

Mapping of nanoscience and nanotechnology research in India: a scientometric analysis, 1990–2009

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Received: 27 February 2011 / Published online: 23 August 2011
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Abstract This paper analyses the growth pattern of Nanoscience and Nanotechnology literature in India during 1990–2009 (20 years). The Scopus international multidisciplinary bibliographical database has been used to identify the Indian contributions on the field of nanoscience and nanotechnology. The study measures the performance based on several parameters, country annual growth rate, authorship pattern, collaborative index, collaborative coefficient, modified collaborative coefficient, subject profile, etc. Further the study examines national publication output and impact in terms of average citations per paper, international collaboration output and share, contribution and impact of Indian Institutions and impact of Indian journals.

Keywords Nanotechnology · Nanoscience · Collaborative coefficient
h-index · *g*-index · *p*-index

Introduction

Nanotechnology is the field of science and technology which deal with the study of matter in nano range i.e. from 1 to 100 nm. A working definition is that “Nanotechnology is the manipulation precision placement, measurement, modeling or manufacture of

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sub-100 nm scale matter” (Meyer 2001). Franks’s (1987) defines nanotechnology as “the technology where dimensions or tolerances in the range 0.1–100 nm play a critical role”.

Meyer (2007) on a patent study of nanotechnology suggests that, “the field is misconstrued as either a field of technology or an area of converging technologies while evidence to date suggests its rather that nanoscience and nanotechnology be considered a set of inter-related and overlapping but not necessarily merging technologies”. Nanotechnology is an interdisciplinary field. Nanoscience and nanotechnology are considered as one of the promising research fields having important social and economic impacts in the future. Industrial sectors such as aerospace, biotech, energy, physics, chemistry, etc. depend on materials and device made up of atoms and molecules, by default can all be improved by application of nanoscience and nanotechnology. A large quantity of literature can be seen on the emerged area (Braun et al. 1997; Meyer et al. 2001; Noyons et al. 2003; Pouris 2007; Schummer 2007).

In India nanotechnology originated around two decades back, implications can be seen in the field of telecommunications, computing, aerospace, solar energy and environment. Nanotechnology is a key to development in all major branches of technology including information technology, electronics, medicine development materials production in coming years. Though in many developed countries like USA it has been in research for quite a few years and in India it is still opening up.

This study is based on scientometric analysis of research trend of nanoscience and nanotechnology on Indian Research output for the years 1990–2009. Scientometrics has typically been defined as the quantitative study of science and technology. Scientometrics includes all quantitative aspects of the science of science, communication in science and science policy (Wilson 2001). Mapping scientific fields is quite a common operation in bibliometric studies, in order to visualize networks explicitly or implicitly carried by articles (collaboration, citation). Mapping is a study of correlation links between the past and present research work using citation analysis or it is a useful graphic technique done by macro and micro levels. Mapping is a technique used to analyze vast literature and molded in a particular form. This particular information format can be used by researcher effectively. Different elements of a bibliographic record may used to generate a map structure. Each element reveals a specific structure, unique in a sense, but always related to the structures based on other element (Mithal et al. 2005). This study, aims to capture the overall publications at macro level of the field among top 10 countries and the micro level relates to analysis of Indian contributions on the subject. The metrics vary according to the particular methods used. In this study the various measures of collaboration and the indices like relative quality index, *h*-index, *g*-index, *p*-index were used to find the author collaboration, quality of the literature based on the pattern of authorship and citation.

Trend in India

The world wide nanotechnology research and development (R&D) investment reported by government organizations has increased by a factor of 3.5 between 1997 and 2001, and the highest rate of 90% is in 2001 (Roco 2001). Annual growth of nanotechnology papers was 33.51% in India between 2000 and 2007 (Liu et al. 2009). As a consequence almost every country in the world has chosen to invest significantly in this area.

The Nano Mission, as per the press release of the Department of Science and Technology, Ministry of Science and Technology, India (http://www.dst.gov.in/whats_new/press-release06/proposal-nano-science.htm), plans to make special efforts for development

and commercialization of nanotechnology, not only through public private partnerships but also by encouraging and enabling the private sector to invest in, and leverage, this sunrise technology. Various Ministries/Departments Various Ministries/Departments of Government of India such as the Department of Science and Technology (DST), Defence Research and Development Organization (DRDO), Council of Scientific and industrial Research (CSIR) and Department of Biotechnology (DBT) have been supporting R&D in Nano Science and Technology. DST launched a special nano Science and Technology initiative (NSTI) in October, 2001. The NSTI has been focusing on research and development in nanoscience and technology in a comprehensive manner so that India can become a significant player in the area and contribute to the development of new technologies besides carrying out basic research at the frontier of knowledge. The programme supports R&D projects strengthening of characterization and infrastructural facilities, creation of centre of excellence, generation of trained manpower, joint projects between educational institutions and industry for application development etc.

NSTC—Nano Science and Nano Technology Consortium works in the area of technology transfer on Nano Silver Technology, Fuel Nano Additive Technology, Bullet Proof Material Technology, etc. (<http://www.nstc.in/>) NSTC provides education and training to under the technology by Nano School, nano kits, nano gallery, nano booklets, hands on lab, training projects, etc., Based on the publications importance for the development of new technologies NSTC publish NanoTrends Journal, Nano Connect, Books & Reports, etc.

India is developing R&D outsourcing and offer benefits at lower costs. Based on the talent and manpower, India can provide a platform and base for the development of nanotechnology by way of research on their own or by outsourcing (Table 1).

Related literature

An extensive literature has developed studying patterns of publication in the field of nanoscience and nanotechnology. These studies have attempted to gain a deeper understanding of topics such as, how nanoscience research is performed, how nanotechnology

Table 1 Symbols used and their descriptions

Symbols	Descriptions
ACPP	Average citation per paper
CC	Collaborative coefficient
CI	Collaborative index
CPP	Citation per paper
DC	Degree of collaboration
Dt	Doubling time
ICP	International collaborative papers
MCC	Modified collaborative coefficient
NC	Number of citations
NHQ	Number of high quality papers
NP	Number of papers
RGR	Relative growth rate
RQI	Relative quality index
TNC	Total number of citations
TNP	Total number of papers

relates to more established field of research, how and where nanotechnologies are being developed, and their potential economic impacts.

