Mapping life sciences research in India: A profile based on *BIOSIS* 1992–1994

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Life sciences research in India, as seen from Biological Abstracts (1992–1994), is quantified and mapped. Researchers from over 1,400 institutions located in over 450 cities/towns have authored 20,046 papers in 1,582 journals published from 52 countries. About 46% of Indian papers have appeared in non-SCI journals, and a further 37.5% in journals with impact factor less than 1.0. The analysis reveals the existence of two clusters: a large number of institutions devoted to agriculture and classical biology, publishing mostly in low-impact journals, and a smaller group publishing some papers in new biology and some areas of medicine in international journals of medium impact.

THIS paper aims to map life sciences research in India as reflected by the journal literature, using standard techniques of scientometrics. This is a macroscopic study, going down to the institutional level. No effort is made to analyse the data at the level of individual investigators.

Biology at centre stage

Biology today is on the fast-forward mode and is making rapid strides on many fronts. Ever since Watson and Crick published their brief note on the structure of DNA in *Nature* in April 1953, biology has been on the upswing. It became increasingly interdisciplinary and soon edged its way to the centre stage, dislodging physics. The transition from classical biology, largely concerned with structure and function at the organism level, to new biology, with its overwhelming and almost reductionist concern for finding molecular-level understanding of all biological phenomena, brought forth many challenges that could not obviously be answered by classical biology. The challenge posed by the complexity of living systems has attracted such scientists as Philip Anderson, Nobel laureate in physics, who a few years ago taught a biology course at Princeton to graduate students of physics. Thanks to the growing perception that a deeper understanding of complex biological systems will need a more quantitative type of biology that is closely integrated with the physical sciences, several front-ranking US universities are starting new institutes to bring physical and biomedical scientists together, according to a report in *Nature* (1999, **397**, 3). At Stanford, for instance, Nobel prize-winning physicist Steven Chu, who works on the behaviour of single protein molecules, and biochemist James Spudich are planning such an interdisciplinary research centre with about 50 faculty members. In addition, Princeton University plans to establish within the next two years an interdisciplinary genomics institute, and Chicago University approved in June 1997 the formation of an interdivisional institute.. The training of the next generation of biologists, says developmental geneticist Shirley Tilghman of Princeton University, will include more mathematics, physics and chemistry. Life scientists have their own newspaper, the 12-year-old bi-weekly *The Scientist*, edited and published by Eugene Garfield, inventor of *Current Contents* and *Science Citation Index* (SCI); furthermore, many web sites on the Internet provide a whole range of information to biologists. Biology is becoming so popular, that it may overtake humanities as the foundation of American undergraduate education, according to Joseph Perpich of the Howard Hughes Medical Institute, probably America's largest philanthropy funding life science research. More than 50,000 students now receive Bachelor degrees in biology each year in the US alone. 'We are beginning to see quite remarkable research and papers co-authored by undergraduates that you just wouldn't have seen 20 years ago', Perpich says. A recent US National Research Council report, however, warns that the stream of life science students entering the graduate school pipeline should be frozen to prevent research job applications from flooding the market.

Mega projects such as the Human Genome Project, the worldwide search for a vaccine for AIDS, viagra jokes and novels like Carl Djerassi's *NO* make sure that biology is never short of media attention. Life sciences research receives far more funding now than ever before. Today life science domains – biology, biomedicine, and clinical medicine – account for 55% of the

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world's publications and 63% of US publications in science, technology and medicine[1], as seen from the journal literature of 1995, comprising papers published in about 4,800 journals selected by the Institute for Scientific Information, Philadelphia in 1981 as the base for *SCI*. The sub-fields under these broad groups as given in NSF's *Science and Engineering Indicators* 1998 appear in Table 1. In contrast, life science research accounts for less than 33% of India's contribution to the journal literature of science and technology (Table 2).

Life sciences in India

As in other fields before, India caught on to new biology after a time lag. However, currently new biology is well-funded in India (relative to other fields), and the field is picking up. In a 1997 meeting on Indian biology for the year 2000 and beyond (IBY2K) at Hyderbad's Centre for Cellular and Molecular Biology (CCMB), less than 5 of the more than 50 papers presented were in classical biology.

This paper looks at India's contributions to life sciences research in the journal literature, as reflected by the CD-ROM edition of *BIOSIS Biological Abstracts* 1992–1994 (Silver Platter). This paper aims to examine the following:

(i) The volume of work published from India;
(ii) Journals often used, their standing (as reflected by their impact factors) and country of publication;
(iii) Sub-fields in which Indian researchers are active; and
(iv) Indian institutions actively publishing.

Arunachalam and Singh[2–5] used print versions of both INSPEC *Physics Abstracts* and *SCI* to quantify India's contribution to some high-tech areas in physics such as lasers, holography, liquid crystals and superconductivity.

Table 1. Broad fields and sub-fields included under 'life sciences'

Clinical medicine	
Addictive diseases	Allergy
Anesthesiology	Arthritis and rheumatism
Cancer	Cardiovascular system
Dentistry	Dermatology and venereal disease
Endocrinology	Fertility
Gastroenterology	General and internal medicine
Geriatrics	Hematology
Hygiene and public health	Immunology
Miscellaneous clinical medicine	Nephrology
Neurology, neurosurgery	Obstetrics, gynaecology
Ophthalmology	Orthopedics
Otorhinolaryngology	Pathology
Pediatrics	Pharmacology
Pharmacy	Psychiatry
Radiology and nuclear medicine	Respiratory system
Surgery	Tropical medicine
Urology	Veterinary medicine
Biomedical research	
Anatomy and morphology	Biochemistry and molecular biology
Biomedical engineering	Biophysics
Cell biology, cytology and histology	Embryology
General Biomedical research	Genetics and heredity
Microbiology	Microscopy
Miscellaneous biomedical research	Nutrition and dietetics
Parasitology	Physiology
Virology	
Biology	
Agriculture and food science	Botany
Dairy and animal science	Ecology
Entomology	General biology
General zoology	Marine biology and hydro-biology
Miscellaneous biology	Miscellaneous zoology

Other broad fields constituting the whole of science and technology are chemistry, physics, earth and space sciences, engineering and technology, and mathematics.

Source: *Science and Engineering Indicators 1998*, NSF, USA, p. A-268 (ref. 1)

Table 2. Distribution of scientific and technical papers for selected countries by field, 1995 (ref. 1)

Field	World	India	USA	UK	Germany	France	Israel	Japan
All S & T fields, No. of papers	438,767	7,851	142,942	32,980	30,654	23,811	4,322	39,498
Clinical medicine, %	30.7	12.2	35.3	38.3	28.4	28.4	34.1	29.0
Biomed. research, %	16.4	13.3	19.7	17.5	14.9	16.9	14.9	15.5
Biology, %	8.0	7.3	7.8	8.1	6.0	5.8	9.0	6.6
Chemistry, %	14.0	30.3	9.0	10.8	17.9	15.4	7.5	16.9
Physics, %	16.9	21.2	12.5	12.0	21.2	19.2	20.5	21.2
Earth and space science, %	5.3	4.8	6.6	5.6	3.9	5.1	4.1	2.5
Engineering and technology, %	7.0	9.9	7.2	6.3	5.9	5.7	6.6	7.6
Mathematics, %	1.8	1.0	2.0	1.4	1.8	3.5	3.3	0.7

Source: *Science and Engineering Indicators 1998*, NSF, based on the 1981 ISI constant journal set of about 4,800 journals.

