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Research Trends in Nanoscience and Nanotechnology in India

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ABSTRACT

This paper attempts to highlight quantitatively the growth and development of Indian research in the field of Nanoscience and Nanotechnology in terms of publication output as per *Science Citation Index* (1982-2008). The whole database contains 296072 records on the subject and among them USA topped the list with 84561 (28.56 per cent) followed by, China with 43393 (14.66 per cent) publications, Japan with 32431 (10.95 per cent) publications, Germany with 28065 (9.48 per cent) publications, France with 18141 (6.13 per cent) publications, and England with 13850 (4.68 per cent) publications. During 1982-2008, a total of 8326 (2.81 per cent) papers were published by the Indian scientists in the field. The yearly average number of documents published was 308.37. The highest numbers of publications (1890) were published in 2008. The premier Indian institutes engaged in Nanoscience and Nanotechnology research were: Indian Institute of Science (IISc), Bangaluru with 723 publications followed by IIT Kharagpur with 606 publications; National Chemical Laboratories (NCL), Pune with 589 publications; Indian Association for the Cultivation of science (IACS), Kolkata with 563 publications; and BARC, Mumbai with 434 publications. Major portion of the publications (96.36 per cent) were written in collaboration with more than one authors. India had collaboration with 67 other countries in the field. C.N.R. Rao, M. Sastry and S. Chaudhuri were the three leading researchers in the field. Researchers from Indian Institute of Science, Bangalore and Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore had most number of collaborative publications. When collaboration among institutes situated in different Indian cities was taken into consideration, Bangaluru and Kolkata were found to have the highest number of collaborative publications. Karnataka and West Bengal, the parent states of these cities were the states with the most collaborative publications in Nanoscience and Nanotechnology research. USA, Germany, and Japan had more number of collaborative publications with India. The most preferred journals for publishing the articles by the scientists were: *Journal of Applied Physics* (293), *Journal of Nanoscience and Nanotechnology* (285), *Applied Physics Letters* (243), *Materials Letters* (232), *Physical Review B* (232), *Nanotechnology* (194), and *Langmuir* (182). The highly occurred keywords in *SCI* records were: Nanoparticles (1244); Particles (756); Films (589); Growth (513); Nanocrystals (501); Thin-Films (484); Nanostructures (427); Optical-Properties (410); Nanocomposites (401); etc.

Keywords: Nanoscience, nanotechnology, scientometrics, bibliometric analysis, content analysis, India

1. INTRODUCTION

The term Nanotechnology is nowadays well known not only in all relevant scientific and technical areas, but also to a considerable extent in the public domain, based on reports in newspapers, on television and, whether justified or not, in a series of commercially available products with “nano” as part of their names. On one hand, this development could be considered in a positive sense, indicating nanotechnology as an accepted new technology. On the other hand, it contains some risks that should not be neglected. This is due to the rather complex definition of nanotechnology and nanoscience as a sectional science, involving natural and materials sciences, engineering, and medicine[1]. Numerous definitions of nanotechnology exist in the literature. Most of these simply say that nanotechnology considers materials and architectures on the nanoscale. In some definitions it is stated that nanotechnology deals mainly with structures in the region between 1 nm and 100 nm. In any case, the dimension plays the dominant role. For a more detailed description, however, this is much too simple. First, nanotechnology follows nanoscience, where fundamental effects have been discovered before. In a long course of development, a technology may result from scientific findings in some cases, but not in all cases by a long way. So, to understand nanotechnology, one has to define properly what nanoscience is. Among the

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numerous attempts to define nanotechnology and nanoscience the definition formulated by a team of scientists at the Europaische Akademie zur Erforschung wissenschaftlich-technischer Entwicklungen Bad Neuenahr-Ahrweiler mbH, seems to be most appropriate: "Nanotechnology comprises the emerging application of Nanoscience. Nanoscience deals with functional systems either based on the use of subunits with specific size-dependent properties or of individual or combined functionalized subunits"[2]. This nanotechnology refers broadly to a field of applied science and technology whose unifying theme is the control of matter on the atomic and molecular scale, normally 1 to 100 nm, and the fabrication of devices with critical dimensions that lie within that size range[3].

Nanoscience explores the possibility of creating new structures and compounds atom by atom. Technologies exist for creating nanometer-sized devices and structures; many fabricated by the same capabilities that fuel the silicon integrated circuit industry. For example, it is possible to create single atom thick tubes of carbon (carbon nanotubes) that have many fascinating structural and electrical properties. It is also possible to engineer nanometer-sized machines that can interact with individual cells. As of yet, the application of many of these structures has yet to be explored.

Nanotechnology by its nature is interdisciplinary, and chemists, physicists, biologists, and engineers all have roles to play in its development and implementation. Several strength areas in nanotechnology have broadly been identified. The first of these is nanostructured materials, which includes both new composite materials as well as electronic and optical materials. Biomimetics is developing biologically inspired technologies, and ranges from materials that work as an artificial eyelid to neural inspired computing models. The nano-bio interface focuses on developing nanotechnologies that are interactive with the biological world for sensing, gene identification, or drug delivery applications[4].

Nanoscience and nanotechnology (NST) is a young scientific and technological field that has generated voluminous information and data in the past two decades[5-6]. Kostoff, *et al*.[7] analysed the nanotechnology/ nanoscience research literature using *Science Citation Index/Social Science Citation Index (SCI/SSCI)* databases. The analysed parameters include: technical structure (taxonomy); prolific authors, key journals/ institutions/countries, most cited authors/journals/ documents; technical thrust areas; and characteristics of 400 most cited nanotechnology papers.

Lin and Zhang[8] have studied the language trends in nanoscience and nanotechnology publications with emphasis on Chinese language publications.

Braun, *et al*.[9] have studied the main growth and trends of this exciting new science and technology fields by measuring the growth rate of the nano-prefixed terms in the title of journal papers appeared in *SCI*. It has been shown that the investigations dealing with graphite nanotubes represent kinetically the most active field of research in the nanosciences. One way of monitoring the emergence of new fields is to peruse the papers and reviews published on the topic. There are many similar studies carried out in the field[10-17]. Considering the importance of this field it was decided to assess the Indian contribution to the literature accumulated on the subject and analyse the published papers where at least one author is affiliated to Indian institutes.

2. OBJECTIVES

The main objective of the study is to present the growth of Indian literature on nanoscience and nanotechnology and make the quantitative assessment of the research in terms of geographical distribution of research output, year-wise research output, characteristics of highly productive institutions nature of collaboration, most productive authors, the channels of communications used by the scientists, and the high frequency keywords appeared in the Key-Words-Plus and Author-Keywords fields in *SCI*.

3. MATERIALS AND METHODS

Science Citation Index, published by a division of the Thomson Corporation Inc. (formerly Institute for Scientific Information, Philadelphia), is one of the comprehensive databases covering all aspects of science. Data was collected from the CD-ROM version of *SCI* for the 1982-2008 (27 years) period. Glanzel[18], *et al.* used the following comprehensive search strings used by Wilson[19], *et al.* to elicit records relevant to nanoscience and nanotechnology from *SCI* database.

Search String

NANO* NOT (NANO2 OR NANO3 OR NANO4 OR NANO5 OR NANO-SECON* OR NANOSECON* OR NANO-GRAM* OR NANOGRAM* OR NANOMOL* OR NANOPHTALM* OR NANOMELI* OR NANOGETEROTROPH* OR NANOPLANKTON* OR NANOKELVIN* OR NANO-CURIE OR NANOCURIE OR NANOS OR NANOS1 OR NANOPROTO* OR NANOPHYTO* OR NANOFLAGELLATE*). OR QUANTUM-DOT* OR QUANTUM-WIRE* OR MOLECULAR-BEAM-EPITAXY OR MBE OR CARBON-TUB* OR CARBONTUB* OR BUCKYTUB* OR BUCKY-TUB* OR FULLERENE-TUB* OR SELF-ASSEMBLED-MONOLAYER* OR SELF-ASSEMBL*-DOT* OR SINGLE-ELECTRON* OR SINGLE-MOLECUL* OR ATOMIC-FORCE-MICROSCOP* OR CHEMICAL-FORCE-MICROSCOP*

The same query was applied in the 'TITLE and KEYWORDS' fields of *SCI* to extract data for the present study. The search was again narrowed down by combining the string with 'INDIA' in ADDRESS field to elicit records with at least one author from India involved in the publication. A total of 8326 records were retrieved and these records were analysed using the spreadsheet application as per the objectives of the study. Similarly data for other countries were retrieved by replacing names of countries in the search string in address field.

4. RESULTS AND DISCUSSION

4.1 Publications growth in Nanoscience and Nanotechnology in Selected Countries

The publication productivity of 15 selected countries is given in Figure 1. A total of 296072 publications were published globally during 1982-2008 out of which more than 271314 (91.64 per cent) publications were from only 15 countries. Among these countries, the USA topped the list with 84561 (28.56 per cent) followed by China with 43393 (14.66 per cent), Japan with 32431 (10.95 per cent), Germany with 28065 (9.48 per cent), France with 18141 (6.13 per cent), England with 13850 (4.68 per cent), Russia with 10135 (3.42 per cent), India with 8326 (2.81 per cent), Canada with 7212 (2.44 per cent), Spain with 7109 (2.40 per cent), Netherlands with 4690 (1.58 per cent), Australia, with 4429 (1.50 per cent), Brazil with 3215 (1.09 per cent) Switzerland with 3115 (1.05 per cent), and Israel with 2642 (0.89 per cent) publications.