Braun et al. (1997) were established the growth and trends of the nano prefixed terms especially the journal papers has been measured. Meyer and Persson (1998) show the interdisciplinary nature of nanotechnology and also look at differences among countries during the period 1991–1996. Schummer (2004) analysed the development of scientists and engineers in nanoscale research of 600 published papers in eight existing nanoscale journals in 2002 and 2003, and also investigated multi- and interdisciplinarity research collaboration in current nanoscale research. Degree of interdisciplinarity is on average but high degree of multi disciplinarity.

Leydesdorff and Zhou (2007) delineated nanoscience in terms of journals and nanotechnology in terms of patents. Leydesdorff (2008) analyzed 12 journals and indicated them as developing interdisciplinarily at the interfaces between applied physics, chemistry, and the life sciences. Due to the technology development and expected impacts on economic activity, the publication trend of nanotechnology has been investigated by bibliometric methods (Takeda et al. 2009). The research output on nanotechnology and nanoscience have been analysed by number of eminent personalities such as Lin and Zhang (2007), Glanzel et al. (2003), Wilson et al. (2002), Mohan et al. (2010). The number of nanoscience and nanotechnology research publications has grown exponentially for more than a decade (Kostoff et al. 2007). Because of the potential applications, nanoscience and nanotechnology is considered a particularly promising research field having both important social and economic impact for the future (Igami 2008). Both scientific literature and patent data have been used to study the development by using various scientometric techniques (Bassecouard et al. 2007; Huang et al. 2003, 2004; Hullmann and Meyer 2003; Pavitt 1998; Schultz and Joutz 2009). Apart from the patent and literature growth study, the delineation of nanoscience and nanotechnology as an emerging science and technology area (Braun et al. 1997; Meyer 2000a, b, c, 2001; Parr 2005; Zitt and Bassecouard 2006) and to distinguish the relationship between nanoscience and nanotechnology (Meyer and Persson, 1998; Meyer 2000a, b, c, 2001). Bassecouard et al. (2007) mapped the citation flows of nanotechnology publications, classified nanotechnology papers into thematic clusters and showed that the themes uncovered in nanotechnology are moderately multidisciplinary. Studies of relevant publications continue to show that nanoscience is drawing on and contributing to multiple areas of science.

Hirsch (2005) introduced a single index *h*-index to quantify a scientist's published research impact created an unprecedented response from the scientometric community. Improvement of the *h*-index, Egghe (2006) proposed the *g*-index and Prathap (2010) proposed the *p*-index. Alonso et al. (2010) presented a new index called hg-index in order to reduce the disadvantages of using *h*-index (Hirsch 2005) and *g*-index (Egghe 2006) without affecting the advantages of both the measures. *h*-index is now used as a tool for research assessment of individuals, research faculties and institutions and even for comparing performance of journals and countries (Prathap 2010).

Worldwide nanotechnology research has experienced rapid growth in recent years. The status of nanotechnology research and development was reviewed in previous papers (Chen and Roco 2009; Hullmann 2007; Kostoff et al. 2006; Li et al. 2008) conducted a longitudinal study of the worldwide nanotechnology development status using papers published in the Thomson Science Citation Index Expanded (SCI) database. Major contributions of nanotechnology innovations are the United States, Europe and Japan (Huang et al. 2004). In India patent analysis studies have been conducted on the publications of the Council of Scientific and Industrial Research (CSIR) in India (Rajeswari 1996; Sangeetha et al. 1999). Bhattacharya and Nath (2002) compared China's and India's technology

impact using patent grant data from the United States Patent and Trademark Office (USPTO). Liu et al. (2009) compares the trends for nanotechnology development of papers and patents in China, Russia and India using SCI papers and USPTO patents database.

Objectives

The main objective of this study is to analyse the trends of Indian research articles related to nanoscience and nanotechnology research. The database covers all relevant documents with at least one Indian author which has been published during the period 1990–2009. The other objectives are to analyse the Indian research output, status, publication share and growth among top 10 countries, to study the pattern of author collaboration by using various scientific measures, to study the contribution of Indian Institutions and their international collaboration, pattern and impact of Indian Institutions contributions by various scientometric measures and to study the pattern of research communication in most productive journals. The results of this will be used to know the strength and weakness of the nanoscience and nanotechnology research in India.

Methodology

For the purpose of the study, the Scopus an international database was searched for all records of papers published by scientists/academicians from the part of the R&D activity that has resulted in publication in peer-reviewed journals. Data was collected from Scopus database, (Scopus Info Site 2010) till 2009. The comprehensive search string, indicated in Appendix 1 used by Glanzel et al. (2003) and Wilson et al. (2002) to elicit records relevant to nanoscience and nanotechnology were used for this study.

It can be seen that nearly 22,765 bibliographic records of Indian contribution in nanoscience and nanotechnology over the period of 20 years (i.e.) 1990–2009. The publication progress and author collaboration on nanotechnology is measured using scientometric tools such as collaborative index (CI), collaborative coefficient, modified collaborative coefficient, *h*-index, *g*-index, hg-index, *p*-index. Further based on citation per paper, number of high quality papers, relative quality index also applied to find out the quality of the research output. The findings of the study will reveal the coherent dynamic nature of the subject. Further it will enable to understand the institutional and temporal dimensions of spread of nanotechnology and nanoscience which is crucial factor in application areas and research directions. Symbols and descriptions used in this study are mentioned in Table 1.

Analysis

Out of 7,59,704 publications, 54.63% of contribution are from USA, China, Japan and Germany. 20.29% of contributions are from USA alone and ranks top in the position. It is followed by China 15.87%; Japan 10.39% and Germany 8.07% (Table 2). Out of the top 10 countries India holds 7th rank with its contribution of 3.00% in the field of nanoscience and nanotechnology during the period 1990–2009. Less productivity of Spain, Canada and Brazil may be due to the policy of publishing their research output in their respective native languages largely.

