Evidently, universities and colleges sector needs to be strengthened for better performance in S&T research.

Collaborative research has been found to influence both the quantity and quality of research output in the country. Collaborative share of the country output has shown significant rise from 7.3 per cent to 40.1 per cent during 1985-86 to 2001-02. Collaborative

Table 17. Distribution of publications output by subject

Subject	Publications output			% share in national output			% growth rate 85-86 & 0-02
	85-86	93-94	01-02	85-86	93-94	01-02	
Chemistry	5106	5791	8633	22.05	21.38	24.57	69.08
Physics	4035	5295	6795	17.43	19.55	19.34	68.40
Engineering	3955	5237	7031	17.08	19.33	20.01	77.77
Agriculture	2864	3461	3388	12.37	12.78	9.64	18.30
Biology	2409	1476	1615	10.40	5.45	4.60	-32.96
Basic Life Sc	2043	2800	3711	8.82	10.34	10.56	81.64
Clinical Med	1724	2623	4166	7.45	9.68	11.85	141.65
Biomedical Sc	1585	2008	2797	6.85	7.41	7.96	76.47
Earth & Envir Sc	1464	1942	2272	6.32	7.17	6.47	55.19
Mathematics	803	842	1003	3.47	3.11	2.85	24.91
Computer Sc	302	601	660	1.30	2.22	1.88	118.54
Multidisciplinary	1252	925	1433	5.41	3.41	4.08	14.46
Total	23153	27088	35142	100.00	100.00	100.00	51.78

research has shown faster growth over 16 years (729.6 per cent) than the country growth in S&T (51.78 per cent). Mission-oriented R&D sector has shown the fastest growth in collaborative research (1017 per cent over 16 years), followed by universities and colleges (726 per cent over 16 years), INI (620 per cent over 16 years) during the corresponding period 1985-86 to 2001-02. Collaborative research activity at national level is greater than that at international level. India's collaborative research with the Europe and Asia is on the rise while with North America (USA and Canada) it is on the decline.

India spreads its research output in far too many journals, leading to low concentration of papers per journal and hence to their low visibility**.** This practice of reporting papers in far too many journals could be one of the reasons for India's low citations impact. There is an urgent need to motivate scientists to publish mostly in specialised and high impact journals. Data reveal that citations received per paper have been on the rise for the Indian research output published in foreign journals and declining for the papers published in Indian journals.

Nearly 70 per cent of the country's output in S&T appears in low or zero impact journals, while 25 per cent output in medium impact journals and only 5 per cent in high impact journals. Average IF per paper has shown rise from 0.748 to 0.806, and to 1.229 during 1985-86, 1994-95, and 2001-02, respectively. Similarly, citations received per paper rose from 4.92 in 1985-86 to 5.26 in 1993-94. The country needs to improve its publications share in medium and high impact journals.

Research output in S&T coming from 90 per cent institutions in the country is still very small and much below the general expectations. The top 10 per cent institutions accounted for as much as 80 per cent of the output, and the remaining 90 per cent account for just 20 per cent output. Thus, special attention needs to be paid to the low and medium productivity institutions to improve the overall performance in S&T. Chemistry, physics, and engineering are the high productivity research areas in Indian science and technology**.** Agriculture, biology, basic life sciences, clinical medicine, biomedical sciences and earth and environment science are its medium productivity research areas. Mathematics and computer science are its low productivity areas. Clinical medicine, basic life sciences and biomedical sciences are the fastest growing areas of Indian S&T**.** Clinical medicine showed publications growth of 141.6 per cent, followed by basic life sciences (81.6 per cent), and biomedical science (76.4 per cent), compared to country average growth rate of 51.7 per cent in sixteen years during 1985-86 to 2001-02.

India holds the potential to give higher growth in S&T in the next 10 years. Given its infrastructure and the skilled and sizeable manpower engaged in R&D, the current growth in publications by India is indeed too low and much below its overall potential.

The country must plan for catalysing higher publications growth at least to catch up with leading developing countries in next 10 years. For catalysing growth and quality in research output, efforts may be made to improve and nurture creativity of individuals and teams, may be by catching talent at young age, organising training programs, and rewarding team efforts and by creating sophisticated instrument facilities in low and medium productivity institutions.Given their qualitative and quantitative performance in the publications output, the INI and Inter-University centers seem to be the effective models for influencing research activity in the country.