Arunachalam and Singh[6] have also analysed India's contribution to the world literature of science using *SCI*. Recently, I have quantified and mapped India's contributions to the literatures of mathematics[7], materials science[8], physics[9], medicine[10], agriculture[11] and science in general[12], using electronic versions of appropriate international bibliographic databases. Encouragingly, the study on medical research in India, published in *Current Science*[13] and the *National Medical Journal of India*[14], has attracted considerable attention[15–23], perhaps because the study addressed the question of relevance of research to local concerns.

Methodology

All papers having a first author address in India were downloaded from *BIOSIS Biological Abstracts* 1992–1994. Incidentally, unlike *SCI*, *BIOSIS* lists the names and addresses of only the first author. Therefore, papers in which Indian authors were not listed as first authors were not captured. The fields downloaded were corporate source or author affiliation (CS), source or journal title including volume and page (SO), and publication year (PY). Names of institutions were standardized. For example, Haryana Agricultural University was merged with CCS Haryana Agricultural University, and University of Saugar merged with Dr H. S. Gour Vishwavidyalaya; names of departments were dropped. Names of states were added to all cities and towns found in the Indian addresses. In addition the following were added to journal titles: country of origin of journals (seen from *Serial Sources for the BIOSIS Previews Database 1993* obtained from BIOSIS, USA) impact factor values from *Journal Citation Reports* (*JCR*) 1992 and 1994; and sub-field classifications for journals, mostly from *SCI Guide* and for some from *Ulrich*. Individual papers were not assigned to sub-fields, since that would take enormous effort and demand considerable amount of subject expertise. Assigning of journals to sub-fields instead was adequate for the kind of mapping exercise undertaken. The data were converted into a database and analysed using FoxPro.

Analysis

For this study, I considered only the journal literature indexed in the CD-ROM edition of *BIOSIS Biological Abstracts* 1992–1994. Here the years indicate the disc years and not the years of publication of the individual papers. In the three years considered, Indian researchers published 20,046 papers. Table 3 lists journals often used by Indian researchers to publish their work in descending order of the number of papers published. Indian researchers published more than 100 papers in the three years in 37 journals and more than 50 papers in 84 journals. At the other extreme, they published only one paper in each of the 482 journals and two papers in each of the 248 journals. Figure 1 shows that the distribution of papers among journals is very nearly Bradfordian. The country of publication of each journal, impact factor (from *JCR* 1994) and the sub-field classification of the journal (mostly from *SCI Guide* and in some cases *Ulrich*) are also given in Table 3. Many journals indexed in *BIOSIS* are not indexed in *SCI*, and therefore they are not included in *JCR*. These journals were assigned an impact factor of 0.0; for some journals, the impact factor column is left blank in *JCR* and the impact factor for these journals is shown as 0.0. Some journals are classified into two or more sub-field categories, e.g. *Bioresource Technology*, a UK journal, is classified into energy, biotechnology and agriculture. More than 700 journals have no papers from India either in 1992 or in 1993–1994. Many of these journals were indexed in *BIOSIS* in both these periods, but had not indexed any paper from India in one of the periods. Some other journals, including such important titles as *Indian Journal of Biochemistry and Biophysics* and *Journal of Biosciences*, are not indexed at all in *BIOSIS* in one of the two periods. Editors of Indian journals should keep in touch with editors and publishers of

Table 3. Journals often used by Indian researchers to publish their work in life sciences

Journal title	Sub-field	Journal country	Impact factor–94	Impact factor–92	No. of papers
Indian journals					
Indian Journal of Experimental Biology	Biology	IND	0.000	0.000	593
Indian Veterinary Journal	Vet sci	IND	0.004	0.007	566
Indian Journal of Agronomy	Agricul	IND	0.002	0.000	448
Indian Journal of Animal Sciences	Agri, Dairy	IND	0.014	0.017	424
Journal of Maharashtra Agricultural Universities	Agricul	IND	0.000	0.000	413
Journal of the Indian Society of Soil Science	Agri, Soil	IND	0.000	0.000	402
Indian Journal of Agricultural Sciences	Agricul	IND	0.026	0.008	333
Journal of Food Science and Technology	Food sci	IND	0.026	0.059	286
Crop Research (Hissar)	Agricul	IND	0.000	0.000	280
Indian Forester	Forestry	IND	0.000	0.000	233
Acta Botanica Indica	Plant sci	IND	0.000	0.000	228
Current Science	Multidis sci	IND	0.271	0.253	226
Proceedings of the National Academy of Sciences India Section B (Biological Sciences)	Biology	IND	0.000	0.000	186
Indian Journal of Plant Physiology	Plant sci	IND	0.000	0.000	182
Indian Journal of Genetics and Plant Breeding	Plant sci//Genetics	IND	0.000	0.000	159
Indian Journal of Physiology and Pharmacology	Pharmacol//Physiol	IND	0.000	0.000	156
Advances in Plant Sciences	Plant sci	IND	0.000	0.000	151
Journal of Entomological Research (New Delhi)	Entomol	IND	0.000	0.000	151
Foreign journals					
Phytochemistry (Oxford)	Plant sci	UKD	1.157	1.113	148
Cytologia (Tokyo)	Cell biol	JPN	0.000	0.000	85
Fitoterapia	Plant sci	ITA	0.000	0.000	84
World Journal of Microbiology and Biotechnology	Biotech//Microbiol	UKD	0.382	0.385	81
Tetrahedron	Chem, org	UKD	2.277	2.830	64
Tetrahedron Letters	Chem, org	UKD	2.378	2.321	64
Mutation Research	Genetics//Biochem//Agricul	UKD	1.975	1.960	62
Biologia Plantarum (Prague)	Plant sci	CSK	0.168	0.215	61
Bioresource Technology	Energy//Biotech//Agricul	UKD	0.785	0.558	59

Source: *BIOSIS* 1992–94.