Table 2 Nanotechnology publications in the competitor countries

Country	No. of publications			Rank		
	1990	2009	1990–2009	1990	2009	1990–2009
USA	240	23,634	1,54,158	1	2	1
China	52	24,083	1,20,551	3	1	2
Japan	50	9,359	78,962	4	4	3
Germany	59	10,785	61,322	2	3	4
France	49	6,950	44,675	5	5	5
UK	46	6,456	38,895	6	6	6
India	10	5,319	22,765	7	7	7
Spain	3	4,091	21,044	9	8	8
Canada	4	3,345	19,498	8	9	9
Brazil	0	1,511	9,750	10	10	10
Other countries	132	31,041	1,88,084			
Total	645	1,26,574	7,59,704			

India—leader in nanoscience and nanotechnology publications among the competitor countries

Indian publication output in Nanoscience and Nanotechnology during the period 1990–2009 consists of 22,765 records, with an average publication per year as 1,138. Of the total publications in nanoscience and nanotechnology, 19112 appeared as articles, 2,538 as conference papers, 861 as reviews, 58 as letters, 42 as editorials, 25 as short survey, 35 as note, etc. The cumulative output of India in this field increased from 10 papers in the year 1990 to 5319 papers in the year 2009 (i.e.) during 20 years of period the growth ratio is 1:532 and holds the 7th position on both the starting and the ending period of the study (Fig. 1).

The growth of Indian publications were analysed by Relative Growth Rate (RGR) and Doubling time (Dt). RGR is a measure to study the increase in number of articles of time (Mahapatra 1985) and the Dt is directly related to RGR. It is the time required for articles to become double of the existing amount. The following Table 3 represents the chronological distribution, RGR, Dt, and mean of RGR and Dt of Indian publications in the field of Nanoscience and Nanotechnology during the period 1990–2009. From the Table 3 it is observed that the mean RGR for the first decade is 0.47 and the Dt is 1.25, for the second

Fig. 1 Publication growth of Indian research

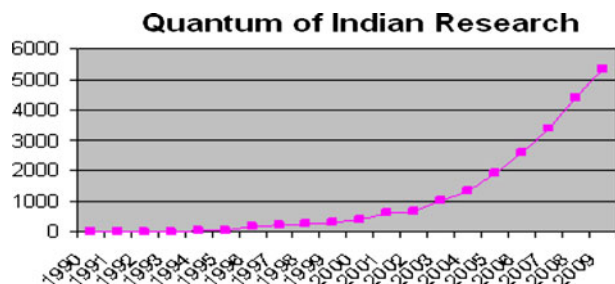


Table 3 Indian's research output and relative growth rate and doubling time of nanoscience and nanotechnology

Year	No. of publications	Cumulative	Log _e 1	Log _e 2	RGR	Mean RGR	Dt	Mean Dt
1990	10	10		2.3		0.47		1.25
1991	8	18	2.3	2.89	0.59		1.17	
1992	18	36	2.89	3.58	0.69		1.00	
1993	20	56	3.58	4.03	0.45		1.54	
1994	40	96	4.03	4.56	0.53		1.31	
1995	58	154	4.56	5.04	0.48		1.44	
1996	166	320	5.04	5.77	0.73		0.95	
1997	204	524	5.77	6.26	0.49		1.41	
1998	271	795	6.26	6.68	0.42		1.65	
1999	319	1,114	6.68	7.02	0.34		2.04	
2000	396	1,510	7.02	7.32	0.3	0.30	2.31	2.31
2001	602	2,112	7.32	7.66	0.34		2.04	
2002	688	2,800	7.66	7.94	0.28		2.48	
2003	1,030	3,830	7.94	8.25	0.31		2.24	
2004	1,351	5,181	8.25	8.55	0.3		2.31	
2005	1,907	7,088	8.55	8.87	0.32		2.17	
2006	2,577	9,665	8.87	9.18	0.31		2.24	
2007	3,392	13,057	9.18	9.48	0.3		2.31	
2008	4,389	17,446	9.48	9.77	0.29		2.39	
2009	5,319	22,765	9.77	10.03	0.26		2.67	

decade it is 0.30 and 2.31 respectively. Dt is the period of time required for a quantity to double in size or value. Hence it can be seen that the Dt is doubled during the second decade. When the RGR is constant, the quantity undergoes exponential growth and has a constant Dt or period which can be calculated directly from the growth rate.

RGR decreased from the rate of 0.59 in 1991 to 0.26 in 2009. The mean relative growth for the first 10 years (i.e. 1990–1999) showed a growth rate of 0.47 whereas the mean RGR for the last 10 years (i.e. 2000–2009) reduced to 0.30. The corresponding Dt for different years gradually increased from 1.17 in 1991 to 2.67 in 2009. The mean Dt for the first 10 years was only 1.25 which was increased to 2.31 during the last 10 years. Thus as the rate of growth of publication was decreased, the corresponding Dt was increased (Table 3).

Research output under various subjects

The nanotechnology publications further grouped based on subjectwise are identified and the same is shown in Table 4. Highest number of publications (>1000) contributed to 4 domains: Material Science (10642), Chemistry (4504), Physics (3534) and Engineering (1242). The top four subject fields receive 87.51% of the country's publications in the field of nanoscience and nanotechnology. Hence, most of the nanotechnology applications can be seen in Materials Science, Physics, Chemistry and Engineering. The application has also spread into other disciplines too. In the near future Nanotechnology will exist has separate subject.

