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PERSPECTIVES

Nanotechnology research output: bibliometric analysis with special reference to India

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Abstract For the last few decades, nanotechnology has emerged as one of the key subject areas in which aggressive development is taking place. The multidisciplinary approach of nanotechnology has opened up a new sphere of research in warfare, engineering, medicine, physics, textile, energy, biology, chemistry, automobiles, agriculture, etc. It has influenced society in every walk of life. Realizing the potential of nanotechnology, the countries across the world have been spending massive amounts and aggressively initiating various programs in research and development of nanotechnology. In this study, efforts are being made to measure the nanotechnology research output published in the form of scholarly literature. The data, for the period of 2014 to 2018, were extracted from the Scopus abstract and citation database and analyzed by using bibliometric techniques. The findings show that China has surpassed the USA by producing more number of scholarly publications in the area of nanotechnology but indicated reservation while collaborating with other countries, whereas the USA has been the second-highest producer of nanotechnology research output and preferred as the most favored nation by other countries to collaborate with in the field of nanotechnology. India attained the third position with respect to nanotechnology publications but has low international collaboration and the quality of publications is also a concern. The findings also show the negative growth of nanotechnology research publications in recent years.

Keywords Nanotechnology research output · Bibliometric study · Citation analysis · Nanotechnology

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Introduction

The word nanotechnology is derived from the words "nano" and "technology." The word "nano" means a billionth (1×10^{-9}) of a quantity. It is defined as "those systems or processes that provide goods and/or services that are obtained from the matter at nonometer (nm) level, that is, from sizes in the range of one-billionth of a meter" (Poole Jr and Owens 2003; Theodore and Kunz 2005). Nanotechnology involves the study of matter at the nanoscale dimensional range approximately from 1 to 100 nm (Arora et al. 2013). The meaning of nanotechnology varies from field to field and country to country. It is reported as "catch all" words that reflect something very small (Sanchez and Sobole 2010). The existence of nanotechnology in various products that already exists is an evolutionary nanotechnology (Whitesides 2005). Manipulation of nanoscale particles in physics, chemistry, and biology leads to exceptional changes in the research output. The application of nanotechnology has been rapidly improving the products being used in everyday life. Nanotechnology is defined as a "technology on a nanoscale that has applications in the real world" (Bhushan 2010). It is also believed that nanotechnology has the strength to make a quality

impact on the economy and society in the twenty-first century.

Nanotechnology has already made an impactful progression when applied in medicines, consumer goods, and construction-related materials. However, it is believed that continuous research and development in the area would surely offer better opportunities with a sustainable environment in the future. For the last couple of decades, various countries have treated nanotechnology as a core area of research and development. India has also not spared from it. It has started national-level programs and initiatives for the development and research in the areas of nanotechnology at the beginning of the twenty-first century.

Literature reviewed

Historically dwelt, the first time use of nanosized materials was reportedly found in the fourth century (Poole Jr and Owens 2003), but any use of nanomaterials before the fourth century is not known. Robert Boyle was the first to scientifically used tiny particles of matter combined to form a corpuscle in 1661. In the eighteenth and nineteenth centuries, photography technology was evolved rapidly as it had the use of nanoparticles. In 1925, Richard Zsigmondy, an Austrian-Hungarian chemistry scholar, and Henry Siedentopf, a German physicist, were the first to introduce the concept of "nanometer" for their notable microscopical research on colloids (Hulla et al. 2015; Mappes et al. 2012). However, the nanotechnology got a boost from Richard Feynman, in 1960, in his presentation entitled "there is plenty of room at the bottom" (Feynman 1992, 2018), he discussed the new concept of manipulating matter on the atomic level. He, for his efforts in nanotechnology research, is known as the father of modern nanotechnology and introduced the enormous potential of nanosized materials before the term nanotechnology emerged. Norio Taniguchi a scientist from Japan and was the first to use the term technology for the semiconductor process that takes place with nanosized materials (Taniguchi et al. 1974).