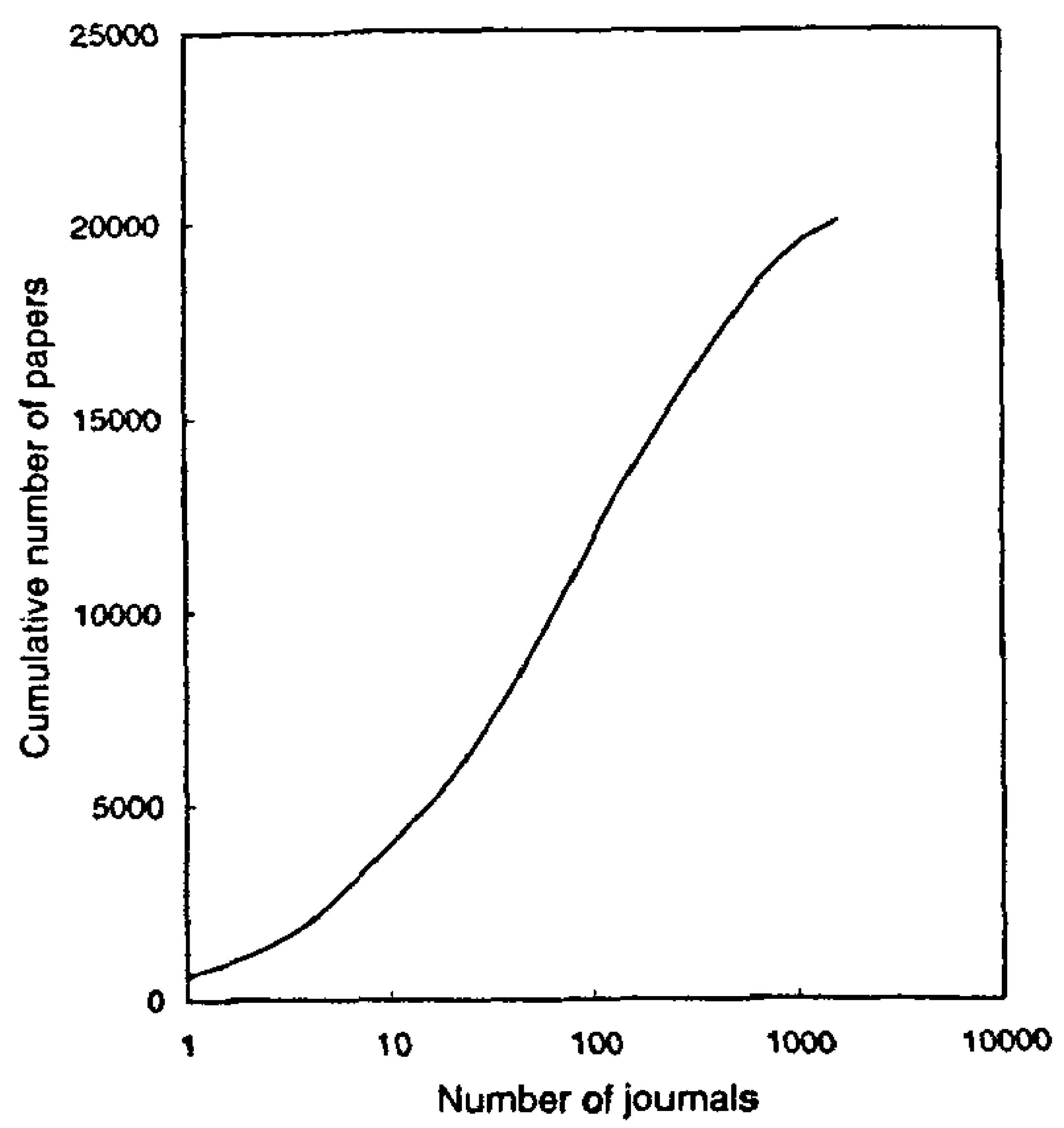

Figure 1. Number of journals vs cumulative number of Indian papers (source: *BIOSIS* 1992–1994).

secondary services (such as *Current Contents*, *BIOSIS*, and *SCI*) and ensure timely coverage of their journals in these services.

Use of letters journals

Only about 2% of the papers have appeared in letters journals (Table 4). Indian life scientists used 26 letters journals to publish 416 papers, and even among these more than 90 papers are not in life sciences proper: (i) 64 papers published in *Tetrahedron Letters* are in the area of organic chemistry; (ii) 18 published in *Analytical Letters* are about analytical chemistry; (iii) Eight papers published in *Acta Crystallographica Section C* concern crystallography; (iv) Two papers in *Newsletters on Stratigraphy* are in the area of geology; and (v) one paper published in *Synthetic Communications* is in organic chemistry. All journals that have the word 'letters' or 'communication(s)' in their titles appear in Table 4 with the exception of *Biochemical and Biophysical Research Communications*, which publishes short papers. In contrast, in physics Indian researchers publish a much higher percentage of papers in letters journals[9].

Table 4. Letters and communication journals used by Indian researchers as seen from *BIOSIS* 1992–94

Journal title	Publication country	Impact factor–94	Impact factor–92	No. of papers
Tetrahedron Letters	UKD	2.378	2.321	64
Biotechnology Letters	UKD	0.976	1.110	53
FEMS (Federation of European Microbiological Societies) Microbiology Letters	NLD	1.597	1.334	46
FEBS (Federation of European Biochemical Societies) Letters	NLD	3.600	3.505	38
Letters in Applied Microbiology	UKD	1.040	1.042	38
Cancer Letters	NLD	1.264	1.137	36
Bioorganic and Medicinal Chemistry Letters	UKD	1.425	1.217	27
Analytical Letters	USA	0.950	1.000	18
Neuroscience Letters	NLD	2.703	2.419	14
Biomedical Letters	UKD	0.000	0.000	13
Cereal Research Communications	HUN	0.102	0.288	12
Immunology Letters	NLD	1.223	1.559	11
Acta Crystallographica Section C Crystal Structure Communications	DEN	0.458	0.479	9
Veterinary Research Communications	NLD	0.592	0.414	8
Communications in Soil Science and Plant Analysis	USA	0.394	0.485	6
Toxicology Letters (Amsterdam)	NLD	1.112	0.774	6
Neuroendocrinology Letters	DEU	0.703	0.395	4
Drug and Chemical Toxicology and International Journal for Rapid Communication	USA	0.532	0.347	3
Newsletters on Stratigraphy	DEU	0.000	0.000	2
Research Communications in Chemical Pathology and Pharmacology	USA	0.780	0.599	2
Cryo Letters	UKD	0.685	1.080	1
Journal of the Chemical Society Chemical Communications	UKD	2.575	2.511	1
Neuroscience Research Communications	UKD	0.917	0.969	1
Nuclear Medicine Communications	UKD	1.078	0.982	1
Rapid Communications in Mass Spectrometry	UKD	2.484	0.000	1
Synthetic Communications	USA	0.699	0.716	1
Total				416

Only journals having the words 'letters' or 'communication(s)' in their title are included in this table. Some journals, such as *Biochemical and Biophysical Research Communications*, may not be letters journals.

Classification by sub-field

Table 5 displays the number of journals under each sub-field in which Indian researchers have published papers, along with the total number of papers from India in the different sub-fields. In order to avoid duplication, a journal is alloted to only one sub-field. For example, *Indian Journal of Genetics and Plant Breeding* is included in plant science and not in genetics. Of the 110 sub-fields, agriculture (2,824 papers), plant science (2,300 papers), biology (1,341 papers) and veterinary science (1,024 papers) are the sub-fields in which Indian researchers are most active. A large majority of life science research in India centers on agriculture and classical biology, while among sub-fields of new biology, biochemistry and molecular biology (674 papers) is an area of more than moderate activity.

Classification by journal country

Table 6 lists the countries bringing out journals in which Indian researchers have published their papers. More than 55% of papers from India have appeared in 118 Indian journals with Indian researchers also publishing many papers in British (2,570 papers or more than 12.8%) and US journals (1,964 papers or 9.8%). These are followed by journals published in The Netherlands, Germany, Switzerland and Japan. In all, Indian researchers have published in journals from 52 countries.

Let us compare the extent of publication in foreign journals by Indian scientists in different fields. Close to 77% of Indian papers indexed in *CAB Abstracts* (agriculture and related fields)[11], 18% of papers in physics (indexed in *INSPEC-Physics*)[9], 33.5% of papers in medicine (indexed in *Medline*)[13], 35% of papers indexed in *Mathsci* (mathematics and related fields)[7], and 9.5% of papers indexed in *Materials Science Citation Index*[8] were published in Indian journals. There is considerable overlap in the coverage of literature in *BIOSIS* and *CAB Abstracts* and no wonder that agriculture and biology are the fields in which Indian scientists publish their findings predominantly in Indian journals.