Table 4 Subjectwise distribution of Indian contributions

S. no.	Subject	No. of publications	%	Cumulative	Cum. %
1	Materials Science	10,642	46.75	10,642	46.75
2	Chemistry	4,504	19.78	15,146	66.53
3	Physics	3,534	15.52	18,680	82.06
4	Engineering	1,242	5.46	19,922	87.51
5	Pharmacology, Toxicology and Pharmaceutics	793	3.48	20,715	90.99
6	Chemical Engineering	574	2.52	21,289	93.52
7	Biochemistry	483	2.12	21,772	95.64
8	Environmental Science	221	0.97	21,993	96.61
9	Multidisciplinary	204	0.90	22,197	97.50
10	Medicine	162	0.71	22,359	98.22
11	Earth and Planetary Sciences	115	0.51	22,474	98.72
12	Computer Science	92	0.40	22,566	99.13
13	Agricultural and Biological Sciences	63	0.28	22,629	99.40
14	Business, Mgmt & Accounting	30	0.13	22,659	99.53
15	Arts and Humanities	28	0.12	22,687	99.66
16	Immunology and Microbiology	25	0.11	22,712	99.77
17	Energy	19	0.08	22,731	99.85
18	Dentistry	8	0.04	22,739	99.89
19	Mathematics	8	0.04	22,747	99.92
20	Neuroscience	8	0.04	22,755	99.96
21	Veterinary	4	0.02	22,759	99.97
22	Social Sciences	4	0.02	22,763	99.99
23	Undefined	2	0.01	22,765	100.00
	Total	22,765	100.00		

Measures of collaboration

To show the trend towards multiple authorships in a discipline, many studies have used either the mean number of authors per paper, termed the CI by Lawani (1980) and the proportion of multiple authored papers, called Degree of Collaboration (DC) by Subramanyam (1983) as a measure of the strength of collaboration in a discipline. Assuming that these two measures were seems to be inadequate, Ajiferuke et al. (1988), who derived a single measure that incorporates some of the merits of both of the above. Ideally, it is desired that a quantification of collaboration should have a value between 0 and 1, with 0 corresponding to single authored papers, and 1 for the case where all papers are maximally authored, i.e. every publication in the collection has all authors in the collection as co-authors. All the above mentioned formulas to find the collaboration coefficient (CC) value have one or other demerit. To overcome some of the demerits of previously explained measures, and propose a simple modification of CC, which is represented as the Modified Collaboration Coefficient (MCC), which improves its performance in this respect. Let the collection K be the research papers published in a discipline or in a journal during a certain period of interest. In the following, we write f_j is the number of papers having j authors in

collection K ; N is the total number of papers in K . $N = \sum_j f_j$; and A is the total number of authors in collection K .

One of the early measures of DC is CI is given by:

$$CI = \frac{\sum_{j=1}^A j f_j}{N} \quad (1)$$

It is a measure of mean number of authors. Although it is easily computable, it is not easily interpretable as a degree, for it has no upper limit. Moreover, it gives a non-zero weight to single authored papers, which involve no collaboration.

DC, a measure of proportion of multiple authored papers is given by:

$$DC = 1 - \frac{f_1}{N} \quad (2)$$

DC is easy to calculate and easily interpretable as a degree (for it lies between zero and one), gives zero weight to single-authored papers, and always ranks higher a discipline for period) with a higher percentage of multiple authored papers. However, DC does not differentiate among levels of multiple authorships.

CC was designed to remove the above shortcomings pertaining to CI and DC. It is given by:

$$CC = 1 - \frac{\sum_{j=1}^A j f_j}{N} \quad (3)$$

The derivation of the new measure is almost the same as that of CC, as given in Ajiferuke et al. (1988). The above equation is not defined for the trivial case when $A = 1$, which is not a problem since collaboration is meaningless unless at least two authors are available. CC approaches MCC only when $A \rightarrow \infty$, but is otherwise strictly less than MCC by the factor $(1 - \frac{1}{A})$ (Savanur and Srikanth 2010)

$$MCC = \frac{A}{A-1} \left\{ 1 - \frac{\sum_{j=1}^A (1/j) f_j}{N} \right\} \quad (4)$$

From the 22,765 articles 39 articles are authored more than 26 authors. Overall the 96% of the articles are collaborative like the other disciplines. Only 4% of the articles are solo authors (Appendix 2).

Based on the CI in the year 1993 it was 5.9, followed by the year 2000 (4.9722), 1997 (4.3182), 1998 (4.2140), 2001 (4.0896), 2008 (4.0659), 2007 (4.0442). DC is 1 during the year 1991. To calculate the differentiations among levels of multiple authors CC and MCC were calculated and presented in the Table 5. CC is between 0.5226 and 0.6728 and the MCC is between (1992) 0.5534 and (1991) 0.6905.

Pattern of citation of research output

Out of the total Indian publications of 22,765 papers, with an average output of 138 papers per year has 1,95,170 citations. The average rate of citation was ~ 9 . Analysis of citation data indicates that, out of the 22,765 published papers, 6,330 (28%) papers did not have any citation and the remaining 72% had one or more citations. 8,630 (38%) papers received citations between one and five. 3,155 papers received citations between six and ten. The citation pattern is shown in Table 6.

Table 5 Authorship collaboration

Year	Single author	Two authors	Three authors	>Three authors	CI	DC	CC	MCC
1990	1	4	2	3	3.0000	0.9000	0.5717	0.6352
1991	0	4	2	2	2.7500	1.0000	0.6042	0.6905
1992	4	4	3	7	2.9444	0.7778	0.5226	0.5534
1993	1	9	4	6	5.9000	0.9500	0.5976	0.6290
1994	2	9	14	15	1.0000	0.9500	0.6427	0.6592
1995	5	18	10	25	1.0000	0.9138	0.6128	0.6235
1996	15	54	40	57	3.7964	0.9102	0.5987	0.6023
1997	19	49	52	84	4.3182	0.9040	0.6115	0.6146
1998	19	90	68	94	4.2140	0.9299	0.6071	0.6093
1999	27	94	95	103	3.5204	0.9154	0.6026	0.6045
2000	26	116	112	142	4.9722	0.9342	0.6212	0.6228
2001	31	165	161	245	4.0896	0.9486	0.6381	0.6392
2002	30	172	184	302	3.8154	0.9564	0.6535	0.6545
2003	49	242	258	481	3.8161	0.9518	0.6549	0.6555
2004	49	325	331	646	3.9393	0.9638	0.6645	0.6650
2005	84	444	492	887	3.7737	0.9560	0.6577	0.6581
2006	98	590	653	1,236	3.8246	0.9620	0.6657	0.6660
2007	124	767	871	1,630	4.0442	0.9634	0.6664	0.6666
2008	146	1,008	1,111	2,124	4.0659	0.9667	0.6655	0.6656
2009	190	1,154	1,299	2,676	3.9921	0.9642	0.6728	0.6729

Citation impact of Indian's research output, 1990–2009

Impact suggested by Nagpaul (1995), Garg and Pandhi (1999) have been used for inter-comparison of quality by making unit of citation indicators such as CPP, NHQ, RQI, NHQ% and TNP% (Garg et al. 2009).

