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A scientometric assessment of research output in nanoscience and nanotechnology: Pakistan perspective

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Abstract In this study we present an analysis of the research trends in Pakistan in the field of nanoscience and nanotechnology. Starting with just seven publications in the year 2000, this number has steadily increased to 542 for the year 2011. Among the top 15 institutions with publications in nanotechnology 13 are universities and only two are R&D organizations. Almost 35 % of the research publications are in the field of material sciences followed by chemistry and physics in that order. The growth in the publications for period 2000–2011 is studied through relative growth rate and doubling time. The authorship pattern is measured by different collaboration parameters, like collaborative index, degree of collaboration, collaboration coefficient and modified collaboration coefficient. Finally the quality of papers is assessed by means of the *h*-index, *g*-index, *hg*-index and *p*-index.

Keywords Bibliometric · Relative growth rate · Degree of collaboration · Nanoscience · Nanotechnology

Introduction

Nano originates from the Greek word meaning "dwarf". A nanometer is one billionth (10^{-9}) of a meter, which is tiny, only the length of ten hydrogen atoms, or about one hundred thousandth of the width of a hair! Although scientists have used matter at the nanoscale for centuries, calling it physics or chemistry, it was not until a new generation of electron microscopes like scanning tunneling microscope (STM) and atomic force microscope (AFM) were invented in the 1980s that the world of atoms and molecules could be seen, manipulated and controlled.

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In simple terms, nanoscience/nanotechnology can be defined as 'science/engineering at a very small scale, i.e., the nano scale'. The properties of materials whether physical, chemical, electronic or magnetic at such small sizes are very different from those at bulk scale. This makes the products of industry and systems made by using nano scale materials smaller in size and better in performance. The vision of nanotechnology dates back to the lecture delivered by the Noble Laureate Professor Richard Feynman in 1959, "There is plenty of room at the bottom" (Feynman 1960). Feynman speculated about all the possible ways in which miniaturization, computer and information technologies and physics can be used to explore the sub-microscopic world.

In the years to follow, in particular during the 1980s and after, the development of STM and AFM led to rapid advances in the field of nanotechnology. It has now come to be known as another "industrial revolution", with a potential of 1–2 trillion dollar marketing of nano based industrial products by 2015 and its application in industry for the foreseeable 40–50 years (Research 2010). Already by Nov. 2009 some 2,500 industrial products and applications of nanotechnology have come in the market (Kaiser 2009), opening vast avenues for job market in industries, R&D organizations, intellectual property rights and influencing world economy and strategic applications for decades to come, thus necessitating the production of specifically trained human resource for such organizations. The growth of nanotechnology is one of the most exciting developments in science and engineering in recent years. Much of the research in this field is interdisciplinary in nature, drawing expertise from different areas across the life science, physical science and engineering disciplines.

One way of monitoring the developments in an emerging scientific field is to study the trends regarding the papers being published in that field. Braun et al. (1997) report an exponential growth of papers containing the prefix of nano in their content for the period 1986–1995. Country specific studies were undertaken by various authors (Karpagam et al. 2011); (Roco 2011); (Liu et al. 2009). All these studies confirm this rising trend in the publications in the field of nanotechnology.

Pakistan scenario

Pakistan is a typical example of a developing country. With a population of over 180 million, the official literacy rate stands at 46 %. The number of those attending university is about quarter of a million and those adopting scientific research as a career is around 35,000 (Shahid 2010). The R&D scientific base is therefore extremely small. Another problem is the inconsistency in implementation of policies. Ever since its independence in 1947, there have been a number of well meaning policies, but lack of financial resources and indifference of the bureaucracy towards science has been a major hindrance in the implementation of these policies. There was a brief period (2000–2008) when a number of schemes were introduced for the promotion of science in the country. Universities and R&D organizations were able to acquire the latest equipment. Students were given liberal stipends to pursue higher studies both abroad and within the country. Publication of research articles were rewarded with cash incentives. All this had a very positive effect on the research publications. Another very important step was the establishment of a "National Commission for Nanoscience and Technology-NCNST" (PINSAT 2010). The Commission was initially established in 2003 for a period of 3 years and its tenure was extended by another 2 years. After 5 years no further extension was granted. These factors will be reflected in the analysis of the data in the subsequent sections.