Nanotechnology has the potential to bring revolutionary changes in society for the betterment at the global level. It has the capacity to enhance human performance, sustainable development in materials, water, energy, and medical domains (Roco 2001). The nanostructured materials open a new world of the horizon for scientists and research scholars. The use of nanoscience or nanotechnology is just not only happening in physics, chemistry, and other core areas but also has been integrating with various microdisciplines as well. Nanotechnology was found to be useful in the development of advanced continuous ceramic fibers with nanoscale diameters (Dzenis 2004). Dzenis further stated that "nanotubes of carbon and other materials are the most fascinating materials playing an important role in nanotechnology today." A study on the application of nanotube and nanoclay for improving the brake friction materials in the automobile sector was also found (Singh et al. 2015). The "convergent" characteristic of nano that brings multidisciplinary sciences and technologies together (Porter and Youtie 2009) was also explored. Nanotechnology has been considered as a multidisciplinary and interdisciplinary area of inquiry and application. It has an important role to play in all areas such as agriculture, electronics, medicine, textile, physics, cosmetics, energy, photography, and healthcare (Kumar 2014). It is being deemed as a revolution that has the potential of enhancing "variety of products, services and industries." The scholars raised their concern and stated that developing nanotechnology materials or products may bring threats to the environment but they further suggested that it can be eliminated or reduced with collective efforts of collaborations and sharing research (Alvarz et al. 2009). In some of the nanotechnology-related studies, the scholars shared their concern over the unsafe hazards of nanotechnology with respect to environmental, health, and other societal aspects. They suggested that having global collaborative research programs and government collaboration with industries on nanotechnology research could be helpful to minimize such hazards (Maynard et al. 2006). It is expected that a better and cheaper product can be made by using nanotechnology. It has an authoritative impact on war, crime, terrorism, and on almost all kinds of industries (Wilson et al. 2002). Keeping a note of nanotechnology potential, countries around the globe have been focusing on its use for the betterment of the society, bringing war competency, and developing security and machines.

After realizing the potential of nanotechnology, the USA started a national-level initiative with the name "National Nanotechnology Initiative" (NNI) in 2001 (Roco 2003). In the similar line, various other countries have also started nanotechnology-based programs. The National Enabling Technologies Strategy (NETS) in

Australia, National Science and Technology Program for Nanoscience and Nanotechnology in Taiwan, and other national initiatives by the countries like the Republic of Korea, Japan, Singapore, and Canada have taken aggressive steps to promote research in nanotechnology-related areas that are supported with a huge amount of funding (Porter and Youtie 2009). In a study, the nanotechnology development in China revealed that China issued a policy plan for a national nanotechnology development strategy for the period 2001 to 2010 (Gu and Schulte 2005). The core focus of this strategic policy plan was on research in nanotechnology. Another study highlighted how China has surpassed the dominance of the USA in the field of nanotechnology development (Dong et al. 2016). India had first time indicated developing nanotechnology as a core area of research in its Ninth Five-Year Plan (1998–2002) document (Kumar 2014). It was reported that under the aegis of the Department of Science and Technology (DST), Government of India, a program called "Nanoscience and Technology Initiative" (NSTI) was launched during the Tenth Five-Year Plan, i.e., 2002–2007 (Beumer and Bhattacharya 2013). Later, another ambitious program, the Nano Mission, was clubbed with NSTI in May 2007. Because of such programs, India established itself among top countries exploring new domains in nanoscience and technology. A report highlighted that India had published over 5000 research papers and 900 Ph.D. theses on nanoscience and technology (Press Information Bureau 2019).

In the present study, bibliometric techniques were used to measure the research output of various countries in the areas of nanotechnology. Although it is not a fully proven technique to measure research output published in the form of scholarly publications, this is the only available technique today. The bibliometric analysis is also helpful in identifying newly emerged fields of technology (Arora et al. 2013). The scholars also highlighted that the availability of data to conduct a bibliometric study is the biggest limitation. They stated that publications recorded or reported at the public domain cannot represent the totality of works done in the specific subject areas (Rueda et al. 2007). However, a bibliometric study is useful in taking strategic decisions and identifying emerging areas of research and technology. Around the globe, various bibliometric studies had been conducted to measure the growth of research output in the areas of nanotechnology. A bibliometric study on active nanotechnologies (Suominen et al. 2016) found that in the recent decade, funding in the area of nanotechnology and publication of research output has been expanded greatly in many countries. Another study analyzed the data extracted from the Science Citation Index and Social Science Citation Index for the period of 1991–2005. It highlighted the phenomenal growth of nanotechnology-related publications across the globe but observed an exponential growth in East Asian nations especially in China and South Korea (Kostoff et al. 2007). A bibliometric assessment was made to highlight the growth of nanotechnology in Russia by comparing research output with eleven other countries for the period from 2000 to 2014 (Terekhov 2017). Terekhov also found China's dominance in the field of nanotechnology after the year 2009. He further assessed that Russia placed within the top producer of nanotechnology research papers. China remained the first position followed by the USA and the third spot was picked up by India. For citation per paper, the USA leads the chart followed by China, whereas Russia was just ahead of Iran among the countries taken for study. An analysis was made on data extracted from the Web of Science for the period 1992–2006. In the analysis, it was identified that the USA, Germany, Japan, UK, and China are the top five countries that published the maximum number of publications on nanotechnology during the period of the study (Rueda et al. 2007). Rediguieri studied nanotechnology development in Brazil and analyzed it by comparing it with nanotechnology development in advanced countries (Rediguiery 2009). Another study analyzed nanotechnology publications' of China, the USA, Japan, Germany, and France for the period from 1985 to 2004. The data were taken from the Web of Science. It was found China is one of the major contributors in the nanotechnology research and even bypassed the USA (Guan and Ma 2007). The rising collaboration of China and the USA in the field of nanotechnology through Chinese nanotechnology publications published during 1990–2009 was also studied. It was found that China was in the eighth position in terms of nanotechnology publications from 1990 to 1994 and contributed 1.4% of nanotechnology publications in 1990. It was the period when nanotechnology research started getting momentum in the country. By the year 2007, Chinese nanotechnology publications rose to second place in the world, and by 2009, China had contributed to 21% of total global publications in nanotechnology. Such aggressive development has taken place because of various national policies and programs on