7. CONCLUSION

The country must draw out long-term and short-term plans for R&D developments in the country. It needs to organise goal-oriented and need-based programmes at the national and institutional level. New programmes needs to be initiated in the country to encourage greater institutional participation, greater collaboration in research at national and international level, attract young talent into science, organise in-service training of staff in creative and innovation ideas, and set-up sophisticated instrument facilities for S&T education and research in the country.

Special attention needs to be given to the universities and colleges to enhance their quantity and quality of research output. This can be done by further improving the universities and colleges sector in terms of the technical and computing infrastructure, course-content, teaching methods, faculty development in newer fields, allocation of funds in highly specialised areas, creating better linkages with R&D and other sectors, and by attracting new and bright talent at masters and doctoral level. This must be accompanied by strict criteria for the selection of students for PhD programmes and their evaluation for the degree and in faculty evaluation for time scale promotion. At least one or two papers in a peer-reviewed journal may be made mandatory for every doctoral thesis, to enhance the growth of Indian research output.

There is an urgent need to strengthen linkages between low, medium and high productivity institutions within their own geographical regions. This would also enable the low and medium productivity institutions to benefit from the rich experiences of high productivity institutions, and use their equipment and facilities available in specific fields. Also, there is a need to change methods of deciding priorities for allocation of funds, particularly the extra-mural funds given by research agencies, and also the priorities for awarding research contracts. An element of competition should be brought into the bidding of funds for large-scale projects. There is strong need to strengthen the monitoring and evaluation system, particularly in the universities and colleges and also in other institutions to ensure that their research output is reported mainly in medium and high impact journals. Strict evaluation measures needs to be evolved for ensuring good quality output from PhD work and from the projects funded by national agencies. Higher budget allocation at the institutional level, for hiring doctoral and post-doctoral students may also increase the research output.

The country needs a much better regional distribution of resources, in terms of funding support for creating infrastructure, so that even low productivity states are able to contribute higher. Develop new institutes and strengthen existing ones especially in the low productivity states on the model of INI. There is a strong and urgent need to develop an effective research strategy to enhance the country performance in S&T research for quality and quantity by strengthening the existing institutes in the low and medium productivity states, as well as opening up new institutes in such states. There is a strong and urgent need to evolve new and effective strategies to improve research productivity in medium productivity areas such as agriculture science, biology, basic life sciences, clinical medicine, biomedical sciences and earth and environment science, as well as in low productivity areas, such as mathematics and computer sciences.

There is a need to draw out plans for encouraging scientists to publish in select high-impact journals. High speciality journals are not being published in the country in large number. Such journals have special importance in arresting India's outflow into foreign journals. The quality of Indian journals may also be improved by strengthening their peer-reviewing system and making them more specialised. There is a need to review and strengthen current arrangements for international collaboration in science and technology with developed and developing countries. India's collaborative research with countries like the USA, UK, Russia, and Canada is on decline and with countries like Germany, France, the Netherlands and Spain is on the rise. New initiatives are needed to strengthen the India's collaboration both with developed and developing countries.

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About the Authors

Dr B.M. Gupta received his PhD in Scientometrics from Karnataka University in 1999 and is working in this area since last 31 years. His areas of interest include measurement of Indian S&T, international collaboration, productivity of scientists, growth and obsolescence. Presently, he is working as Senior Scientist at the National Institute of Science, Technology and Development Studies, a national institute under the Council of Scientific and Industrial Research.

Dr S.M. Dhawan is a senior member of the library profession having special interests in areas such as special library management, library applications of information technology, and scientometric studies. Currently, he is serving the profession as library and information consultant. Formerly, he was Scientist F and Head, Library and Information Services, National Physical Laboratory. Dr Dhawan designed, developed, and hosted the website of the National Physical Laboratory. He has to his credit several papers published in national and international journals.

He had chaired several technical sessions at national and international conferences and was in the Editorial Boards of *ILA Bulletin, Annals of Library Science and Documentation,* and *Libraries, Information and Knowledge.* He has also edited ILA's Conference Volume—Quest for Quality, and authored a festschrift, Library and Information Studies in Cyber Age. He had been in the committees for CSIR e-Journal Consortium, National Science Digital Library, and National Knowledge Commission, and has carried out research projects on scientometric studies for NISSAT and Office of the Principal Scientific Adviser to the Govt of India, New Delhi.