4.2 Activity Index of Selected Countries

The activity index (AI) characterises the relative research efforts of a country in a given field of research. Karki, *et al.*[20] have studied activity and growth of Organic Chemistry in India. This indicator helps us to know which country was active during which period. AI of 15 selected countries is given in Table 1. USA had the highest AI, 1.80 during 1982-84, China 1.35 during 2006-2008, Japan 1.83 during 1988-1990, Germany 1.37 during 1997-1999, France 1.25 during 1997-1999, England 2.17 during 1985-1987, Russia 1.46 during 1997-1999 and India 1.39 during 2006-2008.

4.3 Growth of Indian Publications

An exponential growth in the number of publications on nanoscience and nanotechnology was observed during 1982-2008. The highest growth was found during 2006-2008 with 4786 publications followed by 2028 publications during 2003-2005, and 867 publications during 2000-2002. Table 2 gives the growth rate of publications in nanoscience and nanotechnology research in different three year blocks. The average number of publications produced per year was 308.37 and the highest numbers of publications, 1890, were produced in 2008.

Figure 2 gives year-wise growth of publications in nanoscience and nanotechnology research. It can be clearly visualised from Fig. 2 that growth of the literature was very low during 1982-1999 and it grew very fast during 2000-2008. This indicates that research in nanoscience

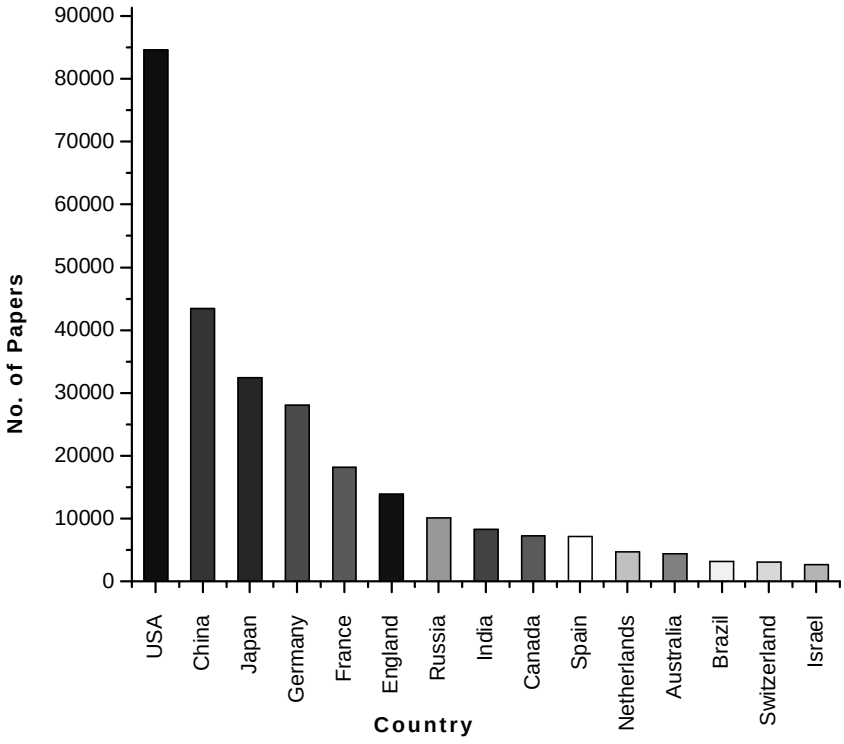

Figure 1. Country-wise distribution of publications in nanoscience and nanotechnology research.

Table 1. Activity index of select 15 countries

S. No	Country	Number of Publications and Activity Index									Total Publications
		82-84	85-87	88-90	91-93	94-96	97-99	00-02	03-05	06-08	1982-2008
1	USA	327 (1.80)	493 (1.49)	938 (1.58)	3147 (1.46)	4509 (1.19)	7779 (1.05)	12682 (1.03)	23675 (1.04)	31011 (0.89)	84561
2	China	1 (0.01)	14 (0.08)	28 (0.09)	186 (0.17)	598 (0.31)	1825 (0.48)	4479 (0.71)	12054 (1.03)	24208 (1.35)	43393
3	Japan	106 (1.52)	230 (1.81)	417 (1.83)	1328 (1.61)	1359 (0.93)	2507 (0.88)	4277 (0.91)	10008 (1.14)	12199 (0.91)	32431
4	Germany	0 (0.00)	0 (0.00)	20 (0.1)	841 (1.18)	1637 (1.3)	3365 (1.37)	5110 (1.25)	7164 (0.95)	9928 (0.85)	28065
5	France	36 (0.92)	85 (1.19)	144 (1.13)	485 (1.05)	908 (1.12)	1989 (1.25)	2996 (1.14)	4743 (0.97)	6755 (0.9)	18141
6	England	62 (2.08)	118 (2.17)	132 (1.36)	464 (1.32)	771 (1.24)	1435 (1.19)	2211 (1.1)	3400 (0.91)	5257 (0.92)	13850
7	Russia	0 (0.00)	0 (0.00)	0 (0.00)	169 (0.66)	590 (1.3)	1295 (1.46)	1941 (1.32)	2738 (1)	3402 (0.81)	10135
8	India	1 (0.06)	11 (0.34)	34 (0.58)	53 (0.25)	159 (0.43)	387 (0.53)	867 (0.72)	2028 (0.9)	4786 (1.39)	8326
9	Canada	6 (0.39)	23 (0.81)	52 (1.03)	219 (1.19)	370 (1.14)	555 (0.88)	873 (0.83)	1850 (0.95)	3264 (1.09)	7212
10	Spain	0 (0.00)	1 (0.04)	3 (0.06)	38 (0.21)	147 (0.46)	559 (0.9)	1012 (0.98)	1872 (0.98)	3477 (1.18)	7109
11	Netherlands	13 (1.29)	16 (0.87)	25 (0.76)	129 (1.08)	254 (1.21)	445 (1.09)	756 (1.11)	1285 (1.01)	1767 (0.91)	4690
12	Australia	3 (0.32)	3 (0.17)	7 (0.23)	44 (0.39)	129 (0.65)	316 (0.82)	494 (0.77)	1192 (1)	2241 (1.22)	4429
13	Brazil	0 (0.00)	0 (0.00)	0 (0.00)	15 (0.18)	45 (0.31)	208 (0.74)	538 (1.15)	880 (1.01)	1529 (1.15)	3215
14	Switzerland	0 (0.00)	1 (0.08)	3 (0.14)	38 (0.48)	198 (1.42)	255 (0.94)	416 (0.92)	491 (0.58)	1713 (1.33)	3115
15	Israel	0 (0.00)	0 (0.00)	2 (0.11)	14 (0.21)	75 (0.63)	260 (1.13)	508 (1.32)	726 (1.02)	1057 (0.97)	2642
World Total papers		**636**	**1162**	**2075**	**7528**	**13275**	**25883**	**42976**	**79956**	**122581**	**296072**

Figures in parenthesis indicate AI

and nanotechnology received a major impetus in India during this period.

4.4 Most Prolific Indian Institutes in Nanoscience and Nanotechnology Research

Seven hundred and eighteen Indian institutes published 8326 research papers in nanoscience and nanotechnology during 1982-2008. Among these institutes only 15 institutes produced more than 64.94 per cent publications (Table 3). The largest number of publications (723) were contributed by Indian Institute of Science, Bangalore followed by Indian Institute of Technology, Kharagpur (606); National Chemical Laboratory, Pune (589); Indian Association of Cultivation Science, Kolkata (563); and Bhabha Atomic Research Centre, Mumbai (434). Bhabha Atomic Research Centre

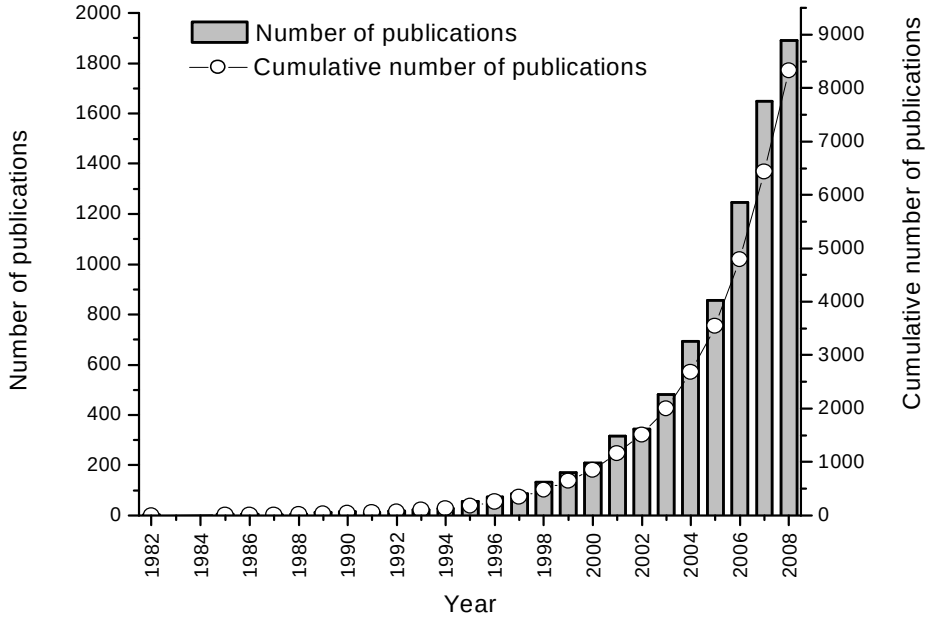

Figure 2. Year-wise publication productivity in nanoscience and nanotechnology research in India as per *Science Citation Index*.