Methodology

The data in this study has been retrieved from Scopus an international database [www.scopus.com]. The Scopus is one of the worlds' largest databases of peer-reviewed literature. For bibliometric analysis some other databases are also being used by different authors these include science citation index expended (SCIE), applied science and technology (ABS), Compendex, and EndIndex/FS.

Previously a number of studies have been published by different authors using bibliometric data analysis technique to present an overview of the growth of emerging field of nanoscience/nanotechnology for different countries (Braun et al. 1997; Gupta 2009; Tang and Shapira 2010; Karpagam et al. 2011).

Recently (Bajwa and Yaldram 2012) have analyzed the publication trends in nanotechnology in Pakistan. They also report similar rising trends of publications in Pakistan with annual growth rate 29 % which is higher than worldwide average annual growth rate 23 % reported by (Roco 2011). In this study we present a scientometric analysis of the output in publications in Pakistan for the period 2000–2011. In particular we look at the factors like (a) growth in publications given by relative growth rate (RGR) and the doubling time (D_t), (b) measure of collaboration given by the mean number of publications per paper (CPP), degree of collaboration (DC), collaborative coefficient (CC), modified collaborative coefficient (MCC), and (c) productivity and quantification of research output determined by parameter like *h*-index, *g*-index, *hg*-index and *p*-index.

Growth of publications

Two parameters viz. RGR and D_t (Mahapatra 1985) are employed to study the growth trend in publications related to nanoscience/nanotechnology for the period 2000–2011. In classical growth analysis RGR is calculated as

$$\mathrm{RGR} = (\ln N_2 - \ln N_1)/(t_2 - t_1)$$

where N_2 and N_1 are the cumulative number of publications in the years t_2 and t_1. In our case the time difference $t_2 - t_1$ is taken as 1 year. Therefore RGR = ln (N_2/N_1).

The D_t is the time required for publications to double in numbers for a given RGR. This is expressed as

$$D_t = (t_2 - t_1)\ln 2/(\ln\ N_2 - \ln\ N_1)$$

or

$$D_t = \ln 2/\mathrm{RGR}$$

A constant RGR suggests that the publications undergo an exponential growth and D_t is a characteristic unit for exponential growth (Table 1).

Table 2 represents RGR and D_t for publications for the period 2000–2011 for nanotechnology and nanoscience in Pakistan.

It is seen that the RGR drops from a value of 1.1 for the years 2001 to 0.40 for 2004 but rises again to peak at 0.63 for the year 2007, thereafter it again starts to drop to reach a value of 0.30 for the year 2011. A similar trend is reflected in the values of D_t. Starting from 0.63 for 2000, it rises to 1.73 in 2004, and thereafter it drops to 1.09 in 2007 and then again rises to attain the value 2.34 for the year 2011.

Table 1 Abbreviation table

S. no.	Abbreviations	Major institutions and terms used
1	BZU	Bahauddin Zakariya University
2	CIIT	COMSATS Institute of Information Technology
3	GCU	Government College University Lahore
4	GIKI	Ghulam Ishaq Khan Institute of Engineering Sciences and Technology
5	NIBGE	National Institute for Biotechnology and Genetic Engineering Pakistan
6	NUST	National University of Sciences and Technology Pakistan
7	PIEAS	Pakistan Institute of Engineering and Applied Sciences
8	PINSTECH	Pakistan Institute of Nuclear Science and Technology
9	PU	University of Punjab Lahore
10	QAU	Quaid-i-Azam University
11	UET	University of Engineering and Technology Lahore
12	UoK	University of Karachi
13	UoP	University of Peshawar
14	UoS	University of Sargodha
15	USindh	University of Sindh
16	RGR	Relative growth rate
17	D_t	Doubling time
18	TP	Total publications
19	TC	Total citations
20	ACPP	Average citation per paper
21	CI	Collaborative index
22	DC	Degree of collaboration
23	CC	Collaboration coefficient
24	MCC	Modified collaboration coefficient