nanotechnology and related fields initiated during the 1990s in the country. China's international collaboration for publishing nanotechnology research output majorly happened with the USA. China's 33.5% of international collaboration for writing nanotechnology papers happened only with the USA (Tang and Shapira 2011). Another study concluded indicating the multidisciplinary approach of nanotechnology that progressing rapidly. The study revealed countries following different patterns of collaboration (based on their bilateral relations) on nanotechnology research with different countries (Meyer and Persson 1998).

A comparative study on the research output of China, Russia, and India on the data extracted from the Science Citation Index and the United States Patent and Trademark Office, during 1976–2007, was done. The study found that the research output of publications on nanotechnology in three countries has grown by an average annual growth rate of 31.43% in China, 11.88% in Russia, and 33.51% in India. It further specified that most of the research publications were published by universities and research institutions whereas private companies were excelled in patent publications. For India, the majority of publications were generated by the Indian Institute of Technology and the Indian Institute of Science (Liu et al. 2009). A quantitative analysis was made to present the growth of nanotechnology and nanoscience publications published by India from 1982 to 2008. In total, 8326 publications were published by Indian scientists. The analysis identified a moderate growth of Indian publications during the later part of the study. Over 92% of the research publications were published by Indian scientists from 2000 to 2008. It shows that, in India, nanotechnology research was taken a real boost at the beginning of the twenty-first century. It also identified the Indian Institute of Science, Bangalore, as the most prolific institution for nanotechnology research (Mohan et al. 2010). An assessment was made on papers published by India and other countries on nanotechnology during 2000–2009. India had published 13,366 papers in this period and ranked at number 10 with the number of publications. China emerged as the most focused country in nanotechnology research and obtained the first rank in the list. The study further highlighted that material science, physics, and chemistry are the three dominant areas of India's research on nanotechnology (Bhattacharya and Shilpa 2011). The nanotechnology, especially in the twenty-first century, has revolutionized the spectrum of industries. China had embarked upon nanotechnology research in 1990. It invested about 228 million USD during 2001–2005 and increased the funding significantly to 760 million USD during 2006–10. This boosted the research and development activities of nanotechnology in China whereas India focused on nanotechnology research in 2001 with the launching of NSTI that received funding of 15 million USD for the first 5 years. The major thrust to nanotechnology developmental activities in the country was taken place with the emergence of the "Nanotechnology Mission" that received funding of 250 million USD for the next 5 years. In 2000, India contributed 2% of the total publications that increased and reached to 5% publications by 2009. China published 9.8% of publications in 2000 and emerged as a new leader by surpassing the USA with a 23% share of publications in 2009 (Bhattacharya et al. 2012). A study analyzed the growth pattern of nanoscience and nanotechnology publications published by India during 1990–2009. A total of 22,765 records were extracted from the Scopus database for the period of 20 years. The analysis revealed that the world has produced 759,704 publications for the same period and the USA had contributed 20.29%. It is followed by China 15.87%, Japan 10.39%, and Germany 8.07%, whereas India contributed 3.0% and hold the seventh spot. The nanotechnology research happened mostly in the subject areas belonging to material science, physics, chemistry, and engineering. In the area of nanotechnology, a substantial contribution from the Indian Institute of Science and Indian Institute of Technologies (IITs) was also observed (Karpagam et al. 2011). Another study examined the nanotechnology research output of India indexed in Web of Science for the period from 1991 to 2006. It analyzed that India had produced 2675 research articles in this period and the majority of these articles were published under multiple authorship patterns. It further specified that considerable growth was seen in research articles in the last decade of the study period (Nazim and Ahmad 2008).