Table 2. Growth rate of publications in different three year blocks

S. No.	Three year blocks	No. of publication
1	1982-1984	1
2	1985-1987	11
3	1988-1990	34
4	1991-1993	53
5	1994-1996	159
6	1997-1999	387
7	2000-2002	867
8	2003-2005	2028
9	2006-2008	4786

has basically focused its activity on micro design, simulation and Micro Electro Mechanical System (MEMS) packaging area. Analyses of the growth and decline in publication productivity using normalised activity index of 15 research institutes showed that only one (IIT M, Chennai) witnessed rise in its activity during 1982-1984. During 1985-1987, two institutes (BARC, Mumbai and IISc, Bangalore) witnessed rise in their activity. During 1988-1990, four institutes (IIT M, Chennai; IACS, Kolkata; TIFR, Mumbai; BARC, Mumbai) witnessed rise in their activity in the field. During 1991-1993 seven institutes (IICT, Hyderabad; IACS, Kolkata; BARC, Mumbai; University of Poona, Pune; IIT, Kanpur; NPL, New Delhi; and NCL, Pune) witnessed rise in their activity. During 1994-1996 seven institutes (TIFR, Mumbai; IACS, Kolkata; IISc, Bangalore; Jawaharlal Nehru Centre for Advance Science Research, Bangalore; University of Poona, Pune; IIT, Kanpur; and NPL, New Delhi) witnessed rise in their activity. During 1997-1999 seven institutes (TIFR, Mumbai, Jawaharlal Nehru Centre for Advance Science Research, Bangalore, IISc, Bangalore, IIT, Khragpur, University of Poona, Pune, IIT M, Chennai, IACS, Kolkata) witnessed rise in their activity. During 2000-2002, 10 institutes (Jawaharlal Nehru Centre for Advance Science Research, Bangalore; TIFR, Mumbai; NCL, Pune; IIT, Khragpur; IISc, Bangalore; BARC, Mumbai; University of Poona, Pune; IIT B, Mumbai; IIT M, Chennai; and IIT, Kanpur) witnessed rise in their activity. During 2003-2005 five institutes (NCL, Pune; IIT, Khragpur; IIT M, Chennai; TIFR, Mumbai; and BARC, Mumbai) witnessed rise in their activity. During 2006-2008 eight institutes (NPL, New Delhi; IIT, Delhi; IICT, Hyderabad; University of Delhi, Delhi; IIT B, Mumbai; IACS, Kolkata; IIT, Kanpur; and BARC, Mumbai) witnessed rise in their activity.

4.5 Authorship Pattern and Nature of Collaboration

The 8326 articles under study were the collaborative efforts of 10701authors. Table 4 shows details of articles in terms of the number of authors observed in the articles. Single authored papers constitute a very less share (only 3.17 per cent) of the total articles. The percentage share of articles, written in collaboration of three authors, was 23.75 and the percentage share of papers written in collaboration of two authors and four authors were almost had same number of publications (21.87 per cent and 20.73 per cent, respectively). Articles with mega-authorships (articles with more than five authors)

Table 3. Publication productivity and activity index of top Indian institutes in nanoscience and nanotechnology research

Institutes	Number of publications and activity index									Total publications
	82-84	85-87	88-90	91-93	94-96	97-99	00-02	03-05	06-08	82-08
Indian Institute of Science, Bangalore	0 (0.0)	1 (1.05)	0 (0.0)	3 (0.65)	27 (1.96)	64 (1.9)	101 (1.34)	175 (0.99)	352 (0.85)	723
Indian Institute of Technology, Kharagpur	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	6 (0.52)	16 (0.57)	79 (1.25)	171 (1.16)	334 (0.96)	606
National Chemical Laboratory, Pune	0 (0.0)	0 (0.0)	1 (0.42)	4 (1.07)	4 (0.36)	42 (1.53)	91 (1.48)	210 (1.46)	237 (0.7)	589
Indian Association of Cultivation Science Kolkata	0 (0.0)	0 (0.0)	5 (2.17)	12 (3.35)	26 (2.42)	28 (1.07)	45 (0.77)	105 (0.77)	342 (1.06)	563
Bhabha Atomic Research Center Mumbai	0 (0.0)	1 (1.74)	2 (1.13)	6 (2.17)	5 (0.6)	10 (0.5)	52 (1.15)	106 (1)	252 (1.01)	434
Jawaharlal Nehru Centre for Advance Science Research Bangalore	0 (0.0)	0 (0.0)	1 (0.72)	0 (0.0)	12 (1.84)	39 (2.45)	62 (1.74)	81 (0.97)	147 (0.75)	342
Indian Institute of Technology Madras, Chennai	1 (24.93)	0 (0.0)	3 (2.2)	0 (0.0)	2 (0.31)	18 (1.16)	35 (1.01)	85 (1.04)	190 (0.99)	334
Indian Institute of Technology, Kanpur	0 (0.0)	0 (0.0)	1 (0.85)	3 (1.64)	7 (1.27)	11 (0.82)	30 (1)	63 (0.9)	173 (1.05)	288
Indian Institute of Technology, Delhi	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	3 (0.6)	9 (0.74)	17 (0.62)	63 (0.99)	170 (1.13)	262
University of Poona Pune	0 (0.0)	0 (0.0)	0 (0.0)	3 (1.93)	7 (1.5)	22 (1.94)	29 (1.14)	45 (0.76)	138 (0.98)	244
Indian Institute of Technology Bombay Mumbai	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.45)	9 (0.82)	30 (1.23)	50 (0.87)	144 (1.07)	235
National Physical Laboratory, New Delhi	0 (0.0)	0 (0.0)	0 (0.0)	2 (1.39)	7 (1.62)	4 (0.38)	17 (0.72)	39 (0.71)	157 (1.21)	226
University of Delhi, Delhi	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	8 (2)	7 (0.72)	15 (0.69)	49 (0.96)	130 (1.08)	209
Indian Institute of Chemical Technology Hyderabad	0 (0.0)	0 (0.0)	0 (0.0)	4 (3.4)	1 (0.28)	7 (0.81)	10 (0.52)	43 (0.95)	120 (1.13)	185
Tata Institute of Fundamental Research Mumbai	0 (0.0)	0 (0.0)	1 (1.47)	0 (0.0)	8 (2.51)	21 (2.71)	28 (1.61)	42 (1.03)	67 (0.7)	167
Total number of Indian publications in respective Year blocks	1	11	34	53	159	387	867	2028	4786	8326

Note: Figures in parenthesis indicate Activity Index (AI)

constituted 30.48 per cent of total articles. There were four papers with 225 authors each and two papers with 255 authors each, respectively.

Table 4. Authorship pattern observed in the nanoscience and nanotechnology research publications as per *Science Citation Index* (1982-2008)

Publications with no. of authors	No. of publications	% of publications
1	264	3.17
2	1821	21.87
3	1977	23.75
4	1726	20.73
5	1152	13.84
6	639	7.68
7	386	4.64
8	175	2.10
9	89	1.07
10	38	0.46
11	24	0.29
12	14	0.17
13	6	0.07
14	2	0.02
15	2	0.02
16	2	0.02
17	1	0.01
19	1	0.01
40	1	0.01
225	4	0.05
255	2	0.02

Figure 3 depicts the time-trend of single-authored and collaborative nanoscience and nanotechnology research publications as per *Science Citation Index* (1982-2008). In both the cases, an upward trend was observed. In recent five years of the study, the numbers of multi-authored publications were more than the single-authored publications indicating the highly multidisciplinary nature of the field which requires collaboration from various disciplines, and National and International laboratories.