Table 2 Pakistan's research output, relative growth rate and D_t in the field of nanoscience and nanotechnology

Year	No. of publications	Cumulative	RGR	Mean RGR	D_t	Mean D_t
2000	7	7				
2001	14	21	1.10		0.63	
2002	14	35	0.51		1.36	
2003	28	63	0.59		1.18	
2004	31	94	0.40		1.73	
2005	50	144	0.43		1.63	
2006	102	246	0.54	0.52	1.29	1.50
2007	218	464	0.63		1.09	
2008	276	740	0.47		1.49	
2009	394	1,134	0.43		1.62	
2010	438	1,572	0.33		2.12	
2011	542	2,114	0.30		2.34	

The sudden increase in RGR and corresponding decrease in the D_t for the years 2006 and 2007 is reflective of the fact that in the year 2003, the Ministry of Science and Technology embarked upon an ambitious project to enhance the human resource engaged in R&D by sending scholars abroad for higher degrees and also by initiating indigenous Ph. D programs. Through this scheme more than 4,000 full time scholarships for Ph. D have been awarded during the period 2003–2010. By 2006–2007 the first batch of these scholars started trickling back to the country (HEC 2010). The surge in the publications can be directly attributed to this returning manpower employed in productive research.

Measure of collaboration

In what follows we use the following notations,

- f_j Number of papers having j authors in certain discipline or a certain period of time
- N Number of research papers in a certain discipline or during a certain period of time
- k Greatest number of collaborating authors for a paper for a certain discipline and in a certain period of time

The collaboration index

This is defined as (Lawani 1980)

$$\mathrm{CI} = \frac{\sum_{j=1}^{k} jf_j}{N}$$

This index gives mean number of authors per paper. It has the disadvantage that it cannot be interpreted as a degree, i.e., lying between 0 and 1. It has no upper limit and it gives a non-zero weight to single authored papers and cannot be expressed as a percentage.

Degree of collaboration

This is expressed as (Subramanyam 1983)

$$\mathrm{DC} = 1 - \frac{f_1}{N}$$

where f_1 is the number of single authored papers.

DC can be interpreted as a degree, i.e., lies between 0 and 1. It gives zero weight to single authored papers. It always ranks higher a discipline with a higher number of multiauthored papers. DC gives a value of 1 for maximum collaboration.

The drawback of DC however is that it does not differentiate between the levels of multiple authorships. It treats anything greater than one on equal footing.

Collaborative coefficient

Collaborative coefficient can be defined as (Ajiferuke et al. 1988)

$$\mathrm{CC} = 1 - \frac{\sum_{j=1}^{k} \frac{1}{j} f_j}{N}$$

In the case of CC each paper carries a certain credit which is shared between all the authors, i.e., for a paper with j authors; each author gets a credit of $1/j$.

CC always lies between 0 and 1. As the number of single authors dominate CC $\to$ 0. CC distinguishes between single authors and multiple authors. The problem with CC is that it does not give the value 1 for maximum collaboration except when the number of authors is infinite.

Modified collaborative coefficient

We have seen that CC is not 1 when the number of single authors is 0. This is taken care of in MCC, which is defined as (Savanur and Srikanth 2010)

$$\mathrm{MCC} = \frac{A}{A-1}\left\{1 - \frac{\sum_{j=1}^{k}\frac{1}{j}f_j}{N}\right\}$$

Here A is the total number of authors in a collection.

MCC is not defined for $A = 1$, i.e., for all single author publications. This not a problem since collaboration always involves more than one author.

CC $\to$ MCC when $A \to \infty$ otherwise it remains less than MCC by the factor $1 - 1/A$.

In Table 3 we present these four coefficients for 12 years (2000–2011) for publications in nanoscience/nanotechnology in Pakistan. The table also shows the publications for single author, two author, three authors and more than three authors for each year. The percentage of papers with single authors, two authors, three authors and more than three authors is 3, 13, 17 and 67 %, respectively.

Collaboration index that is a measure of mean number of authors per paper varies between 3.14 and 4.64 with a mean value of 4.13. DC stabilizes to around 0.97 and 0.98 again shows a preponderance of multiple author papers (DC = 1 indicates that the number of single author papers is zero). CC and MCC, two parameters that differentiate between the levels of authorships are given in the last two columns.