CPP is based on the publication output and the number of citations received by these papers, citation per paper for different countries and different institutions has been calculated. Citation per paper has been calculated by using the following formula:

$$\text{CPP} = \frac{\text{Total number of citations for a country or an institution}}{\text{Total number of papers for that country or institution}}$$

NHQ is based on the calculation of the citation per paper for different countries and institutions were calculated as the pattern of citation varied from one country to another country. Papers that received more than twice the average citations have been considered as high quality papers.

RQI is an indicator and it is the ratio of the proportion of NHG% to the proportion of the TNP%

$$\text{NHQ}\% = \left(\frac{\text{number of high quality papers for a country or an institution}}{\text{Total number of high quality papers}} \right) \times 100$$

Table 6 Distribution of citations

No. of citations	TNP	TNC
0	6,330	0
1	2,917	2,917
2	1,967	3,934
3	1,568	4,704
4	1,171	4,684
5	1,007	5,035
6	812	4,872
7	729	5,103
8	637	5,096
9	506	4,554
10	481	4,810
11–20	2,531	37,146
21–30	909	22,494
31–40	436	15,227
41–50	221	9,944
51–60	143	7,903
61–70	91	5,898
71–80	68	5,105
81–90	47	3,989
91–100	31	2,967
>100	163	38,788
Total	22,765	1,95,170
Average		9

$$\text{TNP}\% = \left(\frac{\text{Total publication output of a country or an institution}}{\text{Total publication output for all countries or institutions}} \right) \times 100$$

The stated citation index calculated for Indian contributions are shown in Table 6.

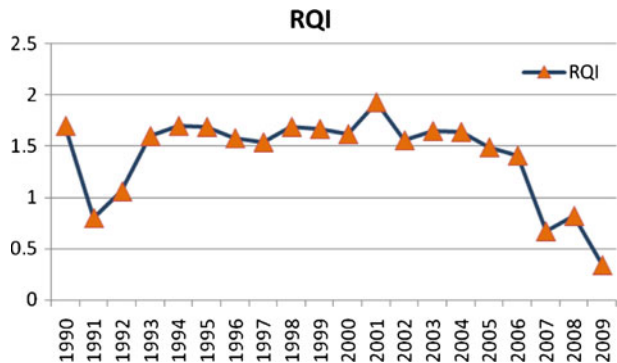
A value of RQI > 1 indicates higher than average quality, whereas a value of RQI < 1 indicates lower than average quality. Table 7 indicates yearwise total number of publications, total citations, citation per paper, number of high quality and relative quality index. The value of RQI is high in the 1990. RQI is lower than average during the year 1991, 2007, 2008 and 2009. RQI is maximum in the year 2001 and it was 1.70 during the year 1994 and 1990 (Fig. 2).

Index technique in Scientometric

Hirsch (2005) introduced the *h*-index to measure both the productivity and impact of the published work of a scientist or scholar. The index is based on the set of the scientist's most cited papers and the number of citations that they have received in other people's publications. The index can also be applied to the productivity and impact of a group of scientists, such as a department or university or country. The *g*-index was introduced by Egghe (2006) as an improvement of Hirsch's *h*-index for measuring the overall citation record of a set of articles. The influence of the self citations appears to be more significant

Table 7 Citation impact of research output

Year	TNP	TNC	CPP	NHQ	RQI
1990	10	219	22	8	1.70
1991	8	64	6	3	0.80
1992	18	161	7	9	1.06
1993	20	346	16	15	1.60
1994	40	553	11	32	1.70
1995	58	1,289	19	46	1.69
1996	166	3,119	12	123	1.58
1997	204	4,079	12	148	1.54
1998	271	7,298	18	215	1.69
1999	319	6,423	11	250	1.67
2000	396	11,466	21	302	1.62
2001	602	12,354	10	546	1.93
2002	688	13,511	10	503	1.56
2003	1,030	21,504	9	799	1.65
2004	1,351	25,213	8	1,041	1.64
2005	1,907	22,419	3	1,336	1.49
2006	2,577	22,815	1	1,712	1.41
2007	3,392	21,347	1	1,071	0.67
2008	4,389	14,396	0	1,688	0.82
2009	5,319	6,594	0	849	0.34
Total	22,765	1,95,170	9	10,696	

Fig. 2 Relative quality index

for the g -index than the h -index (Schreiber 2008). To increase the h -index is difficult. It is usual to find that many different researchers have the same h -index with a very different number of publications and cities. The hg -index provides a more fine-grained way to compare scientists, balance between the impact of the majority of the best papers of the author and very highly cited ones. Prathap (2010), has introduced a new index, called the p -index or the mock h -index, which is given by $(C * C/P)^{(1/3)}$, where C is the number of citations and P is the number of publications (Table 8).