4.6 Most Prolific Authors

The 8326 publications under study were the result of collective efforts of 10701 individual authors having 33704 authorships. Table 5 provides the list of most prolific authors (those who have contributed at least 25 papers) in the nanoscience and nanotechnology research during the period under study. The total contribution of these 86 authors contributed almost 46.87 percent of the total number of articles published. The first publication year and last publication year of the individual authors was also analysed to find out the active period of researchers in the field. The most prolific authors were: C.N.R Rao with 198 publications; M. Sastry with 177 publications; S. Chaudhuri with 120 publications; D. Chakravorty with 114 publications; A. Govindaraj with 94 publications; T. Pradeep and K. Vijayamohanan with 79 publications; T. Pal with 77 publications; D.K. Avasthi with 74 publications; A.K. Bhowmick with 73 publications; R. Pasricha with 71 publications; P. Pramanik with 70 publications; S. Ram with 64 publications; S.K. Kulkarni with 60 publications; K. Chattopadhyay with 58 publications; S. Kar with 56 publications; A.K. Tyagi and C.D. Lokhande with 55 publications.

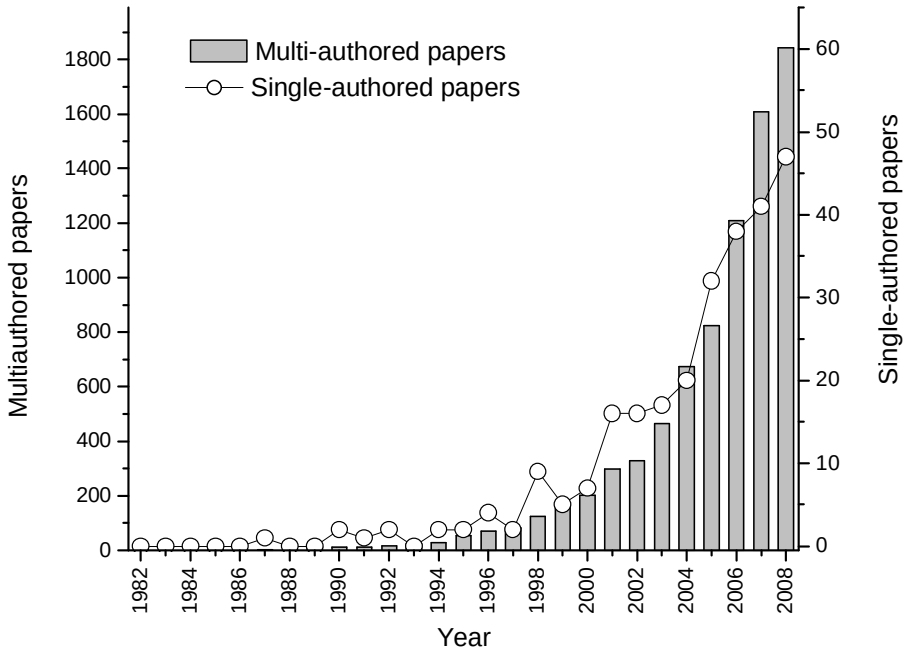

Figure 3. Time trend of single-authored and multi-authored publications in nanoscience and nanotechnology research in India as per *Science Citation Index* (1982- 2008).

Table 5. Most prolific authors in nanoscience and nanotechnology research in India as per *Science Citation Index* (1982-2008)

Authors	Publications	Institutes	FPY*	LPY*	Duration (years)
Rao, CNR	198	Indian Institute of Science, Bangalore	1994	2008	15
Sastry, M	177	National Chemical Laboratory, Pune	1994	2008	15
Chaudhuri, S	120	Indian Association of Cultivation Science, Kolkata	1994	2008	15
Chakravorty, D	114	Indian Association of Cultivation Science, Kolkata	1989	2008	20
Govindaraj, A	94	Indian Institute of Science, Bangalore	1994	2008	15
Pradeep, T	79	Indian Institute of Technology Madras, Chennai	1996	2008	13
Vijayamohanan, K	79	National Chemical Laboratory, Pune	1997	2008	12
Pal, T	77	Indian Institute of Technology, Kharagpur	1996	2008	13
Avasthi, DK	74	Inter University Accelerator Center, New Delhi	1999	2008	10
Bhowmick, AK	73	Indian Institute of Technology, Kharagpur	2000	2008	9
Pasricha, R	71	National Chemical Laboratory, Pune	2002	2008	7
Pramanik, P	70	Indian Institute of Technology, Kharagpur	1998	2008	11
Ram, S	64	Indian Institute of Technology, Kharagpur	1998	2008	11
Kulkarni, SK	60	University of Poona, Pune	1993	2008	16
Chattopadhyay, K	58	Indian Institute of Science, Bangalore	1993	2008	16
Kar, S	56	Indian Association of Cultivation Science, Kolkata	2004	2008	5
Tyagi, AK	55	Bhabha Atomic Research Center, Mumbai	2000	2008	9
Lokhande, CD	55	Shivaji University, Kolhapur	1997	2008	12
Ghosh, SK	54	Indian Institute of Technology, Kharagpur	2001	2008	8
Satyam, PV	50	Indian Institute of Physics, Bhubaneswar	2003	2008	6
Sreedhar, B	48	Indian Institute of Chemical Technology, Hyderabad	2002	2008	7
Sood, AK	48	Indian Institute of Science, Bangalore	1992	2008	17
Gajbhiye, NS	47	Indian Institute of Technology, Kanpur	1998	2008	11
Kulkarni, GU	47	Jawaharlal Nehru Centre for Advanced Science Research, Bangalore	1995	2008	14
Ayyub, P	47	Tata Institute of Fundamental Research	1995	2008	14
Gupta, SK	46	Bhabha Atomic Research Center, Mumbai	1992	2008	17
Khanna, PK	46	Centre for Materials for Electronic Technology, Pune	2003	2008	6
Ganesan, V	45	UGC-DAE-CSR, Indore	1998	2008	11
Kantam, ML	44	Indian Institute of Chemical Technology, Hyderabad	2002	2008	7
Singh, F	44	Inter University Accelerator Center, New Delhi	2002	2008	7
Kapoor, S	43	Bhabha Atomic Research Center, Mumbai	1998	2008	11
Pal, AK	42	Indian Association of Cultivation Science, Kolkata	1995	2008	14
Raychaudhuri, AK	42	Indian Institute of Science, Bangalore	1993	2008	16
Srivastava, ON	41	Banaras Hindu University, Banaras	1995	2008	14
Nair, KGM	41	Indira Gandhi Center for Atomic Research, Kalpakkam	2000	2008	9
Kanjilal, D	41	Inter University Accelerator Center, New Delhi	1999	2008	10
Mulla, IS	40	National Chemical Laboratory, Pune	2000	2008	9
Kulshreshtha, SK	38	Bhabha Atomic Research Center, Mumbai	1998	2008	11
Viswanathan, B	38	Indian Institute of Technology Madras, Chennai	2000	2008	9
Mehta, BR	38	Indian Institute of Technology, Delhi	1999	2008	10
Warrier, KGK	36	CSIR, Regional Research Laboratory, Trivandrum	1997	2008	12
Sahu, SN	36	Indian Institute of Physics, Bhubaneswar	1997	2007	11
Bahadur, D	35	Indian Institute of Technology Bombay, Mumbai	2002	2008	7
Kabiraj, D	35	Inter University Accelerator Center, New Delhi	2005	2008	4
Joy, PA	35	National Chemical Laboratory, Pune	1996	2008	13

Authors	Publications	Institutes	FPY*	LPY*	Duration (years)
Yakhmi, JV	34	Bhabha Atomic Research Center, Mumbai	2001	2008	8
Ghatak, J	34	Indian Institute of Physics, Bhubaneswar	2005	2008	4
Manna, I	34	Indian institute of Technology, Khragpur	1998	2008	11
Biswas, M	34	Presidency College, Kolkata	1998	2008	11
Dey, GK	33	Bhabha Atomic Research Center, Mumbai	1999	2008	10
Mukherjee, T	32	Bhabha Atomic Research Center, Mumbai	2001	2008	8
Mandal, S	32	National Chemical Laboratory, Pune	2001	2007	7
Choudary, BM	31	Indian Institute of Chemical Technology, Hyderabad	2002	2008	7
Chattopadhyay, KK	31	Jadavpur university, Kolkata	1998	2008	11
Ravi, V	31	National Chemical Laboratory, Pune	2003	2008	6
Kawazoe, Y	31	Tohohu University, Miyagi, Japan	2002	2008	7
Narayanasamy, A	31	University of Madras, Chennai	1999	2008	10
Dev, BN	30	Indian Institute of Physics, Bhubaneswar	2000	2008	9
Satpati, B	30	Indian Institute of Physics, Bhubaneswar	2003	2006	4
Sarma, DD	30	Indian Institute of Science, Bangalore	1992	2008	17
Mandale, AB	30	National Chemical Laboratory, Pune	1999	2008	10
Pradhan, SK	30	University of Burdwan, Burdwan	1996	2008	13
Murty, BS	29	Indian Institute of Technology, Kharagpur	1996	2008	13
Panigrahi, S	29	Indian Institute of Technology, Kharagpur	2004	2007	4
Ahmad, A	29	National Chemical Laboratory, Pune	2001	2008	8
Prasad, BLV	29	National Chemical Laboratory, Pune	2004	2008	5
Shivaprasad, SM	29	National Physical Laboratory, New Delhi	2001	2008	8
Thomas, KG	28	CSIR, Regional Research Laboratory, Trivandrum	1994	2008	15
Das,D	28	Indian Association of Cultivation Science, Kolkata	1990	2008	19
Malhotra, BD	28	National Physical Laboratory, New Delhi	2006	2008	3
Lee, KP	27	Algappa University, Karaikkudi	2005	2008	4
Manorama, SV	27	Indian Institute of Chemical Technology, Hyderabad	1999	2008	10
Nanda, KK	27	Indian Institute of Physics, Bhubaneswar	1997	2008	12
Pivin, JC	27	Inter University Accelerator Center, New Delhi	2004	2008	5
Bhoraskar, SV	27	University of Poona, Pune	1994	2008	15
Ravishankar, N	26	Indian Institute of Science, Bangalore	1998	2008	11
Jog, JP	26	National Chemical Laboratory, Pune	2001	2008	8
Kumar, A	26	National Chemical Laboratory, Pune	2000	2006	7
Sainkar, SR	26	National Chemical Laboratory, Pune	1996	2007	12
Mandal, TK	25	Indian Association of Cultivation Science, Kolkata	2003	2007	5
Pal, AJ	25	Indian Association of Cultivation Science, Kolkata	2003	2008	6
Subbanna, GN	25	Indian Institute of Science, Bangalore	1994	2004	11
Ramaprabhu, S	25	Indian Institute of Technology Madras, Chennai	2003	2008	6
Praharaj, S	25	Indian institute of Technology, Khragpur	2004	2006	3
Rajam, KS	25	National Aerospace Laboratory, Bangalore	2002	2008	7
Joag, DS	25	University of Poona, Pune	2000	2008	9