At least 7 journals in the top ten of the 118 Indian journals used by Indian life scientists concern agriculture. Of the 50 journals most often used by Indian researchers to publish their work, only 5 are foreign journals: *Phytochemistry* (United Kingdom), *Biochemistry International* (Australia) which has been renamed *Biochemistry and Molecular Biology International*,

Table 5. Indian research papers covered by *BIOSIS* 1992–94 classified by sub-fields (arranged by number of papers)

Sub-field	No. of journals	No. of papers
Agriculture	54	2824
Plant science	112	2300
Biology	33	1341
Veterinary sciences	25	1024
Agriculture, Dairy and Animal science	17	861
Pharmacology and Pharmacy	64	789
Biochemistry and Molecular biology	66	674
Agriculture, Soil science	15	583
Food Science and technology	32	580
Zoology	57	554
Entomology	46	547
Environmental sciences	35	391
Microbiology	37	383
Medicine, general and internal	36	354
Chemistry, organic	14	352
Multidisciplinary sciences	15	329
Forestry	9	291
Tropical medicine	11	270
Biotechnology and Applied microbiology	12	261
Genetics and Heredity	39	251
Pediatrics	15	211
Medicine, research and experimental	15	204
Oncology	28	202
Ecology	20	200
Cell biology	24	196
Biophysics	12	190
Public health	22	171
Fisheries	13	155
Immunology	31	145
Chemistry, analytical	21	142
Toxicology	21	135
Neurosciences	43	134
Geosciences	8	119
Chemistry	14	118
Cardiovascular system	22	111
Oceanography	9	105
Physiology	15	105
Ophthalmology	13	102
72 other sub-fields	499	2327
Unknown	8	15
Total	7455	20,046

Journals (and papers published in them) are included in only one sub-field, even though the journal may have relevance to more than one sub-field.

Table 6. Indian research papers covered by *BIOSIS* 1992–94 classified by sub-fields (arranged by number of papers)

Journal country	No. of journals	No. of papers	% of papers in world journals
India	118	11,109	55.42
UK	345	2570	12.82
USA	409	1964	9.80
The Netherlands	148	1347	6.72
Germany	146	889	4.43
Switzerland	64	274	1.37
Japan	56	261	1.30
Czech republic	11	227	1.13
Australia	18	195	0.97
Italy	32	175	0.87
Denmark	29	154	0.77
France	32	105	0.52
Hungary	13	72	
Poland	19	62	
Pakistan	7	50	
37 other countries	135	592	
Total	1582	20,046	

Cytologia (Japan), *Fitoterapia* (Italy), and *World Journal of Microbiology and Biotechnology* (United Kingdom). Similar lists for physics[9] and chemistry contain many more foreign journals. There are two reasons for this difference. (i) A large part of biological science research done in India is in the areas of agriculture (including veterinary science and dairy science) and classical biology. The classical biology work done in India, with a few exceptions, is not of great current interest to researchers in the scientifically advanced countries and it may be difficult to get Indian papers in this area published in good foreign journals. Much of what is done in agriculture is of considerable local interest and publishing such research in Indian journals may serve the purpose better than publishing it in foreign journals. Then there are medical journals such as *Indian Pediatrics* and *Indian Journal of Medical Research*, which carry articles of relevance to the Indian situation; (ii) India's share of new biology literature is rather small, and these papers are scattered in a number of journals. The 4 frequently used foreign journals in new biology are: *Biochemistry International* (Australia), 143 papers; *World Journal of Microbiology and Biotechnology* (UK), 81 papers; *Mutation Research* (The Netherlands), 62 papers; and *Biochimica Biophysica Acta* (The Netherlands), 56 papers.

Classification by journal impact factor

The journals publishing Indian papers considered in this study are classified into different ranges of impact factors as seen from *JCR* 1992 and 1994 in Tables 7*a* and *b* respectively. We see that a very large number of papers, about 84%, have appeared in journals whose impact factor is either zero (meaning these journals are not included in *SCI*) or less than 1.0. About two-thirds of the journals used are in this lowest impact category. At the other extreme, 54 papers have been published in 10 journals whose impact factor (IF 92) is higher than 6.0, and 103 papers appeared in 24 journals with an impact

Table 7*a*. Distribution of Indian life sciences papers by impact factor range of journals (based on impact factor data from *JCR* 1992)

IF range (*JCR* 1992)	No. of journals	No. of papers
0.000	443	9861
>0.0–0.5	305	4944
>0.5–1.0	326	2127
>1.0–1.5	206	1494
>1.5–2.0	125	716
>2.0–2.5	62	339
>2.5–3.0	39	196
>3.0–3.5	24	98
>3.5–4.0	11	132
>4.0–4.5	13	29
>4.5–5.0	4	7
>5.0–5.5	10	44
>5.5–6.0	4	5
>6.0–6.5	2	2
>6.5–7.0	2	35
>8.0	6	17
Total	1582	20,046

Table 7*b*. Distribution of Indian life sciences papers by impact factor range of journals (based on impact factor data from *JCR* 1994)

IF range (*JCR* 1994)	No. of journals	No. of papers
0.000	408	9310
>0.0–0.5	289	5166
>0.5–1.0	345	2337
>1.0–1.5	207	1487
>1.5–2.0	129	658
>2.0–2.5	73	417
>2.5–3.0	44	256
>3.0–3.5	27	145
>3.5–4.0	10	82
>4.0–4.5	15	61
>4.5–5.0	13	21
>5.0–5.5	4	22
>5.5–6.0	3	12
>6.0–6.5	3	15
>6.5–7.0	2	2
>7.0–7.5	2	7
>7.5–8.0	1	30
>8.0	7	18
Total	1582	20,046

factor of over 5.0. There was a slight increase in the impact factor of many journals between 1992 and 1994. For example, there are 15 journals with a 1994 impact factor higher than 6.0 (as against 10 in 1992), and these journals published 72 Indian papers in the three years under study (as against 54 in the 10 journals whose 1992 impact factor was above 6.0).

Classification by institution

Leading Indian institutions whose work is indexed in *BIOSIS* 1992–1994 are listed in Table 8. There are 3 agricultural universities and 2 medical education and research institutes in the top 7 institutions. Banaras Hindu University (BHU), University of Delhi, University of Calcutta and Indian Institute of Science (IISc) are among the most prolific publishers of life sciences research in India. Fourteen institutions have published more than 200 papers, and 35 have published between 100 and 200 papers in the three years considered. Leaving out home addresses, one finds that life science research is published from over 1,400 institutions in India. The distribution of papers over institutions follows a typical Bradford curve (Figure 2). Academic institutions consisting of general, agricultural and medical universities and colleges and engineering colleges account for 64.5% of all papers from India (Figure 3). Scientific agencies of the Central Government such as the Indian Council of Agricultural Research (1,708 papers), Council of Scientific and Industrial Research (1,545 papers), and Indian Council of Medical Research (416 papers) have published 4,179 papers (about 21%). Organizations under the Central Ministries account for 1,092 papers. The reason for the greater volume of work at the higher educational institutions, compared to the better-endowed national laboratories, is the presence of a very large number of doctoral students. Unlike scientists in various Central Government laboratories, who enjoy the benefits of a decent income, job security and no penalties for non-performance, the students have to perform well to be able to make a career or to win overseas fellowships.