Table 8 Various index techniques in Scientometric

S. no.	Index type	Contributor	Purpose	Definition/formula
1.	<i>h</i> -index	Hirsh	To measure both the productivity and impact of the published work of a scientist or scholar	A scientist has index <i>h</i> if <i>h</i> of [his/her] N_p papers have at least <i>h</i> citations each, and the other $(N_p - h)$ papers have at most <i>h</i> citations each
2.	<i>g</i> -index	Leo Egghe	For quantifying the scientific productivity of physicists and other scientists based on their publication record	The index is calculated based on the distribution of citations received by a given researcher's publications
3.	hg-index	Rousseau	hg-index of a researcher is computed as the geometric mean of his <i>h</i> - and <i>g</i> -indices	\sqrt{hg}
4.	<i>p</i> -index	Gangan Prathap	To compare institutions and countries on this index, combination of quantity and quality	$\left[\frac{C^2}{P}\right]^{\frac{1}{3}}$

Indian institutions contribution

Indian contribution accounts to 3.00% in nanotechnology publications. The contributions of the Indian Institutions and the citation, average citation, international collaboration, *h*-index, *g*-index, hg-index and *p*-index has been analysed and the same is shown in Table 9. Liu et al. (2009) analyzed that the Indian Institute of Technology (IIT) produced 1831 papers during the period 2000–2007. In this study it was found that the IIT's in six different places in India produced 4313 papers during the period 1990–2009.

The international collaborative publication share of these 25 institutions varies from 33.80 to 6.46, with an average share of international collaborative publications as 20.84%. Eight institutions has published higher share of international collaborative publications than the average share of international collaborative publications of all 25 institutions. The maximum share of (34.52) of international collaborative publication by Tata Institute of Fundamental Research, followed by Indian Institute of Bombay (33.80), University of Hyderabad (33.11), Anna University (31.02) and Inter University Accelerator Centre India (30.15) (Table 9).

Based on *h*-index (Hirsch 2005) productivity and impact of the published work of the institutions were analyzed (Table 9 and Fig. 3). Among the top 25 institutions, Indian Institute of Science (61) holds the first position and followed by Indian Institute of Technology, Khanpur (51), National Chemical Laboratory India (50) and Jawaharlal Nehru Centre for Advanced Scientific Research (50).

The quantification of the productivity of the institutions and based on their publication record were identified by using *g*-index (Egghe 2006) technique. *g*-index is more sensitive than *h*-index in the assessment of selective scientists, since this type of scientist shows in average a higher *g*-index/*h*-index ratio and a better position in *g*-index rankings than in the *h*-index ones (Radriago and Maria 2008). Tata Institute of Fundamental Research (99), Indian Institute of Bombay (97), Indian Institute of Science (93) holds first three ranks. Based on the results it is found that *g*-index is always higher or equal to *h*-index (Egghe 2006). Geometric mean of *h* and *g* indices is hg index (Alonso et al. 2010). hg index value

Table 9 Indian Institutions contribution, the international collaborative publication share and various indices in the field of Nanoscience and Nanotechnology

S. no.	Indian institutions	TP	TC	ACPP	ICP	ICP%	<i>h</i> -index	<i>g</i> -index	hg-index	<i>p</i> -index
1	Indian Institute of Science	1,641	19,157	11.67	106	6.46	61	93	75.32	60.70
2	Indian Institute of Technology, Kharagpur	1,199	8,319	0.00	148	12.34	38	58	46.95	38.65
3	Bhabha Atomic Research Centre	965	7,302	0.00	124	12.85	34	53	42.45	38.09
4	National Chemical Laboratory India	900	12,255	0.00	150	16.67	50	75	61.24	55.05
5	Indian Association for the Cultivation of Science	821	7,268	8.85	166	20.22	35	50	41.83	40.07
6	Indian Institute of Technology, Kanpur	810	12,142	14.99	205	25.31	51	86	66.23	56.67
7	Indian Institute of Technology, Madras	736	5,637	7.66	132	17.93	33	56	42.99	35.08
8	Indian Institute of Technology, Bombay	648	3,358	5.18	219	33.80	31	97	54.84	25.91
9	Indian Institute of Technology, Delhi	604	3,626	6.00	119	19.70	29	40	34.06	27.92
10	Jadavpur University	518	3,671	7.09	109	21.04	29	42	34.90	29.63
11	Jawaharlal Nehru Centre for Advanced Scientific Research	513	10,619	20.70	104	20.27	50	84	64.81	60.35
12	University of Delhi	507	3,814	7.52	108	21.30	27	49	36.37	30.61
13	Indian Institute of Chemical Technology	504	6,504	12.90	103	20.44	37	56	45.52	43.78
14	National Physical Laboratory India	479	2,695	5.63	91	19.00	22	33	26.94	24.75
15	Tata Institute of Fundamental Research	365	9,713	26.61	126	34.52	32	99	56.28	63.70
16	University of Pune	337	3,020	8.96	61	18.10	25	41	32.02	30.02

Table 9 continued

S. no.	Indian institutions	TP	TC	ACPP	ICP	ICP%	<i>h</i> -index	<i>g</i> -index	hg-index	<i>p</i> -index
17	Central Electrochemical Research Institute India	322	1,784	5.54	65	20.19	20	29	24.08	21.46
18	Indira Gandhi Centre for Atomic Research	317	1,787	5.64	51	16.09	21	28	24.25	21.60
19	Indian Institute of Technology Roorkee	316	2,355	7.45	43	13.61	20	39	27.93	25.99
20	Banaras Hindu University	309	2,141	6.93	65	21.04	22	36	28.14	24.57
21	Anna University	303	2,253	7.44	94	31.02	23	43	31.45	25.59
22	University of Hyderabad	302	5,257	17.41	100	33.11	34	66	47.37	45.06
23	Shivaji University	278	2,133	7.67	57	20.50	22	31	26.12	25.39
24	Inter University Accelerator Centre India	272	1,988	7.31	82	30.15	17	39	25.75	24.40
25	Saha Institute of Nuclear Physics	235	2,021	8.60	36	15.32	20	38	27.57	25.90
	Total	14,201	1,40,819	217.75	2,664	520.98	783	1361	1025.41	900.94
	Average			9		20.84				