FPY = First Publication Year; LPY = Last Publication Year

4.7 Inter-Institution, City and State Collaboration

The study has analysed the collaboration of affiliations of authors who wrote the nanoscience and nanotechnology articles. Table 6 gives the list of inter-institution collaboration. Indian Institute of Science, Bangalore had 134 collaborative papers with Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore followed by NCL, Pune had 54 collaborative papers with University of Poona, Pune, IIT Bombay, Mumbai had 25 collaborative papers with TIFR, Mumbai. A close watch on the table reveals that maximum institutes had collaboration with the institutes in the same city. The collaboration of the major cities in India was analysed and the maximum number of collaboration was found with the institutes in Bangalore and with the institutes in Kolkata. The other part of the results is presented in Table 7. Collaboration among the institutes spread across Indian states in the field of nanoscience and nanotechnology was also analysed and it is presented in Table 8. Collaboration was maximum among the institutes of Karnataka and West Bengal states.

4.8 International Collaboration

In recent years, every country has realised the importance of collaborative research to tackle many scientific problems resulting in many international collaborations. There were 2566 internationally collaborated papers with 67 countries. Table 9 provides international collaboration pattern of Indian institutes in Nanoscience and Nanotechnology. Indian institutes had the highest number of collaborative papers with countries like the United States, Germany, Japan, South Korea, France and England. The institutes from other countries who collaborated with Indian institutes in the field of nanoscience and nanotechnology were analysed and found that there were 1045 foregin institutes as per *Science Citation Index* (1982-2008). The most occurred 15 institutes are listed in Table 10.

4.9 Highly Preferred Journals and Article Types

Table 11 Provides a list of journals which published at least 51 Indian articles in nanoscience and technology. The articles are distributed over 612 journals. The most preferred five journals were: *Journal of Applied Physics* (293); *Journal of Nanoscience and Nanotechnology* (285); *Applied Physics Letters* (243); *Materials Letters* (232); *Physical Review B* (232); *Nanotechnology* (194); *Langmuir* (182); *Journal of Physical Chemistry B* (167). These journals have fairly good impact factors (IF) and immediacy index (II). The journal publications under study were categorised into eight categories of document types and the distribution of publications is given in Table 12.

Table 6. Inter-institute collaboration in nanoscience and nanotechnology research in India as per *Science Citation Index* (1982-2008)

Inter-institute collaboration	No. of publications
Indian-Inst-Sci, Bangalore and Jawaharlal-Nehru-Ctr-Adv-Sci-Res, Bangalore	134
Natl-Chem-Lab, Pune and Univ-Pune, Pune	54
Indian-Inst-Technol-Bombay, Mumbai and Tata-Inst-Fundamental-Res, Mumbai	25
Ctr-Mat-Elect-Technol, Pune and Natl-Chem-Lab, Pune	21
Bhabha Atom Res Ctr, Mumbai and Indian-Inst-Technol-Bombay, Mumbai	19
Indian-Assoc-Cultivat-Sci, Kolkata and Jawaharlal-Nehru-Ctr-Adv-Sci-Res, Bangalore	19
Natl-Phys-Lab, New-Delhi and Univ-Delhi, New-Delhi	19
Indian-Inst-Sci, Bangalore and Univ-Madras, Chennai	17
Indian-Inst-Technol, New-Delhi and Natl-Phys-Lab, New-Delhi	15
Bhabha Atom Res Ctr, Mumbai and Indian-Inst-Technol-Madras, Chennai	14
Indian-Inst-Chem-Technol, Hyderabad and Ogene-Syst-Pvt-Ltd, Hyderabad	14
Bhabha Atom Res Ctr, Mumbai and Tata-Inst-Fundamental-Res, Mumbai	13
Indian-Inst-Sci, Bangalore and SN-Bose-Natl-Ctr-Basic-Sci, Kolkata	13
Indian-Inst-Sci, Bangalore and St-Josephs-Coll, Dept Chem, Bangalore	13
Bhabha Atom Res Ctr, Mumbai and Univ-Pune, Pune	12
Indian-Assoc-Cultivat-Sci, Kolkata and Saha-Inst-Nucl-Phys, Kolkata	12
Indian-Assoc-Cultivat-Sci, Kolkata and Univ-Calcutta, Kolkata	11
Indian-Inst-Technol-Madras, Chennai and Indira-Gandhi-Ctr-Atom-Res, Kalpakkam	11
Cent-Electrochem-Res-Inst, Karaikkudi and Alagappa-Univ, Karaikkudi	10
Indian-Assoc-Cultivat-Sci, Kolkata and Inter-Univ-Consortium-Sci-Res, Kolkata Ctr, Kolkata	10
Indian-Assoc-Cultivat-Sci, Kolkata and Univ-Kalyani, Nadiad	10
Indian-Inst-Technol-Bombay, Mumbai and Univ-Bombay, Mumbai	10

Table 7. Collaboration among institutes situated in different cities in nanoscience and nanotechnology research in India

S. No.	Collaboration among institutes in different cities	No. of publications
1	Bangalore and Kolkata	71
2	Mumbai and Pune	46
3	Bangalore and Chennai	33
4	New Delhi and Indore	28
5	Chennai and Kalpakkam	27
6	Pune and Indore	26
7	Kolkata and Bhubaneswar	24
8	Kolkata and Kharagpur	24
9	Mumbai and Indore	24
10	Kolkata and Howrah	22
11	Mumbai and Bangalore	22
12	Mumbai and Kharagpur	22
13	Mumbai and Kanpur	21
14	New Delhi and Bhubaneswar	21
15	Mumbai and New Delhi	20
16	Mumbai and Chennai	18
17	Mumbai and Bhubaneswar	17
18	Mumbai and Kolkata	17
19	Bangalore and Hyderabad	15
20	Bhubaneswar and Kanpur	15
21	New Delhi and Hyderabad	14
22	New Delhi and Kanpur	14
23	Bangalore and Pune	13
24	Bangalore and Tirupati	13
25	Kolkata and Burdwan	13
26	Kolkata and Hyderabad	13
27	Bangalore and New Delhi	12
28	Kolkata and New Delhi	12
29	New Delhi and Agra	12
30	New Delhi and Jaipur	12
31	Chennai and Pune	11
32	Kolkata and Chennai	11
33	Kolkata and Kanpur	11
34	Chennai and Hyderabad	10
35	Chennai and Kharagpur	10
36	Kharagpur and Howrah	10

The normal research articles constitute 95.56 percentage of the total number of articles.