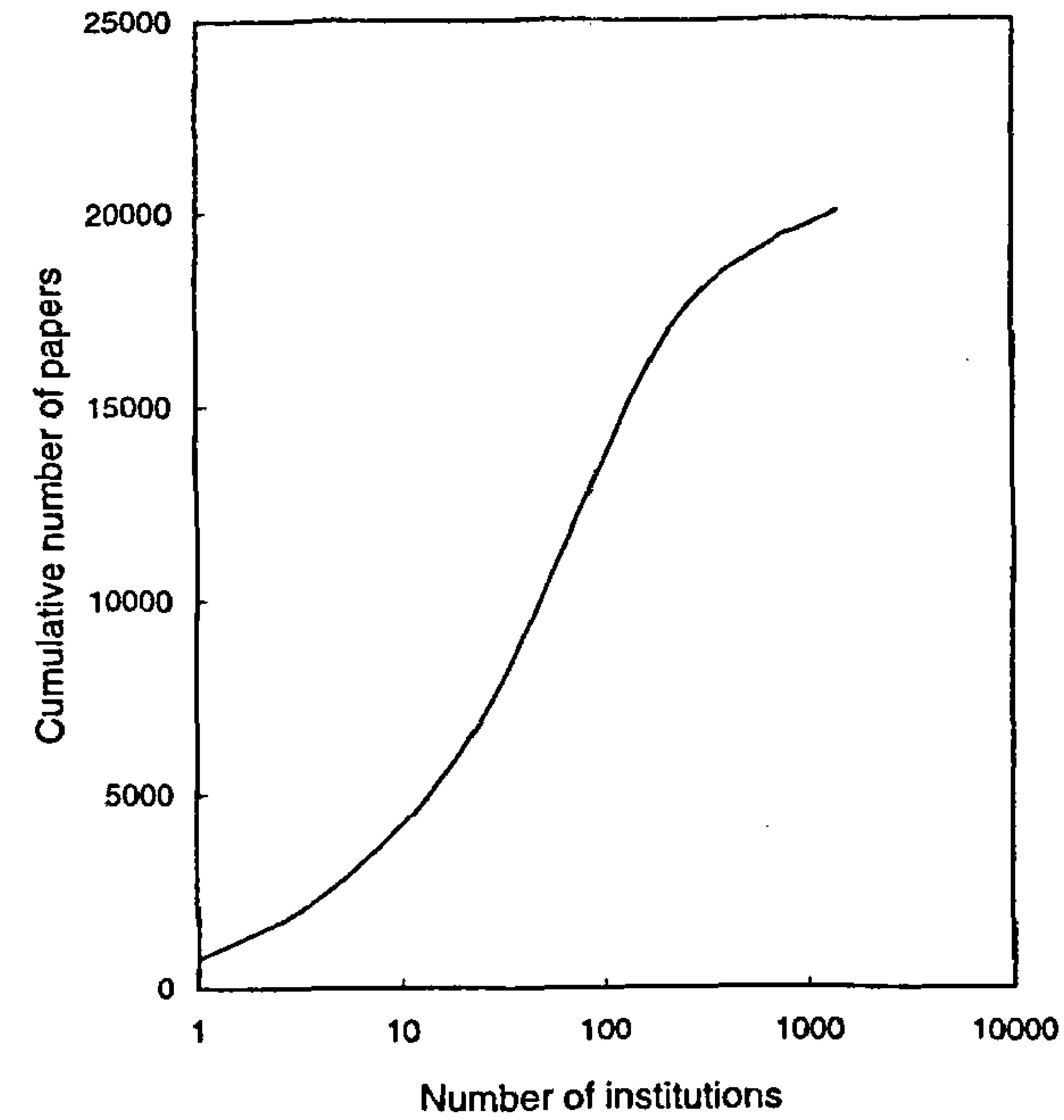

Figure 2. Number of institutions vs cumulative number of Indian papers (source: *BIOSIS* 1992–1994).

Table 8. Indian institutions publishing papers as seen from *BIOSIS* 1992–94

Institute	City/town	No. of papers
Chaudhary Charan Singh Haryana Agri University	Hissar	752
Punjab Agri University	Ludhiana	692
Banaras Hindu University	Varanasi	440
All India Institute of Med Science	New Delhi	372
Indian Agri Research Institute	New Delhi	367
University of Delhi	New Delhi	316
Postgraduate Institute Med Education Research	Chandigarh	295
University of Calcutta	Calcutta	271
Indian Institute Science	Bangalore	224
Himachal Pradesh Krishi Vishvavidyalaya	Palampur	222
Central Food Technological Research Institute	Mysore	221
Central Drug Research Institute	Lucknow	216
Aligarh Muslim University	Aligarh	215
Indian Vet Research Institute	Izatnagar	209
GB Pant University of Agriculture and Technology	Pantnagar	186
Bhabha Atomic Research Centre	Mumbai	173
Bidhan Chandra Krishi Viswavidyalaya	Kalyani	169
Marathwada Agri University	Parbhani	169
Punjabrao Krishi Vidyapeeth	Akola	169
National Chemical Laboratory	Pune	168
Jawaharlal Nehru University	New Delhi	163
Panjab University	Chandigarh	163
Indian Institute of Chemical Biology	Calcutta	136
National Institute of Immunology	New Delhi	120
Indian Institute of Chemical Technology	Hyderabad	99
Center for Cellular and Molecular Biology	Hyderabad	86
Other 1381 Addresses		12,978
Private Addresses		455
Total		20,046

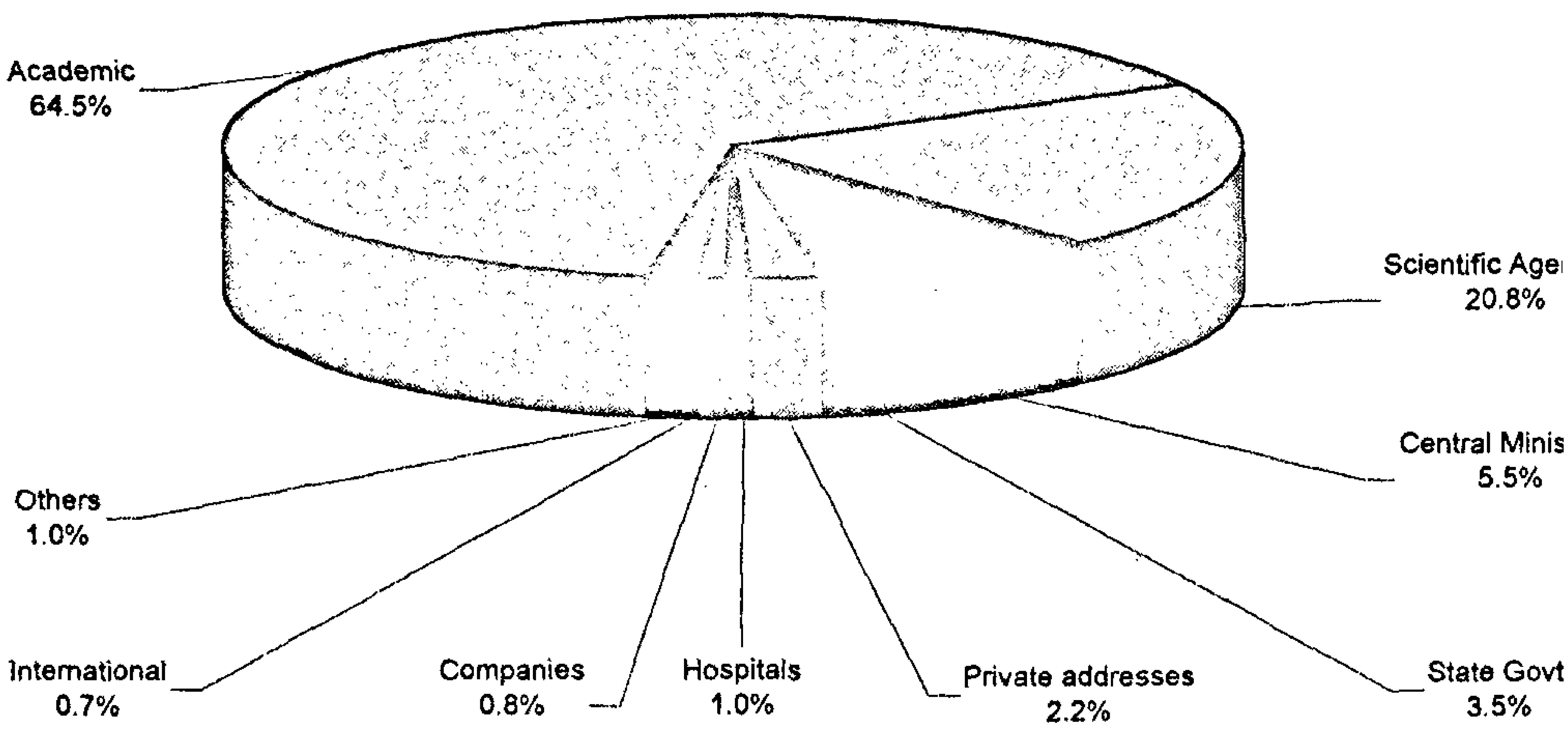

Figure 3. Contributions made by different types of organizations as seen from *BIOSIS* 1992–1994.