Based on the above-reviewed literature, it was found that many bibliometric studies have been taken place

across the globe to measure research output in the areas of nanotechnology. However, the potential nanotechnology has been shown and highlighted in the previous studies; it is essential to keep an eye on its development and subject areas where nanotechnology has been used prominently.

Methodology

Scholarly literature, in the form of publications, in the area of nanotechnology was extracted from the Scopus abstract and citation database of Elsevier Science. The Scopus is known as the premier database that indexes peer-reviewed literature published in all areas of learning. In the present study, a query for the term "nanotechnology" was placed in the title, abstract, and keyword indexes of the database. Since publications generally started attracting citations after two or more years, therefore, the query was further limited to research articles published in scholarly journals during the year 2014 to 2018. The following search string was formed to extract the needed data.

For all nanotechnology publications of the world—

TITLE-ABS-KEY (nanotechnology) AND DOCTYPE (ar) AND PUBYEAR > 2013 AND PUBYEAR < 2019.

For Indian content—

"AND AFFILCOUNTRY (INDIA)" was added in the above string.

The extracted data were synthesized and analyzed in MS Excel by using relevant bibliometric techniques.

Data analysis

On the basis of extracted data, it was found that the world had produced 30,126 articles on nanotechnology during the period from 2014 to 2018. Among these, 5514 (18.30%) articles were published in open access journals and 24,612 were published in proprietary journals. During the same period, in total, India had produced 2290 articles in nanotechnology subject; out of these, 253 (11.05%) were published in open access journals and 2033 in others.

Number of publications

Table 1 represents the number of publications published from 2014 to 2018 around the globe and Indian share to these publications. The Indian share marginally improved from 6.94 to 8.36%. It was recorded that in the year 2016, India had produced 514 articles that come to 8.36% of the total nanotechnology articles published in the world. In the year 2017, India produced the lowest share of nanotechnology publications, i.e., 6.94%. The cumulative share of Indian nanotechnology publications was recorded to 7.60% in the world nanotechnology publications.

Table 1 Number of publications

Year	World	India	% of Indian share
2014	5976	444	7.43
2015	7087	554	7.82
2016	2148	514	8.36
2017	5804	403	6.94
2018	5111	375	7.34
Total	30,126	2294	7.60

Citation and cited rate of Indian publications

The analysis was also made to know the citations received by the Indian nanotechnology articles along with the cited rate. Table 2 highlights that Indian nanotechnology articles published during 2014–2018 have received 23,466 citations. That computed to average citations per publication to 10.25 and 81.53% cited rate. The average citation per publication was reported highest (16.47) for the publications in 2014 and lowest (1.94) for the year 2014. As specified by Radicchi and Castellano (2011), the publications started attracting citations after 2–3 years; therefore, the publications published during 2017 and 2018 may have fewer citations as compare with older publications. It indicates that the old publications may have chances to get more number of citations. Therefore, the publications published during 2018 or 2017 may have their share of citations in due course of time.

The highest cited rate of 89.11% was reported for the publications of 2016 and the lowest (55.20%) for the year 2018.

Annual growth rate

The following matrix was used to know the average annual growth rate (GR) of nanotechnology publications produced during the year 2014–2018.

Table 2 Indian nanotechnology publications, citations, and cited rate

Year	TP	TC	ACPP	CR (%)
2014	444	7311	16.47	88.06
2015	554	7316	13.21	86.82
2016	514	6046	11.76	89.11
2017	403	2066	05.13	81.89
2018	375	727	01.94	55.20
Total (2014–18)	2290	23,466	10.25	81.53

TP total publications, *TC* total citations, *ACPP* average citations per publications (ACPP = TC/TP), *CR* cited rate (CR is the percentage of articles having one or more number of citations)

$$\text{Annual Growth Rate (GR)} = \left(\frac{\text{Present Publications}}{\text{Past Publications}}\right)\wedge\left(\frac{1}{\text{Number of Years}}\right)-1$$

As highlighted in Fig. 1, the growth rate was found positive in the year 2015 in which world-published nanotechnology publications have a growth rate of 18.59% whereas India published its research with a growth rate of 24.77%. The growth rate of nanotechnology publications globally and India was found negative in 2016, 2017, and 2018. The overall average annual growth rate for the nanotechnology publications of the globe was reported negative, i.e., − 3.08%. Similarly, the average growth of nanotechnology publications published by India during 2014–2018 was also reported negative with − 3.32%.