4.10 Country-wise Distribution of Journals

The journals (612) publishing articles on nanoscience and nanotechnology research are geographically distributed over 29 countries. Table 13 gives country-wise distribution of journals and number of publications. USA has published 3546 (42.59 per cent) articles in 209 (34.15 per cent) journals, followed by England with 1463 (42.49 per cent) articles in 156 (17.57 per cent) journals, the

Table 8. Collaboration among institutes situated in different Indian states involved in nanoscience and nanotechnology research in India

S. No.	Collaboration among institutes in different Indian states	No. of publications
1	Karnataka and West Bengal	78
2	Maharashtra and West Bengal	54
3	Delhi and Uttar Pradesh	52
4	Karnataka and Tamil Nadu	51
5	Madhya Pradesh and Maharashtra	51
6	Maharashtra and Uttar Pradesh	45
7	Maharashtra and Tamil Nadu	42
8	Karnataka and Maharashtra	41
9	Delhi and Maharashtra	38
10	Karnataka and Andhra Pradesh	37
11	Orissa and West Bengal	36
12	Delhi and Madhya Pradesh	33
13	Kerala and Tamil Nadu	32
14	Uttar Pradesh and West Bengal	30
15	Madhya Pradesh and West Bengal	25
16	Delhi and Orissa	24
17	Maharashtra and Orissa	24
18	Andhra Pradesh and West Bengal	21
19	Delhi and West Bengal	21
20	Karnataka and Uttar Pradesh	21
21	Andhra Pradesh and Maharashtra	19
22	Orissa and Tamil Nadu	19
23	Delhi and Rajasthan	18
24	Andhra Pradesh and Tamil Nadu	17
25	Orissa and Uttar Pradesh	17
26	Andhra Pradesh and Delhi	16
27	Tamil Nadu and West Bengal	16
28	Gujarat and Maharashtra	14
29	Karnataka and Delhi	14
30	Kerala and Maharashtra	14
31	Madhya Pradesh and Tamil Nadu	13
32	Assam and Tamil Nadu	12
33	Delhi and Haryana	12
34	Haryana and Punjab	11
35	Karnataka and Kerala	11
36	Karnataka and Rajasthan	11
37	Jharkhand and Uttar Pradesh	10
38	Assam and Delhi	9
39	Delhi and Gujarat	9
40	Delhi and Himachal Pradesh	9
41	Andhra Pradesh and Rajasthan	8
42	Delhi and Tamil Nadu	8
43	Madhya Pradesh and Uttar Pradesh	8
44	Maharashtra and Rajasthan	8
45	Maharashtra and Uttrakhand	8
46	Karnataka and Madhya Pradesh	7
47	Maharashtra and Punjab	7

S. No.	Collaboration among institutes in different Indian states	No. of publications
48	Pondicherry and Tamil Nadu	7
49	Andhra Pradesh and Kerala	6
50	Assam and West Bengal	6
51	Delhi and Punjab	6
52	Madhya Pradesh and Orissa	6
53	Andhra Pradesh and Pondicherry	5
54	Andhra Pradesh and Uttar Pradesh	5
55	Jharkhand and Maharashtra	5
56	Karnataka and Orissa	5
57	Assam and Maharashtra	4
58	Gujarat and Tamil Nadu	4
59	Gujarat and Uttar Pradesh	4
60	Himachal Pradesh and Madhya Pradesh	4
61	Jharkhand and Orissa	4
62	Kerala and Madhya Pradesh	4
63	Punjab and Uttrakhand	4
64	Rajasthan and Uttar Pradesh	4
65	Tamil Nadu and Uttar Pradesh	4
66	Andhra Pradesh and Madhya Pradesh	3
67	Assam and Uttar Pradesh	3
68	Delhi and Kerala	3
69	Goa and Maharashtra	3
70	Gujarat and West Bengal	3
71	Haryana and Maharashtra	3
72	Jharkhand and Uttrakhand	3
73	Madhya Pradesh and Rajasthan	3
74	Rajasthan and Tamil Nadu	3
75	Sikkim and West Bengal	3
76	Andhra Pradesh and Assam	2
77	Andhra Pradesh and Gujarat	2
78	Andhra Pradesh and Jharkhand	2
79	Andhra Pradesh and Uttrakhand	2
80	Chattisgarh and Delhi	2
81	Delhi and Jharkhand	2
82	Delhi and Uttrakhand	2
83	Goa and Uttar Pradesh	2
84	Gujarat and Punjab	2
85	Haryana and Himachal Pradesh	2
86	Haryana and Madhya Pradesh	2
87	Himachal Pradesh and Uttar Pradesh	2
88	Jharkhand and Madhya Pradesh	2
89	Karnataka and Punjab	2
90	Kerala and Uttar Pradesh	2
91	Kerala and West Bengal	2
92	Madhya Pradesh and Punjab	2
93	Maharashtra and Nagaland	2
94	Punjab and Rajasthan	2
95	Rajasthan and West Bengal	2
96	Andhra Pradesh and Orissa	1
97	Andhra Pradesh and Punjab	1
98	Arunachal Pradesh and Meghalaya	1
99	Assam and Gujarat	1
100	Assam and Kerala	1
101	Assam and Madhya Pradesh	1
102	Assam and Orissa	1
103	Delhi and Goa	1
104	Delhi and Meghalaya	1
105	Delhi and Nagaland	1
106	Goa and Orissa	1
107	Gujarat and Karnataka	1
108	Gujarat and Madhya Pradesh	1
109	Gujarat and Rajasthan	1
110	Haryana and West Bengal	1
111	Himachal Pradesh and Rajasthan	1
112	Jharkhand and Tamil Nadu	1
113	Karnataka and Gujarat	1
114	Karnataka and Pondicherry	1
115	Karnataka and Sikkim	1
116	Kerala and Orissa	1
117	Kerala and Rajasthan	1
118	Maharashtra and Manipur	1
119	Maharashtra and Pondicherry	1
120	Meghalaya and Uttar Pradesh	1
121	Nagaland and Punjab	1
122	Punjab and Tamil Nadu	1
123	Punjab and Uttar Pradesh	1
124	Tamil Nadu and Uttrakhand	1

Netherlands with 1993 (23.94 per cent) articles in 106 (17.32 per cent) journals, Germany with 289 (3.47 per cent) articles in 47 (7.68 per cent) journals, and Switzerland with 554 (6.65 per cent) articles in 23 (3.76 per cent) journals.

4.11 Distribution of Keywords

Keywords are one of the best scientometric indicators to understand and grasp instantaneously the thought content of the papers and to find out the growth of the subject field. By analysing the keywords appeared either in the title or assigned by the indexer or the author himself help in knowing in which direction the knowledge grows. The high frequency keywords in a micro-field will enable us to understand the direction of research in the micro-field. The present study has identified the keywords appeared in the Key-Words-Plus and Author Keywords fields of *SCI*. There were a total of 19718 individual keywords occurred. Table 14 lists the frequently occurred

Table 9. International collaboration of premier Indian institutes engaged in nanoscience and nanotechnology research with other countries

S. No.	Collaboration among different countries	No. of publications
1	USA	525
2	Germany	321
3	Japan	312
4	South-Korea	227
5	France	182
6	England	113
7	Taiwan	78
8	Peoples-R-China	75
9	Italy	60
10	Canada	50
11	Australia	49
12	Israel	46
13	Spain	38
14	Singapore	37
15	Switzerland	32
16	Brazil	31
17	Russia	27
18	Sweden	23
19	Malaysia	22
20	Netherlands	21
21	Hungary	20
22	Wales	20
23	Hong-Kong	17
24	Mexico	16
25	Scotland	16
26	Ireland	14
27	Belgium	13
28	Iran	13
29	Poland	13
30	Portugal	13
31	Austria	10
32	Oman	10
33	South-Africa	10
34	Czech-Republic	9
35	Finland	9
36	Greece	8
37	Denmark	7
38	Romania	6
39	Thailand	6
40	Byelarus	5
41	Saudi-Arabia	5
42	Argentina	4
43	Bulgaria	4
44	Ukraine	4
45	Uzbekistan	4
46	Egypt	3
47	Jordan	3
48	North-Ireland	3
49	Turkey	3
50	Yemen	3
51	Bangladesh	2
52	Chile	2
53	Colombia	2
54	Cyprus	2
55	Ethiopia	2
56	Libya	2
57	New-Zealand	2
58	Nigeria	2
59	Vietnam	2
60	Armenia	1
61	Croatia	1
62	Ecuador	1
63	Qatar	1
64	Slovakia	1
65	Tunisia	1
66	U-Arab-Emirates	1
67	Yugoslavia	1

Table 10. Foreign collaborated institutes (≥ 25) with Indian institutes in the field of nanoscience and nanotechnology research as per *Science Citation Index* (1982-2008)

S. No.	International institutes	No. of publications
1	Tohoku-Univ, Sendai, Miyagi, Japan	69
2	Chonbuk-Natl-Univ, Chonju, South-Korea	64
3	Natl-Inst-Mat-Sci, Tsukuba, Ibaraki, Japan	36
4	Kyungpook-Nalt-Univ, Taegu, South-Korea	32
5	CNRS, CSNSM, IN2P3, Orsay, France	30
6	Nagoya-Inst-Technol, Nagoya, Aichi, Japan	30
7	Univ-Paris, Paris, France	30
8	Hahn-Meitner-Inst, Berlin, Germany	29
9	Natl-Taiwan-Univ, Taipei, Taiwan	28
10	Forschungszentrum-Karlsruhe, Karlsruhe, Germany	27
11	Korea-Res-Inst-Chem-Technol, Taejon, South-Korea	27
12	Natl-Univ-Singapore, Singapore, Singapore	27
13	Acad-Sinica, Inst Atom & Mol Sci, Taipe, Taiwan	25
14	Univ-Notre-Dame, Notre-Dame, USA	25
15	Univ-Western-Ontario, London, Canada	25

Table 11. Journals publishing articles (≥ 51) in nanoscience and nanotechnology research as per *Science Citation Index* (1982-2008)