Classification by city and state

Tables 9 and 10 present the number of papers published from different cities/towns and states of India with Uttar Pradesh, Maharashtra and Delhi as leaders. In particular, Delhi (1,935 papers) leads the rest of the cities by a large margin which is largely because of the concentration of varied research institutions in the capital. Four other cities, viz. Calcutta, Lucknow, Mumbai, and Bangalore have published more than 800 papers. Ludhiana and Hissar, largely thanks to the Punjab and CSS Haryana Agricultural University, and Hyderabad have published more than 700 papers each. In total, papers have come from more than 450 Indian cities and towns, of which 47 have published at least 100 papers in the three years and 82 more than 50 papers.

Use of high-impact journals

Table 11 provides the number of papers published by some large institutions (prolific publishers) in journals of different impact factors (as given in *JCR* 1994). One has to be extremely cautious in interpreting the data presented in this table. Ideally, one should count the actual number of times a paper is cited and see in which journals these citations occur, rather than merely look at the impact factor of the journal in which a paper is published. Very often Indian authors publish papers in journals above a certain threshold impact factor, but these papers do not get cited as often as would be expected on the basis of the impact factors of the journals. In an earlier paper I showed that Indian papers often lower the impact factors of journals. Tibor Braun and colleagues have demonstrated that in most fields the relative citation rates of India (ratios of actual citation rate/expected citation rate) is less than one.

Table 9. Indian cities/towns contributing to the world literature of life sciences as seen from *BIOSIS* 1992–94 (arranged by number of papers)

City/town	State	No. of papers
Delhi	Delhi	1935
Calcutta	West Bengal	1000
Lucknow	Uttar Pradesh	845
Mumbai	Maharashtra	816
Bangalore	Karnataka	812
Hyderabad	Andhra Pradesh	793
Hissar	Haryana	783
Ludhiana	Punjab	713
Chennai	Tamil Nadu	575
Chandigarh	Chandigarh	502
Varanasi	Uttar Pradesh	455
Mysore	Karnataka	365
Pune	Maharashtra	353
Izatnagar	Uttar Pradesh	257
Kalyani	West Bengal	250
Coimbatore	Tamil Nadu	245
Jabalpur	Madhya Pradesh	240
Palampur	Himachal Pradesh	232
Aligarh	Uttar Pradesh	222
Karnal	Haryana	190
Pantnagar	Uttar Pradesh	186
Anand	Gujarat	184
Bhubaneswar	Orissa	178
Trichur	Kerala	178
Ankola	Maharashtra	175
433 other towns		7562
	Total	20,046

Table 10. Indian states contributing to the world literature of life science as seen from *BIOSIS* 1992–94

State	No. of Indian papers
Uttar Pradesh	2471
Maharashtra	2010
Delhi	1935
West Bengal	1581
Karnataka	1569
Tamil Nadu	1424
Andhra Pradesh	1398
Haryana	1141
Kerala	1114
Punjab	862
Madhya Pradesh	739
Gujarat	650
Chandigarh	512
Rajasthan	448
Bihar	442
Himachal Pradesh	420
Orissa	344
Jammu and Kashmir	242
Assam	197
Meghalaya	159
Pondicherry	136
Goa	124
Andaman and Nicobar	32
Manipur	31
Sikkim	22
Tripura	17
Arunachal Pradesh	3
Mizoram	1
Unknown	30
Total	20,046

Since the impact factors of agricultural and classical biology journals are low, not many highly cited papers emerge from agricultural universities. As pointed out in my report on agricultural research in India[11], communication habits differ from field to field, and results of agricultural research are best published in local/national journals. Institutions carrying out work in new biology and medicine have a better chance of placing some of

Table 11. India's contribution to the world literature of life sciences categorized by leading institutions and impact factors (IF 94) of journals used

Institution	Impact factor range (IF 94)															
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Total
CCS Haryana Agri University	360	293	57	40	2	0	0	0	0	0	0	0	0	0	0	752
Punjab Agri University	375	208	84	21	2	0	2	0	0	0	0	0	0	0	0	692
Banaras Hindu University	180	98	71	62	17	3	5	4	0	0	0	0	0	0	0	440
All India Inst Med Science	105	99	52	41	21	25	12	6	3	1	1	1	3	0	2	372
Indian Agri Research Institute	200	96	35	25	7	1	2	0	1	0	0	0	0	0	0	367
University of Delhi	101	60	55	41	22	14	15	2	2	1	2	0	0	1	0	316
Postgraduate Institute Med Educ and Research, Chandigarh	57	82	60	38	26	14	10	2	3	0	1	0	0	0	2	295
University of Calcutta	123	69	25	29	8	7	5	3	1	1	0	0	0	0	0	271
Indian Institute of Science	20	46	17	39	17	24	10	14	7	10	0	2	7	7	4	224
Himachal Pradesh Krishi Vishwavidyalaya	113	89	15	3	1	0	1	0	0	0	0	0	0	0	0	222
Central Food Technological Research Institute	39	72	72	22	10	1	3	1	1	0	0	0	0	0	0	221
Central Drug Research Institute	96	33	31	21	12	13	1	5	2	1	1	0	0	0	0	216
Aligarh Muslim University	121	30	31	18	5	4	0	0	0	1	0	0	0	0	0	215
Indian Vet Research Institute	51	122	23	8	4	1	0	0	0	0	0	0	0	0	0	209
Bhabha Atomic Research Centre	37	40	44	26	12	4	2	5	2	0	0	0	1	0	0	173
National Chemical Laboratory	16	49	28	21	17	19	3	5	3	6	0	0	1	0	0	168
Jawaharalal Nehru University	29	52	19	18	12	11	7	8	1	1	1	2	0	2	0	163
Panjab University	59	45	34	17	3	3	2	0	0	0	0	0	0	0	0	163
University of Madras	51	39	37	15	9	4	1	1	0	0	0	0	0	0	0	157
Indian Institute of Chemical Biology	10	22	19	33	9	21	6	4	1	5	2	1	1	2	0	136
National Institute of Immunology	13	14	19	17	8	20	8	2	6	4	3	0	0	6	0	120
Indian Institute of Chemical Technology	8	8	19	20	4	33	7	0	0	0	0	0	0	0	0	99
Center for Cellular and Molecular Biology	6	16	7	3	5	5	8	6	13	7	0	8	0	2	0	86
	2170	1682	854	578	233	227	115	68	46	38	11	14	13	20	8	6077

A, 0.0; B, > 0.0 – <= 0.5; C, > 0.5 – <= 1.0; D, > 1.0 – <= 1.5; E, > 1.5 – <=2.0; F, > 2.0 – <= 2.5; G, > 2.5 – <= 3.0; H, > 3.0 – <=3.5; I, > 3.5 – <= 4.0; J, > 4.0 – <= 4.5; K, > 4.5 – <= 5.0; L, > 5.0 – <= 6.0; M, > 6.0 – <= 7.0; N, > 7.0 – <= 8.0; O, > 8.0.
Source: *BIOSIS* 1992–94.

their papers in high impact journals. IISc, for example, has published 61 out of 284 papers in journals with impact factors higher than 2.5. CCMB has published 44 papers, about half of its entire output, in journals with impact factors higher than 2.5. National Institute of Immunology (NII) has 29 papers, Indian Institute of Chemical Biology 22 papers, and University of Delhi 37 papers in journals with impact factors higher than 2.5. The Post-graduate Institute of Medical Education and Research, Chandigarh, has 18 papers, All India Institute of Medical Sciences (AIIMS) 29 papers, and National Chemical Laboratory (NCL) 18 papers in this list. Scientists from some of these institutions also publish their work in non-*SCI* journals, mostly Indian journals (such as *Indian Journal of Experimental Biology*) that could, with a little improvement, get into *SCI*.