The negative growth of publications somehow represents the contrary status of research in the area of nanotechnology in which various initiatives have been taken place around the globe. It may be because the emergence of more specialized sub-area nanotechnology like nanoparticle, nanotube, nanometer, bulk technology, nanomachine, nanosurgery, etc. and research in these areas has been started taking place extensively. Another possible reason for the negative growth of nanotechnology publications is that many countries prominently working on the use of nanotechnology in warfare and defense are hiding the outcome of their research because of various reasons.

Authorship pattern

An assessment was made to understand the authorship pattern of Indian nanotechnology publications. It was recorded that 46 publications that come to 2.01% of total publications were authored in single authorship. The share of two-authored publications was 18.86% (432), and three-authored publications were 495 enveloping a 21.62% share. The four-authored publications (420) and five-authored publications (897) contributed to 18.34% and 39.17% share respectively.

As depicted in Fig. 2, the publications with more number of authors have more number of citations. The publications authored by five or more authors have a 53.03% share of total citations received by nanotechnology publications. The citations' share remained lowest at 0.58% for the single-authored publications. It means the two- or more (multiple) authored publications

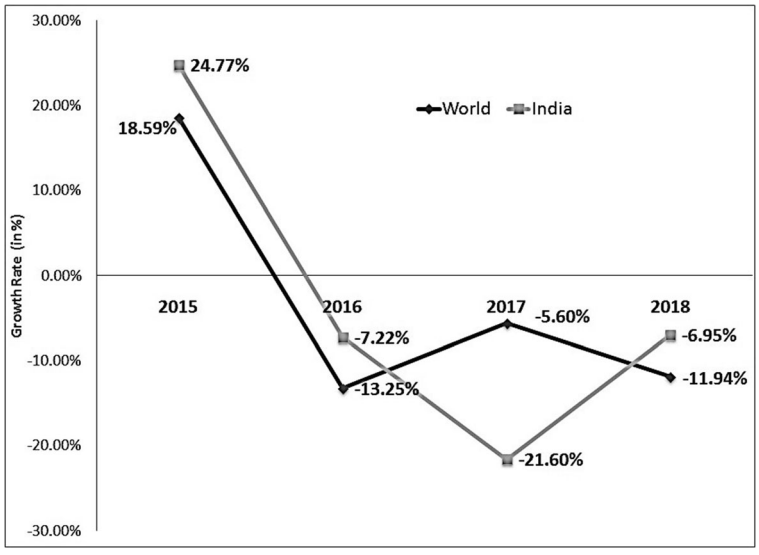

Fig. 1 Average annual growth rate of nanotechnology publications

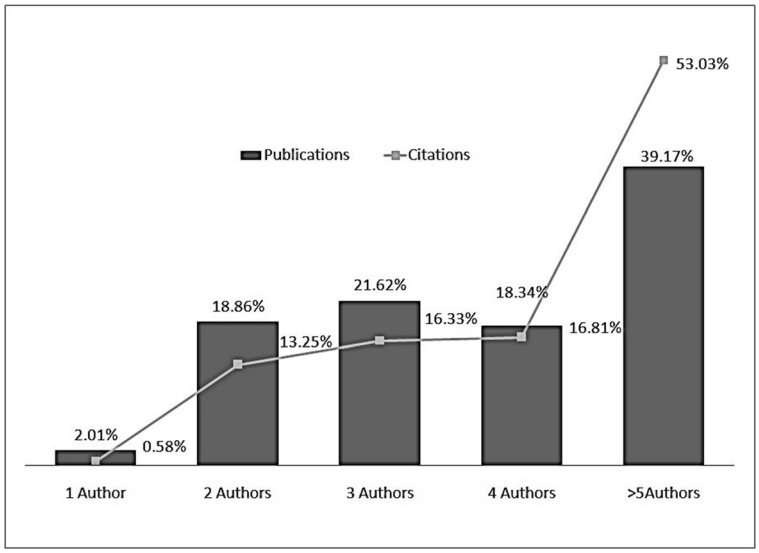

Fig. 2 Authorship pattern and citation received

have better quality or citations as compared with single-authored publications.