S. No.	Journal	No. of publications	IF*- 2007	II*- 2007	FPY-LPY*	Publishing country
1	*Journal of Applied Physics*	293	2.171	0.393	1985-2008	USA
2	*Journal of Nanoscience and Nanotechnology*	285	1.987	0.308	2006-2008	USA
3	*Applied Physics Letters*	243	3.596	0.627	1990-2008	USA
4	*Materials Letters*	232	1.625	0.246	1991-2008	Singapore
5	*Physical Review- B*	232	3.172	0.652	2000-2008	USA
6	*Nanotechnology*	194	3.31	0.461	2000-2008	UK
7	*Langmuir*	182	4.009	0.657	1995-2008	USA
8	*Journal of Physical Chemistry- B*	167	4.086	0.629	1997-2008	USA
9	*Journal of Physical Chemistry- C*	160	-	-	2007-2008	USA
10	*Journal of Applied Polymer Science*	159	1.008	0.173	1998-2008	USA
11	*Applied Surface Science*	140	1.406	0.219	1996-2008	Singapore
12	*Chemical Physics Letters*	138	2.207	0.418	1994-2008	Singapore
13	*Materials Chemistry and Physics*	122	1.871	0.179	1993-2008	Singapore
14	*Journal of Physics- D*	120	2.2	0.383	1989-2008	UK
15	*Materials Research Bulletin*	118	1.484	0.227	1992-2008	Singapore
16	*Journal of Magnetism and Magnetic Materials*	117	1.704	0.216	1993-2008	Singapore
17	*Journal of Materials Science*	112	1.081	0.135	2006-2008	Netherlands
18	*Solid State Communications*	112	1.535	0.297	1990-2008	UK
19	*Journal of Colloid and Interface Science*	106	2.309	0.321	1994-2008	Singapore
20	*Journal of Physics-Condensed Matter*	105	1.886	0.404	1990-2008	UK
21	*Thin Solid Films*	100	1.693	0.258	1988-2008	Singapore
22	*Journal of Materials Chemistry*	95	4.339	0.799	1995-2008	UK
23	*Nuclear Instruments & Methods in Physics Research- B*	93	0.997	0.103	1999-2005	Singapore
24	*Journal of Materials Research*	85	1.916	0.312	1993-2008	USA
25	*Materials Science and Engineering- A*	85	1.457	0.24	1996-2008	Switzerland
26	*Physica- E*	85	0.834	0.215	2001-2005	Singapore
27	*Pramana-Journal of Physics*	81	0.383	0.051	1992-2008	India
28	*Current Science*	78	0.8	0.182	1991-2008	India
29	*Journal of Alloys and Compounds*	78	1.455	0.304	1996-2008	Switzerland
30	*Synthesis and Reactivity in Inorganic Metal-Organic and Nano-Metal Chemistry*	75	0.784	0.1	2005-2008	USA
31	*Chemistry of Materials*	71	4.883	0.632	1997-2008	USA
32	*Journal of Crystal Growth*	69	1.824	0.353	1992-2008	USA
33	*Journal of the American Ceramic Society*	61	1.792	0.264	1998-2008	USA
34	*Scripta Materialia*	60	2.481	0.427	1996-2008	USA
35	*Journal of Chemical Physics*	59	0.469	0.036	1997-2008	USA
36	*Materials Science and Engineering- B*	59	1.33	0.151	1995-2008	Switzerland
37	*Sensors and Actuators- B*	56	2.934	0.449	1998-2008	Switzerland
38	*Chemical Communications*	51	5.141	1.297	1996-2008	UK

IF=Impact Factor; II=Immediacy Index; FPY=First Publication Year; LPY=Last Publication Year

Table 12. Distribution of publications by document types of Indian publications on nanoscience and nanotechnology research as per *Science Citation Index* (1982-2008)

S. No	Types of documents	Number of papers	Percentage of total	Cumulative percentage
1	Articles	7956	95.56	95.56
2	Reviews	197	2.37	97.92
3	Letters	61	0.73	98.65
4	Editorial-Materials	36	0.43	99.09
5	Meeting-Abstracts	34	0.41	99.50
6	Notes	24	0.29	99.78
7	Corrections	12	0.14	99.93
8	News-Items	6	0.07	100.00

Table 13. Country-wise distribution of journals

S. No.	Publishing country	Number of journals	% of Total journals	No. of articles published	% of total articles
1	USA	209	34.15	3546	42.59
2	England	156	17.57	1463	25.49
3	Netherland	106	17.32	1993	23.94
4	Germany	47	7.68	289	3.47
5	Switzerland	23	3.76	554	6.65
6	Japan	13	2.12	65	0.78
7	France	9	1.47	42	0.50
8	India	9	1.47	256	3.07
9	China	6	0.98	6	0.07
10	Poland	4	0.65	6	0.07
11	Russia	4	0.65	4	0.05
12	Singapore	3	0.49	52	0.62
13	South Korea	3	0.49	11	0.13
14	Czech Republic	2	0.33	5	0.06
15	Denmark	2	0.33	7	0.08
16	Hungary	2	0.33	3	0.04
17	Spain	2	0.33	3	0.04
18	Australia	1	0.16	2	0.02
19	Austria	1	0.16	1	0.01
20	Canada	1	0.16	2	0.02
21	Greece	1	0.16	1	0.01
22	Ireland	1	0.16	1	0.01
23	Israel	1	0.16	1	0.01
24	Italy	1	0.16	3	0.04
25	New Zealand	1	0.16	1	0.01
26	Scotland	1	0.16	1	0.01
27	South Africa	1	0.16	1	0.01
28	Sweden	1	0.16	4	0.05
29	Taiwan	1	0.16	3	0.04

Table 14. Most occurred keywords (≥ 51) appeared in keywords field in publications on nanoscience and nanotechnology research as per *Science Citation Index* (1982-2008)

S. No.	Keywords	Frequency	S. No.	Keywords	Frequency
1	Nanoparticles	1244	48	Polymers	151
2	Particles	756	49	Surfaces	151
3	Films	589	50	Atomic Force Microscopy	149
4	Growth	513	51	Transition	148
5	Nanocrystals	501	52	Fabrication	147
6	Thin-Films	484	53	Nanocomposite	145
7	Nanostructures	427	54	Oxides	144
8	Optical-Properties	410	55	Polyaniline	139
9	Nanocomposites	401	56	Reduction	139
10	Photoluminescence	391	57	Transport	138
11	Size	382	58	Silica	137
12	Temperature	366	59	Systems	132
13	Clusters	329	60	Room-Temperature	128
14	Behavior	320	61	Chemical-Vapor-Deposition	127
15	Spectroscopy	268	62	Chemistry	127
16	Luminescence	267	63	Crystallization	125
17	Surface	265	64	Alloys	124
18	Nanowires	259	65	Phase	124
19	Composites	231	66	Silicon	123
20	Carbon Nanotubes	225	67	Spectra	123
21	Quantum Dots	224	68	Mechanism	122
22	Deposition	223	69	Arrays	119
23	X-Ray Diffraction	218	70	Metal Nanoparticles	119
24	Gold Nanoparticles	216	71	Silver Nanoparticles	118
25	Powders	215	72	Kinetics	116
26	Nanotubes	212	73	Route	116
27	Morphology	207	74	Sol-Gel	114
28	Water	201	75	Atomic-Force Microscopy	113
29	Magnetic-Properties	190	76	Model	111
30	Adsorption	184	77	Semiconductor	111
31	Gold	181	78	Electron Microscopy	109
32	Microstructure	179	79	Complexes	108
33	Nanorods	175	80	Dependence	106
34	Self-Assembled Monolayers	175	81	XRD	104
35	Semiconductors	171	82	Irradiation	102
36	Oxide	170	83	Optical Properties	102
37	Polymer	169	84	Dynamics	101
38	Absorption	166	85	Nanoclusters	101
39	Conductivity	166	86	TiO2	101
40	Mechanical-Properties	166	87	Nanomaterials	100
41	Silver	166	88	Stability	100
42	System	166	89	Molecules	98
43	Oxidation	161	90	Emission	97
44	Ceramics	158	91	Composite	96
45	Chemical Synthesis	156	92	Scattering	95
46	Nanocrystalline	156	93	ZnO	95
47	Molecular-Beam Epitaxy	151	94	Colloids	94

S. No.	Keywords	Frequency
95	Metals	93
96	Thin Films	93
97	Aqueous-Solution	92
98	Polymerization	90
99	Acid	89
100	Fluorescence	87
101	Monolayers	87
102	Diffusion	86
103	Electrodes	86
104	CdS	84
105	Nanocrystalline Materials	83
106	Catalysts	82
107	TEM	82
108	Copper	80
109	Energy	80
110	Metal	79
111	Montmorillonite	79
112	DNA	78
113	Matrix	77
114	Performance	77
115	Solar-Cells	77
116	States	77
117	Glass	76
118	Coatings	75
119	Superlattices	75
120	Nickel	74
121	Electrodeposition	73
122	State	73
123	Crystal-Structure	71
124	Raman-Scattering	71
125	Alumina	70
126	Devices	70
127	Crystallites	69
128	Crystals	69
129	Intercalation	69
130	Polypyrrole	69
131	Electrical-Properties	68
132	Langmuir-Blodgett-Films	68
133	Sensors	67
134	Si	67
135	Semiconductor Clusters	66
136	Zinc-Oxide	66
137	Cells	65
138	Degradation	65
139	AFM	64
140	Magnetic Properties	64