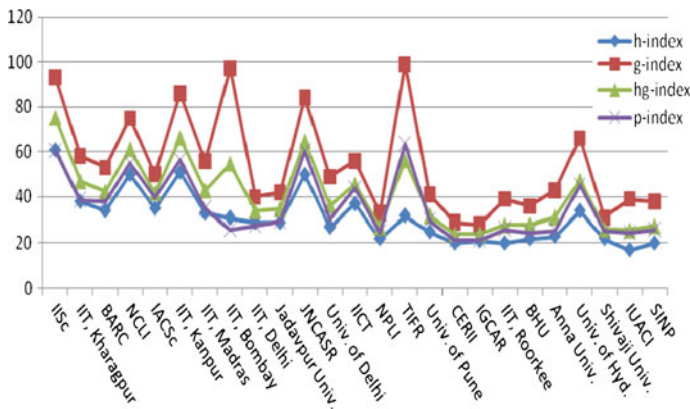


Fig. 3 Various indices of Top 25 institutions

nearer to *h* than to *g*. i.e. $h \leq hg \leq g$ and $hg - h \leq g - hg$. The hg-index provides gain to compare scientists. hg-index is used to balance between the impact of the majority of the best publications of the author and very highly cited ones, that is it reduces the impact of single very high cited publications. *p*-index is the performance index balanced between

activity and excellence (Prathap and Gupta 2009). A mock h -index h_m is an ideal performance indicator that can evaluate activity/quantity and excellence/quality and must increase when quantity i.e. number of publication increases and the quality i.e. number of citations increases (Tol 2009). The p -index provides the best balance between quantity and quality (Prathap 2010). The p -index represents a combination of size and quality, it would be ideal to compare institutions and countries on this index. Hence the institutions were compared by using p -index. Tata Institute of Fundamental Research holds first position based on g -index (99) and p -index (63.70). h -index, g -index and p -index are one type of indices describe the most productive core of the output of a scientist and tell us the number of papers in the core.

Impact of journals of Indian contributions with more than 100 articles in nanoscience and nanotechnology

Further impact of journals of Indian contributions with more than 100 articles in nanoscience and nanotechnology has been given in the Table 10. The impact factor is one of these; it is a measure of the frequency with which the “average article” in a journal has been cited in a given period of time. The impact factor for a journal is calculated based on a 3-year period, and can be considered to be the average number of times published papers are cited up to 2 years after publication. Impact factor of the nanoscience and nanotechnology journals are mentioned in the Table 10.

Based on the average citations per paper the *Journal of Material Chemistry* holds the first position (21.658), followed by *Chemical Physics Letter* (19.00), *Inorganic Chemistry* (16.781), *Journal of Physical Chemistry B* (16.714) and *Journal of the America Ceramic Society* (16.706).

Conclusion

Due to technological importance and expected economic activity, nanotechnology has been intensively investigated by scientometric methods. In this paper, the current status of nanoscience and nanotechnology has been presented. Initially frequency and percentile method have been evolved chronologically. The progress has further been measured using growth rate and Dt . In the present decade the Dt of nano-science and nano-technology literature is once in 3 years. Just one specific measure is not shrewd to power the assessment of researchers or of research groups. It is even unsafe, because it strengthens the opinion of administrators and politicians that scientific performance can be expressed simply by one note. Hence we always stress that a reliable set of several indicators is necessary, in order to explicate different aspects of performance. Hence to evaluate the author collaboration, CI, collaborative coefficient, DC and modified collaborative coefficient were employed to prove that the 96% of the research outputs are of collaborative in nature. As like that of other discipline collaborative research is predominance.

The aim of the study is to illustrate the different approaches in bibliometricians have dealt with this emerging area so far and presented a variety of data. This raises the question to what extent the data presented can provide useful information to various stakeholders, such as scientists and engineers working in one of the fields related to nanotechnology, decision-makers in R&D administrations and industry. Some of the bibliometric data may be of interest to researchers in the field. Often they are specialists focused on one of the several strands in nanotechnology and may be interested in data that provides them with a

Table 10 Impact of journals of Indian contributions in the journals

S. no.	Journals more than 100 articles	TNP	TNC	ACPP	Impact factor
1.	<i>Journal of Applied Physics</i>	431	2,436	5.652	2.072
2.	<i>Physical Review B condensed Matter and Materials Physics</i>	358	3,263	9.115	3.322
3.	<i>Materials Letters</i>	340	2,939	8.644	1.940
4.	<i>Journal of Nanoscience and Nanotechnology</i>	337	919	2.727	1.987
5.	<i>Journal of Alloys and Compounds</i>	335	1,444	4.310	1.973
6.	<i>Journal of Applied Polymer Science</i>	325	1,704	5.243	1.187
7.	<i>Applied Physics Letters</i>	303	2,957	9.759	3.544
8.	<i>Bulletin of Materials Science</i>	268	1,216	4.537	0.783
9.	<i>Journal of Physical Chemistry B</i>	266	4,446	16.714	3.471
10.	<i>Materials Chemistry and Physics</i>	261	2,477	9.490	1.799
11.	<i>Journal of Magnetism and Magnetic Materials</i>	231	1,848	8.000	1.283
12.	<i>Journal of Physics D Applied Physics</i>	231	1,079	4.671	2.104
13.	<i>Journal of Materials Science</i>	221	1,168	5.285	1.471
14.	<i>Applied Surface Science</i>	195	1,124	5.764	1.616
15.	<i>Langmuir</i>	188	2,856	15.191	4.097
16.	<i>Journal of Physical Chemistry C</i>	182	1,206	6.626	4.224
17.	<i>Materials Science and Engineering A</i>	180	1,296	7.200	1.901
18.	<i>Journal of Physics Condensed Matter</i>	177	1,056	5.966	1.964
19.	<i>Materials Research Bulletin</i>	158	1,642	10.392	1.812
20.	<i>Chemical Physics Letters</i>	154	2,926	19.000	2.291
21.	<i>Synthesis and Reactivity in Inorganic Metal Organic and Nano Metal Chemistry</i>	150	206	1.373	0.569
22.	<i>Nuclear Instruments and Methods in Physics Research Section B Beam Interactions with Materials and Atoms</i>	148	614	4.149	1.156
23.	<i>Sensors and Actuators B Chemical</i>	146	1,426	9.767	3.083
24.	<i>Nanotechnology</i>	145	845	5.828	3.137
25.	<i>Journal of Molecular Catalysis A Chemical</i>	145	1,332	9.186	3.135
26.	<i>Journal of the American Ceramic Society</i>	140	1,498	16.706	2.101
27.	<i>Thin Solid Films</i>	139	1,592	11.453	1.884
28.	<i>Journal of Colloid and Interface Science</i>	139	1,618	11.640	3.019
29.	<i>Physica B Condensed Matter</i>	138	483	3.500	1.056
30.	<i>Solid State Communications</i>	131	709	5.412	1.837
31.	<i>Current Science</i>	128	802	6.266	0.782
32.	<i>Tetraheron Letters</i>	123	1,382	11.236	2.615
33.	<i>Journal of Chemical Physics</i>	116	749	6.457	3.093
34.	<i>Inorganic Chemistry</i>	114	1,913	16.781	4.657
35.	<i>Journal of Materials Research</i>	114	938	8.228	1.743
36.	<i>Journal of Materials Chemistry</i>	111	2,404	21.658	4.646
37.	<i>Industrial and Engineering Chemistry Research</i>	112	742	6.625	1.752
38.	<i>Indian Journal of Chemistry Section A Inorganic Physics Theoretical and Analytical Chemistry</i>	107	178	1.664	0.617
39.	<i>Pramana—Journal of Physics</i>	107	205	1.916	0.274