Table 3 Authorship collaborations

Year	Single author	Two authors	Three authors	>Three authors	CI	DC	CC	MCC
2000	1	3	0	3	3.1429	0.8571	0.5548	0.6472
2001	1	2	4	7	4.0714	0.9286	0.6738	0.7256
2002	2	1	0	11	4.3571	0.8571	0.6667	0.7179
2003	1	2	2	23	4.3929	0.9643	0.7310	0.7580
2004	2	1	16	12	3.5806	0.9355	0.6661	0.6883
2005	4	3	14	29	3.8800	0.9200	0.6747	0.6884
2006	2	10	19	71	4.5000	0.9804	0.7353	0.7426
2007	6	33	40	139	4.2018	0.9725	0.7091	0.7124
2008	9	40	48	179	4.2536	0.9674	0.7097	0.7122
2009	12	66	78	246	4.1548	0.9695	0.7021	0.7039
2010	14	53	66	305	4.4863	0.9680	0.7247	0.7263
2011	11	65	71	395	4.6439	0.9797	0.7398	0.7412

Productivity and impact

The productivity and impact of a paper has been defined through various indices. Some of the important ones are described here.

h-index

Hirsch (2005) proposed the "*h*-index". If the total number of publications of a scientist or researcher is N_p then he has an index *h*, if *h* of his papers have at least *h* citations each, the remaining N_p *h* have citations less than *h*.

h gives a lower bound on the total citations. The total citations can be expressed as

$$N_{total} = ah^2$$

Typically the constant *h* lies between 3 and 5.

h gives an estimate of the importance, significance and broad impact of a scientist's research output. Two researchers with the same number of papers and citations counts can have different *h* values. The one having the higher *h* value would have made significantly more valuable contribution than his colleague.

Conversely two researchers with different citations counts and number of papers can have the same *h*-index.

g-index

The *h*-index is insensitive to the number of lowly cited papers, but it is also at the same time insensitive to the highly cited papers. The first aspect may be an advantage but the second aspect is surly a drawback of the *h*-index.

Egghe (2006) introduced the *g*-index that accounts for this drawback but at the same time keeps the advantages of the *h*-factor. A set of papers has a *g*-index if *g* is the highest rank such that the top *g* papers have, together at least g^2 citations. This means that the top $g + 1$ papers have less than $(g + 1)^2$ citations. In all cases $g \geq h$.

hg-index

The *g*-index has a drawback that it can give undue advantage to a researcher with a single highly cited paper as compared to a researcher having a consistently moderate number of citations for all of his papers.

Alonso et al. (2010) proposed the *hg*-index that minimizes the drawbacks of both *h* and *g* indexes. They define the *hg*-index as

$$hg = \sqrt{h \times g}$$

hg-index lies between *h*-index and *g*-index index.

p-index

Prathap (2010) has proposed the *p*-index defined as

$$p = \left(C \cdot \frac{C}{P}\right)^{\frac{1}{3}}$$

where C is the total citations and P is the total number of papers.

The p-index gives the best balance between the quality (C/P) and quantity C

Major contributors

Top 15 institutions of Pakistan contributing towards publications in the field of nanotechnology are listed in Table 4. It is interesting to note that among the top 15 institutions 13 are universities and only two namely Pakistan Institute of Nuclear Science and Technology (PINSTECH) and National Institute of Bio Genetic Engineering (NIBGE) are R&D organizations.

A comparison of number of publications, citations, average citations and the four indices h, g, hg and p, places Quaid-i-Azam University on the top in all respects. However, if one uses p-index to compare the size and quality of the publications then National Institute of Biotechnology and Genetic Engineering (NIBGE) would occupy the second place, followed by University of Peshawar. Keeping in mind the advantages and disadvantages of each index one can use them for comparison between authors, institutions or countries.

As pointed out by Egghe (2006) in order to calculate g-index fictitious papers with 0 citations have been added until g-index can be determined.