S. No.	Keywords	Frequency
141	Self-Assembly	63
142	Transformation	63
143	Co	62
144	Mechanical Properties	62
145	Mossbauer	62
146	SEM	62
147	Clay	61
148	Field	61
149	Porous Silicon	61
150	Relaxation	61
151	Electronic-Structure	60
152	Particle-Size	60
153	Raman	60
154	Semiconductor Nanocrystals	60
155	Transmission Electron Microscopy	60
156	Nanoparticle	59
157	Reverse Micelles	59
158	Drug-Delivery	58
159	Carbon	57
160	Combustion Synthesis	57
161	Decomposition	56
162	X-Ray-Diffraction	56
163	Aggregation	55
164	Enhancement	55
165	Ferrite	55
166	In-Vitro	55
167	Sensor	55
168	Confinement	54
169	Gas	54
170	Magnetoresistance	54
171	Mossbauer Spectroscopy	54
172	Platinum	54
173	Powder	54
174	Catalysis	53
175	Precursor	53
176	ZnS	53
177	Derivatives	52
178	Giant Magnetoresistance	52
179	Multilayers	52
180	Nanofibers	52
181	Precursors	52
182	Design	51
183	Electrode	51
184	Layered Silicate Nanocomposites	51
185	Layers	51
186	X-Ray	51

keywords and the most occurred keywords (at least 51 times) were: Nanoparticles (1244); Particles (756); Films (589); Growth (513); and Nanocrystals (501).

5. CONCLUSION

A total of 296072 publications were published globally in the field of nanoscience and nanotechnology during 1982-2008. USA topped the list with 84561 (28.56 per cent) followed by, China with 43393 (14.66 per cent) publications, Japan with 32431 (10.95 per cent) publications, Germany with 28065 (9.48 per cent) publications, France with 18141 (6.13 per cent) publications, and England with 13850 (4.68 per cent) publications. India contributed to the field with 8326 (2.81 per cent) publications during 1982-2008.The study reveals that Indian Institute of Science, Bangalore contributed the highest number of publications (723) followed by Indian-Institute of Technology, Kharagpur with 606 publications, National Chemical Laboratory, Pune with 589 publications, Indian Association for Cultivation Science, Kolkata with 563 publications and Bhabha Atomic Research Centre, Mumbai with 434 publications.

The steep growth in number of publications from India on nanoscience and nanotechnology during 2000-2008 shows the magnitude and sustained impetus received for the field. The recent science research fields are witnessing high collaboration of authors in local, national and international levels. In the present study, 96.83 per cent of the total publications were collaborative in nature and among the collaborated papers, 48.79 per cent had three authored papers. The percentage share of collaborative publications with two authors and four authors had almost same number of publications (21.87 per cent and 20.73 per cent respectively) and mega-authorships publications (publications with > 5 authors) constituted 30.48 per cent. C.N.R. Rao, M. Sastry, S. Chaudhuri, D. Chakravorty, A. Govindaraj, T. Pradeep, K. Vijayamohanan, T. Pal, D.K. Avasthi, A.K. Bhowmick, R. Pasricha and P. Pramanik were the most productive authors in the field.

The study reveals that IISc, Banglore, IIT Kharagpur, NCL, Pune, IACS, Kolkatta and BARC Mumbai are the top five institutes in India, where extensive level of research on nanoscience and nanotechnology is going on and these institutes have collaborated papers with institutes from USA, Germany and Japan. Acad-Sinica, Inst Phys, Taipei, Taiwan; Hahn-Meitner-Inst-Berlin-Gmbh, Berlin, Germany; Chonbuk-Natl-Univ, Dept-Text-Engn, Chonju, South-Korea; Austrian-Acad-Sci, Inst-Biophys-Xray-Struct-Res, Austria; Sincrotrone-Trieste, Italy were the most collaborated foreign institutes with Indian Institutes. A noteworthy number of collaborative publications (134) were from Indian Institute of Science, Bangalore and Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore. Bangalore city was found to be the centre of activity in nanoscience and nanotechnology research. The institutes located in Bangalore and Kolkata had the highest collaborative publications (71).

More than 95.38 percent of the articles were published in journals with high impact factors which is suggestive of the publications behaviour of scientists who preferred to publish their papers in highly reputed journals like *Journal of Applied Physics, Journal of Nanoscience and Nanotechnology, Applied Physics Letters, Materials Letters, Physical Review B, Nanotechnology, Langmuir, Journal of Physical Chemistry B, Journal of Physical Chemistry C, and Journal of Applied Polymer Science*.It will be quite interesting if one attempts to carryout citation analysis of these papers which may give interesting insights into the dynamics of this field.

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REFERENCES

1. Schmid, Gunter. Nanotechnology, Vol. 1: principles and fundamentals, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, 2008.

2. Brune, H.; Ernst, H.; Grunwald, A.; Grunwald, W.; Hofmann, H.; Krug, H.; Janich, P.; Mayor, M.; Rathgeber, W.; Schmid, G.; Simon, U.; Vogel, V. & Wyrwa, D. Wissenschaftsethik and technikfolgenab schatzung, Vol. 27. Nanotechnology-assessment and perspectives, Springer, Berlin, 2006.

3. Wikipedia contributors. Nanotechnology. http://en.wikipedia.org/w/index.php?title=Nanotechnology&oldid=190342707 (accessed on 11 February 2008).

4. University of Florida. Nanoscience and technology. http://www.phys.ufl.edu/teresa/nano/index.html (accessed on 11 February 2008).

5. Roco, M.C. International strategy for nanotechnology research and development. *J. Nanoparticle Res.* 2001, **3**, 353–60.

6. Schummer, Joachim. Multidisciplinarity, interdisciplinarity, and patterns of research collaboration in nanoscience and nanotechnology. *Scientometrics*, 2004, **59**(3), 425-65.

7. Kostoff, Ronald N.; Koytcheff Raymond, G. & Lau Clifford, G.Y. Technical structure of the global nanoscience and nanotechnology literature. *J. Nanoparticle Res.* 2007, **9**, 701-24.

8. Lin, Min-Wei & Zhang, Jingjing. Language trends in nanoscience and technology: The case of Chinese-language publications. *Scientometrics*, 2007, **70**(3), 555–64.

9. Braun, Tibor; Schubert, Andras P. & Zsindely, S. Nanoscience and nanotechnology on the balance. *Scientometrics*, 1997, **38**(2), 321-25.

10. Meyer, M. & Persson O. Nanotechnology-Interdis ciplinarity, patterns of collaboration and differences in application. *Scientometrics*, 1998, **42**(2), 195-205.

11. Hullmann A. & Meyer M. Publications and patents in nanotechnology: An overview of previous studies and the state of the art. *Scientometrics*, 2003, **58**(3), 507-27.

12. Huang Z.; Chen H.; Yan L. & Roco M.C. Longitudinal nanotechnology development (1991-2002): National science foundation funding and its impact on patents. *J. Nanoparticle Res.* 2005, **7**, 343-76.

13. Huang Z.; Chen H.; Li X. & Roco M.C. Connecting NSF funding to patent innovation in nanotechnology (2001-2004). *J. Nanoparticle Res.* 2006, **8**(6), 859-79.

14. Zitt M. & Bassecoulard E. Delineating complex scientific fields by an hybrid lexical-citation method: An application to nanosciences. *Inform. Process. Manage.*, 2006, **42**(6), 1513-531.

15. Guan, J. & Ma N. China's emerging presence in nanoscience and nanotechnology. A comparative bibliometric study of several nanoscience 'giants'. *Research Policy*, 2007, **36**(6), 880-86.

16. Schummer J. The global institutionalisation of nanotechnology research: A bibliometric approach to the assessment of science policy. *Scientometrics*, 2007, **70**(3), 669-92.

17. Youtie J.; Shapira P. & Porter A.L. Nanotechnology publications and citations by leading countries and blocs. *J.Nanoparticle Res.* 2008, **10**(6), 981-86.

18. Glanzel, W.; Meyer, M.; Du Plessis, M.; Thijs, B.; Magerman, T.; Schlemmer, B.; Debacker, K. & Veugelers, R. Nanotechnology: Analysis of an Emerging domain of Scientific and Technological endeavour. Steunpunt O&O Staisitieken. Katholieke Universiteit Leuven. 2003.

19. Wilson, Mick; Kannangara, Kamali; Smith, Geoff; Simmons, Michelle & Raguse, Burkhard. Nanotechnology: Basic science and emerging technologies, Chapman and Hall/CRC Press, 2002.

20. Karki, M.M.S.; Garg, K.C. & Sharma, P. Activity and growth of organic chemistry research in India during 1971-1989. *Scientometric, 2000,* **49**(2), 279-288.

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