In all, India as a whole has published 671 papers (about 3.35% of all papers) in journals with an impact factor (IF 94) higher than 2.5 and 270 papers in journals with an impact factor higher than 4.0. In these high impact journals (IF 94 > 4.0), Indian researchers have published 103 papers in biochemistry and molecular biology, 11 in microbiology, 10 each in general medicine and immunology, 4 in development biology, and 3 in endocrinology. Of the 190 papers in biophysics, 41 were published in journals whose impact factors were higher than 3.5. As pointed out by C. N. R. Rao, one of India's leading policy makers and a prolific publisher of research papers, Indian researchers find it difficult to place their papers in high impact journals. Among the papers indexed in *BIOSIS* 1992–94, only 2 papers in *Nature* and 6 in *Lancet* are from India. Indian researchers, however, manage to publish a larger number of papers in decent biochemistry journals. In the three years considered, they have published 30 papers in *Journal of Biological Chemistry*, 17 in *Biochemistry*, 56 in *Biochimica et Biophysica Acta*, 13 in *Journal of Molecular Biology*, 48 in *Biochemical and Biophysical Research Communications*, 21 in *Biochemical Journal*, and 19 in *European Journal of Biochemistry*. Apart from biochemistry and molecular biology (238 of the 674 papers), Indian researchers have published in medium-high impact journals (IF > 2.5 in *JCR* 1994) in neuroscience (46 papers), biophysics (41 papers), microbiology (41 papers), immunology (39 papers) and genetics (33 papers). A small number of institutions account for a large percentage of papers in high impact journals. Scientists at IISc have published 8 of the 30 Indian papers in *Journal of Biological Chemistry*, 7 of the 13 Indian papers in *Journal of Molecular Biology*, 1 in *Journal of Immunology*, and 1 in *Nature*. Scientists at that Indian Institute of Chemical Biology have published 7 papers in *Journal of Biological Chemistry*. AIIMS had 1 paper in *Journal of Molecular Biology*, 2 papers in *American Review of Respiratory Diseases*, 2 in *Hepatology*, 2 in *Lancet*, and 1 in *Arthritis*. The International Centre for Genetic Engineering and Biotechnology had 4 papers in *Journal of Immunology* and 1 in *Journal of Biological Chemistry*. All 4 Indian papers in *Journal of Biomolecular NMR* came from Tata Institute of Fundamental Research (TIFR). The only Indian paper in *FASEB Journal* came from the Christian Medical College in Vellore, and the only Indian paper in *Journal of Cell Biology* originated from the University of Hyderabad. The Indian Statistical Institute provided the only Indian paper in *American Journal of Human Genetics*. Considering the large number of people engaged in new biology research in India, this infrequent use of high impact journals is disconcerting. Throughout the three years studied, as seen from *BIOSIS*, no Indian researcher published a single paper in *Science*, the weekly journal of the American Association for the Advancement of Science. Sadly, more than 46.4% of India's work indexed in *BIOSIS* 1992–1994 appeared in journals not indexed in *SCI*, and another 37.4% of papers appeared in journals with impact factor below 1.0. The silver lining to the cloud is provided by a few lesser-known institutions publishing papers in some better-known journals, for example, a paper in *Lancet* from Dharbhanga Medical Hospital, and another in *Nature* from Utkal University.

A few well-meaning scientists are worried that studies such as this might encourage Indian scientists to publish their work in foreign journals to the great detriment of national initiatives to publish quality journals. While I appreciate their concern, I believe that without a large number of Indian scientists and institutions performing first-rate work we cannot sustain the quality of our journals for long. Remember the US was on the periphery of European science in the early decades of the century, but today the US is the centre in virtually every field of science and technology, and most leading journals are published in the US. It would be educative to examine this transformation as Valiathan[24] proposed, in a different context in his A. L. Mudaliar lecture at the University of Madras more than a decade ago. In his example, in the early part of the century, students of surgery from both India and the US went to Great Britain to hone their skills. According to Valiathan, most Indians returned and set up lucrative practice, whereas the Americans went home, built institutions and transformed their country into the world leader in surgery.

Clustering of institutions

I have mapped the contributions of major publishing institutions to often-used journals and to different sub-fields in the form of matrices (not shown here). From these matrices, one can gain an insight into the cognitive profile – areas of publishing activity – of an institution. For example, NII is strong in immunology, biochemistry and molecular biology, genetics and biophysics. IISc has many papers in biochemistry and molecular biology and biophysics, and a small number of papers in plant sciences, microbiology, genetics, immunology and biotechnology. Besides, IISc has 18 papers in journals grouped under biology and 23 papers in multi-disciplinary journals (such as *Nature*, *Proceedings of the National Academy of Sciences USA* and *Current Science*). For a rigorous analysis, one needs to classify these papers into appropriate sub-fields. From Table 11 and these matrices, one can see that a cluster of institutions working on classical biology and agriculture concentrate on certain sub-fields and publish often in journals of low impact, and another smaller cluster of institutions working on new biology publish part of their papers in high-impact journals. For example, IISc, University of Delhi, Aligarh Muslim University, NCL, Indian Institute of Chemical Biology, CCMB, University of Madras and NII publish often in biochemistry and molecular biology, whereas the agricultural universities concentrate on agriculture, plant science, zoology, entomology, etc. It would be useful to investigate this phenomenon in detail and to examine the cognitive cross-links between institutions in the two clusters. I believe it would be in the nation's interest if the same set of practical problems were tackled both by classical biologists in the larger cluster and the new biologists in the smaller cluster, and if researchers enter into a dialogue across the cluster boundary. At the moment, there seems to be very little overlap between the interests of the two, and one hardly sees joint efforts involving institutions across the cluster boundary. Funding agencies such as DST and SERC might wish to encourage such collaborations.

Conclusions

BIOSIS is a good source of information on India's contribution to life science research. It covers all areas of life sciences, viz. classical and new biology, agriculture and some areas of medicine. In addition, from a bibliometrician's point of view, *BIOSIS*, like *SCI* and *Mathsci*, is easy to work with. Journal titles are given in full, and journal country information is provided in the print version of *Serial Sources*. The one apparent lacuna

Table 12. Per cent of internationally co-authored scientific and technical papers for selected countries, by field, 1991–1995 (ref. 1)

Field	World	India	USA	UK	Germany	France	Israel	Japan
All S & T fields	13	13	16	26	30	32	37	13
Clinical medicine	10	11	12	18	21	22	23	11
Biomedical research	14	13	17	29	35	32	42	16
Biology	11	15	13	25	26	28	33	12
Chemistry	11	8	14	25	23	28	39	8
Physics	19	20	25	40	43	45	51	15
Earth and space sciences	20	21	24	43	52	51	46	32
Engineering and technology	11	12	14	20	22	27	36	12
Mathematics	19	31	24	36	36	29	55	19

Source: *Science and Engineering Indicators 1998*, NSF, based on the 1981 ISI constant journal set of about 4,800 journals.

is that it indexes less than 120 Indian journals, although Insdoc's *Directory of Indian Periodicals* lists several hundred under biology, life sciences, medicine and agriculture. Considering that *BIOSIS* is an international database with a mandate to cover the entire world's literature output, one cannot find fault with the decision not to index more than about 120 Indian journals. The poor quality content of many Indian journals and delays in publication also do not help. Some other international databases index even fewer Indian journals. For example, *SCI*, which cares for quality of contents, indexes about a dozen Indian journals, and *Medline* about 25. Another lacuna is that *BIOSIS* has indexed certain journals either in 1992 or in 1993–1994, but not in both periods. Even journals like *Indian Journal of Biochemistry and Biophysics* and *Journal of Biosciences* have suffered.