A subject-wise distribution of publications is given in Table 5. Materials Science heads the list of publications with almost 35 % share of the total. This is followed by Physics, Chemistry, and Chemical Engineering. This trend is similar to the one reported by Karpagam et al. (2011) for India. Nanotechnology is not shown as an independent discipline.

Table 4 Contribution of top 15 Pakistani institutions towards publications, citations and various indices in the field of nanoscience and nanotechnology

S. no.	Institution	TP	TC	ACPP	h-index	g-index	hg-index	p-index
1	QAU	459	2,624	5.72	11	51	23.69	24.66
2	PINSTECH	203	841	4.14	8	29	15.23	15.15
3	CIIT	178	720	4.04	6	26	12.49	14.28
4	PU	120	321	2.68	8	17	11.66	9.50
5	NUST	103	541	5.25	4	23	9.59	14.16
6	PIEAS	122	411	3.37	5	20	10.00	11.14
7	NIBGE	107	913	8.53	7	18	11.22	19.82
8	UET	103	219	2.13	5	14	8.37	7.75
9	UoP	100	787	7.87	8	23	13.56	18.36
10	GCU	95	355	3.74	7	18	11.22	10.98
11	UoK	80	332	4.15	7	18	11.22	11.12
12	GIKI	72	197	2.74	6	14	9.17	8.13
13	USindh	50	157	3.14	4	12	6.93	7.89
14	BZU	45	173	3.84	7	13	9.54	8.72
15	UoS	35	72	2.06	3	8	4.90	5.29

Table 5 The subject-wise distribution of Pakistani contributions in nanotechnology

S. no.	Subject	No. of publications	%	Cumulative	Cum %
1	Materials science	744	35.19	744	35.19
2	Chemistry	422	19.96	1,083	51.23
3	Physics and astronomy	339	16.04	1,505	71.19
4	Chemical engineering	113	5.35	1,618	76.54
5	Biochemistry, genetics and molecular biology	138	6.53	1,756	83.07
6	Engineering	73	3.45	1,829	86.52
7	Environmental science	32	1.51	1,861	88.03
8	Agricultural and biological sciences	62	2.93	1,923	90.96
9	Medicine	65	3.07	1,988	94.04
10	Energy	29	1.37	2,017	95.41
11	Pharmacology, toxicology and pharmaceutics	25	1.18	2,042	96.59
12	Immunology and microbiology	28	1.32	2,070	97.92
13	Computer science	13	0.61	2,083	98.53
14	Mathematics	10	0.47	2,093	99.01
15	Multidisciplinary	8	0.38	2,101	99.39
16	Earth and planetary sciences	7	0.33	2,108	99.72
17	Dentistry	3	0.14	2,111	99.86
18	Health professions	1	0.05	2,112	99.91
19	Neuroscience	1	0.05	2,113	99.95
20	Psychology	1	0.05	2,114	100.00
		2,114	100.00		

Conclusion

Research in the field of nanoscience and nanotechnology started somewhere around the year 2000 in Pakistan. During the decade that followed the number of publications has shown a rapid increase from just seven in 2000 to 542 in 2011. Most of the publications are related to materials sciences (35 %) followed by chemistry (20 %), and physics (10 %). The concentration of research is mainly in the universities. Among the top 15 institutions contributing towards publication in nanotechnology 13 are universities and only two are R&D organizations. The collaboration coefficient (CC) point to the fact that a preponderant number of papers (67 %) have three or more authors. Single author papers are only 3 % of the total. A comparison of different institutions places Quid-e-Azam University (QAU) on top in all respects. Pakistan Institute of Engineering and Applied Sciences (PIEAS) is placed at number two position as far as *h*, *g* and *hg* indices are concerned. However, the comparison of *p*-index puts National Institute of Biotechnology and Genetic Engineering (NIBGE) in the second position. It so happens that QAU, PIEAS and NIBGE were able to procure the latest equipment for their laboratories with funding from NCNST during the period 2003–2008 when this agency was still active. A combination of heavy spending by the government on manpower training and procurement of the latest equipment for some of the active laboratories has led to a spurt in activity in the field of nanotechnology as is evident from the various indicators. Unfortunately the present financial crunch could faced by the country could have a negative impact on the progress achieved so far.

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