Table 10 continued

S. no.	Journals more than 100 articles	TNP	TNC	ACPP	Impact factor
40.	<i>Materials Science and Engineering B Solid State Materials for Advanced Technology</i>	105	669	6.371	1.756
41.	<i>Journal of Power Sources</i>	104	1,191	11.452	3.792
42.	<i>Journal of Hazardous Materials</i>	102	867	8.500	4.144
43.	<i>Solar Energy Materials and Solar Cells</i>	101	1,026	10.158	3.858
	Total	8,006	63,691	7.918	

more general picture. They, just like policy analysts, may also be interested in the overall standing of countries in terms of publication output. Students of science and technology may find the parallel observation of publication data of interest.

This study presented a summary of bibliometric research in the nanotechnology area. Using publication of literature, an overview of bibliometric efforts have been presented to trace the emergence of this new technological area. The paper has also presented data that gives an idea about which countries are the most active in terms of scientific publications in nanoscience and nanotechnology. France, United Kingdom and India are very active, following the big four countries USA, China, Japan and Germany. At the moment, nanotechnology appears to enter a phase of concentration. For instance, most of the nano publications so far have occurred in the materials sciences, physics, chemistry and engineering.

India has a substantial contribution on nanotechnology research. Indian Institute of Science, Indian Institute of Technologies, Bhabha Atomic Research Centre and National Chemical Laboratory are the major institutional contributors. Share of International collaborative publication among the top 25 institutions were Tata Institute of Fundamental Research, Indian Institute of Bombay, University of Hyderabad, Anna University and Inter University Accelerator Centre India have more than 30%. To engage with nanotechnology successfully, developing countries would need to address a range of issues pertaining to research, technology development, skills requirement, institutions involved, risks issues, regulatory and governance structure and stakeholder engagement. Regulatory oversight for nanotechnology is necessary to channelize research efforts in a responsible direction. The regulatory regime for nanotechnology needs to be dynamic and should be reviewed from time to time. Transparency and public involvement in the design and implementation of regulatory structure in nanotechnology should be ensured.

This paper focused on the presentation of bibliometric data only. Understanding the development of a field such as nanotechnology could be made easier by integrating the informetric findings with results of other studies. Market analyses and future studies, which were not discussed in this place, remind us that there is still a long way ahead for this emerging area to become a generic discipline or technology.

Finally concluded that the results of a scientometric study that focuses on the field of nanoscience and nanotechnology is that the contribution of India has increased greatly in the last 5 years. However, it is sound to say based on the number of publications that the field of nanoscience and nanotechnology is currently led by USA, China, and Japan. Countries that lack a research and development infrastructure to develop the nanoscience and nanotechnology may use scientometric trends to analyse the intrinsic variety in approaches to technology development.

Appendix 1: Search term

AFFIL(INDIA) AND PUBYEAR AFT 1989 AND PUBYEAR BEF 2010 AND NANO* AND 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 NANOPRTO* OR NANOPHYTO* OR NANOFLAGELLATE*) OR QUANTUM-DOT* OR QUANTUM-WIRE* OR MOLECULAR-BEAM-EPITAXY OR MBE OR CARBONTUB* 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*

Appendix 2

See Table 11.

Table 11 Distribution of authorship

No. of authors	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
1	1	0	4	1	2	5	15	19	19	27
2	4	4	4	9	9	18	54	49	90	94
3	2	2	3	4	14	10	40	52	68	95
4	1	2	5	4	5	10	23	37	53	46
5	1	0	1	1	7	7	15	21	19	24
6	1	0	0	0	2	5	10	10	7	18
7	0	0	1	0	1	1	7	2	5	6
8	0	0	0	0	0	2	2	4	6	4
9	0	0	0	0	0	0	0	1	0	2
10	0	0	0	0	0	0	0	0	1	2
11–25	0	0	0	0	0	0	0	1	0	0
>26	0	0	0	1	0	0	1	2	3	1
Total	10	8	18	20	40	58	166	204	271	319
No. of authors	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	26	31	30	49	49	84	98	124	146	190
2	116	165	172	242	325	444	590	767	1008	1154
3	112	161	184	258	331	492	653	871	1111	1299
4	61	116	128	187	272	393	513	679	887	1033
5	34	65	73	127	172	241	319	448	868	736
6	22	25	43	80	97	123	187	267	162	416
7	10	17	35	43	49	69	113	120	89	244
8	6	10	7	15	26	27	50	46	51	111

Table 11 continued

No. of authors	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
9	2	6	4	13	14	13	24	37	31	45
10	0	2	4	0	4	8	11	13	10	67
11–25	2	4	7	0	11	12	18	15	17	38
>26	4	1	1	3	2	3	1	4	7	5
Total	396	602	688	1,030	1,351	1,907	2,577	3,392	4,389	5,319

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