Life science research in India is much larger than physics research. There are about 4,100 to 4,300 papers from India indexed in a year's *Physics Abstracts* (or *INSPEC–Physics* CD), compared to about 7,000 in *BIOSIS*. Although this large volume can be attributed in part to the coverage of the literature of agriculture and medicine in *BIOSIS*, the fact is there are more biologists than physicists in India, a very large proportion of them working in classical biology. Enrollment figures and the number of doctoral dissertations submitted every year will bear this out. This analysis shows that more than 55% of Indian papers indexed in *BIOSIS* are published in Indian journals. One reason is that a substantial percentage of Indian papers in life sciences concern agriculture and most of it is published in Indian journals (including animal and veterinary science, horticulture and forestry). The extent of use of local journals varies from field to field. My analysis of agricultural research in India, based on *CAB Abstracts* 1990–1994, showed that close to 77% of papers were published in Indian journals[11]. Corresponding figures for other fields are as follows: 35% in mathematics, based on an analysis of *Mathsci* 1988–1995 (ref. 7); 18.3% in physics, based on *INSPEC – Physics* 1992 (ref. 9); 9.5% in materials science, based on *Materials Science Citation Index* 1991–1994 (ref. 8); 33.5% in medicine, based on *Medline* 1988–1994 (ref. 10).

A very large proportion of Indian life science papers are published either in low-impact journals (impact factor less than 1.0) or in journals not indexed in *SCI*. According to Veena Parnaik from CCMB, one reason for the relatively poor quality of Indian research papers in life sciences, is the relatively poor quality of biological education in schools and colleges, which cannot be easily set right at the Master's level. The training in physics and chemistry is somewhat better, says Parnaik. Less than 1.0% of Indian papers have appeared in journals with an impact factor higher than 4.0. That only a very small percentage of Indian papers are published in high impact journals is not unique to life sciences. Indeed, an even smaller percentage of papers become well-cited.

What should be of concern to policy makers and funding agencies is the fact that even scientists from better-known institutions publish a large number of papers in journals not indexed in *SCI*. For example, 20 of the 224 papers from IISc, 13 of the 120 papers from NII, 6 of the 86 papers from CCMB, 96 of the 216 papers from Central Drug Research Institute, and 37 of the 173 papers from Bhabha Atomic Research Centre have appeared in non-*SCI* journals. Some of these appeared in Indian journals such as *Indian Journal of Experimental Biology* (which was indexed in *SCI* a few years ago but was dropped), *Journal of the Indian Institute of Science*, *Indian Journal of Physiology and Allied Sciences*, *Indian Pediatrics*, and *Bulletin of the Postgraduate Institute of Medical Education and Research Chandigarh*. It is also possible that a few papers from India might have appeared in journals which are new and therefore not yet listed in *JCR*. The least that Indian life scientists could do is to avoid publishing their work in non-*SCI* journals and strive instead to build up Indian journals.

Academia accounts for a very large percentage of India's publications, although one is painfully aware of the tremendous state of neglect of most of India's higher educational institutions. This is due to the large number of doctoral students, who are keen to finish their work quickly and publish it in the best possible journals.

Literature-based mapping can provide valuable insights for science-policy makers. It can reveal a nation's (or any large aggregate's) strengths in terms of journals used for publishing, active institutions and sub-fields. This study is an analysis of publications only from a single database. One could extend this by consulting more databases, looking at actual citations to Indian papers (instead of being content with the impact factors of journals, as done here), and by looking at the extent and impact of collaboration, both national and international. I have presented some comparative data on the distribution of papers in different fields in Table 2 and the extent of international collaboration in Table 12. It would also be useful to look at the anatomy of the performance of different institutions, in conjunction with data on funds received for research by different investigators. I hope to look at these issues in the near future.

1. National Science Board, *Science and Engineering Indicators 1998*, National Science Foundation, Arlington, VA, USA, 1998, NSB-98-1.
2. Arunachalam, S. and Singh, U. N., Proceedings of the 3rd International Conference on Informetrics, DRTC, Bangalore, 1991.
3. Singh, U. N. and Arunachalam, S., *Scientometrics*, 1991, **20**, 197–220.
4. Arunachalam, S. and Singh, U. N., *J. Inf. Sci.*, 1984, **8**, 93–102.
5. Singh, U. N. and Arunachalam, S., *J. Sci. Ind. Res.*, 1991, **50**, 516–532.
6. Arunachalam, S. and Singh, U. N., *J. Sci. Ind. Res.*, 1992, **51**, 99–119.
7. Arunachalam, S., India's contribution to the literature of mathematics and related fields: An analysis based on *Mathsci* 1988-mid-1995, Report submitted to the Department of Science and Technology, New Delhi, 1996.
8. Arunachalam, S., Meyyappan, N. and Sridhar, G. S., India's contribution to the literature of materials science and related fields: An analysis based on *Materials Science Citation Index* 1991–1997, Report submitted to the Department of Science and Technology, New Delhi, 1996.
9. Arunachalam, S. and Dhawan, S. M., Physics research in India: An analysis based on *Physics Abstracts* 1992, Report submitted to the Department of Science and Technology, New Delhi, 1996.
10. Arunachalam, S., Mapping medical research in India: An analysis based on *Medline* Nov. 1987–Dec. 1994, Report submitted to the Department of Science and Technology, New Delhi, 1997.
11. Arunachalam, S., Agricultural research in India – A profile based on *CAB Abstracts* 1990–1994, Report submitted to the NISSAT, DSIR, New Delhi, 1998.
12. Arunachalam, S., Srinivasan, R. and Vidyalakshmi, Raman, *Curr. Sci.*, 1998, **74**, 433–441.
13. Arunachalam, S., *Curr. Sci.*, 1997, **72**, 912–922.
14. Arunachalam, S., *Nat. Med. J. India*, 1998, **11**, 27–34.
15. *Sci. Now*, Web journal of AAAS, 21 July 1997.
16. Jayaraman, K. S., *Nature*, 1997, **388**, 410.
17. *Science*, 1997, **277**, 643.
18. Mudur, G., *Br. Med. J.*, 1997, **315**, 271.
19. Balaram, P., *Curr. Sci.*, 1997, **72**, 899.
20. Valiathan, M. S., *Curr. Sci.*, 1997, **72**, 911.
21. Ramamurthi, B., *Curr. Sci.*, 1997, **73**, 7–8.
22. Rajagopalan, A., *Curr. Sci.*, 1997, **73**, 313.
23. Sunderrajan, P., *The Hindu*, 31 July 1997, p. 14.
24. Valiathan, M. S., Surgery in India, Sir A. L. Mudaliar Endowment Lectures, Madras University, 1987.

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