Degree of author collaboration

The analysis was also made to understand collaboration among authors with respect to nanotechnology publications. The following mathematical formula was used to compute the degree of author collaboration (Subramanyam 1983).

$$\text{Degree of author collaboration } (C) = \frac{\text{Nm}}{\text{Nm} + \text{Ns}}$$

Here, *C*—degree of author collaboration

Nm—number of publications with multiple (two or more than two authors) authorship

Ns—number of publications with a single author

Based on the above formula, the degree of author collaboration was calculated and indicated in Table 3 for easy representation. It was found that in 2014, the degree of collaboration was 0.98 that got improved to 0.99 in 2015.

The degree of collaboration was remained lowest, i.e., 0.97 in 2016 and it remained static at 0.98 in 2017 and 2018. The degree of author collaboration cumulatively for the period 2014–2018 was recorded to 0.98. That means, during the period of the study, 98% of nanotechnology publications in India were written in multiple authorship. It can clearly be stated that multi-authored publications among Indian nanotechnology researchers prevailed highly.

Most prolific Indian authors

A list of most prolific Indian authors was also compiled. The authors have written 11 or more articles that were placed on the list. The listed authors were highlighted in Table 4 with total publications (TP), total citations received by him/her, and average citations per publication (ACPP). The data revealed that K Murugan of Bharathiar University, Coimbatore, has written maximum articles, i.e., 26 in numbers during 2014–2018, followed by M Govindarajan of Annamalai University with 21 articles. D Mandal of Jadavpur University and D De of the West Bengal University of Technology have written 16 articles each. Panneerselvam of Bharathiar University authored 13 publications and Karthick Raja from Sathyabama University wrote 12. M S Muthu of the Indian Institute of Technology Vara-

Table 3 Degree of author collaboration

Year	Ns	Nm	Ns + Nm	*C*
2014	8	436	444	0.98
2015	5	549	554	0.99
2016	15	499	514	0.97
2017	9	394	403	0.98
2018	9	366	375	0.98
Total (2014–18)	46	2244	2290	0.98

Table 4 Most prolific Indian authors (contributed 11 or more publications)

Author	Affiliation	TP	TC	ACPP
Murugan K.	Department of Zoology, School of Life Sciences, Bharathiar University, Coimbatore	26	661	25.42
Govindarajan, M.	Department of Zoology, Annamalai University, Tamil Nadu	21	438	20.86
Mandal, D.	Department of Physics, Jadavpur University, Kolkata	16	580	36.25
Panneerselvam, C.	Department of Zoology, School of Life Sciences, Bharathiar University, Coimbatore	13	424	32.62
De, D.	Department of Computer Science and Engineering, West Bengal University of Technology, West Bengal	16	306	19.13
Karthick Raja Namasivayam, S.	Department of Biotechnology, Sathyabama University, Chennai, Tamil Nadu	12	16	01.33
Muthu, M.S.	Department of Pharmaceutics, Indian Institute of Technology (BHU), Varanasi, Uttar Pradesh	11	344	31.27
Subramaniam, J.	Department of Zoology, School of Life Sciences, Bharathiar University, Coimbatore	11	418	38.00

nasi and J Subramaniam of the Bharathiar University have contributed 11 articles each.

On the basis of citations received, the quality of publications of each author was assessed and represented in the form of Average Citations per Publication (ACPP). The ACPP was recorded 38.00 for the publications authored by J Subramaniam which is higher among the top eight Indian contributors of nanotechnology publications. It shows the quality of the research he produced. The publications of D Mandal have also achieved 36.25 ACPP, followed by Panneerselvam and M S Muthu who achieved 32.62 and 31.27 ACPP respectively. The nanotechnology publications authored by Karthick Raja Namasivayam received the lowest ACPP, i.e., 1.33. It is also interesting to know that out of the 8 most prolific authors, three are from the same university and have been working in the same subject area, i.e., zoology. The Zoology Department of Bharathiar University has focused its research on nanoinsecticides and natural plant products. The faculty members of this university have been working on different projects of nanoinsecticides. Therefore, the majority of their publications were in each others' collaboration which led to having their names in the list of the most prolific Indian authors in the area of nanotechnology.

Source title impact ratio

The STIR is used to identify the source (journal) title in which Indian authors prefer to publish their nanotechnology-related publications. The Source Title Impact Ratio (STIR) can be computed with the use of the following matrix.

$$\text{Source Title Impact Ratio (STIR)} = \frac{\text{TP} + \text{CR} + \text{ACPP}}{100}$$

TP—total publications (consider number—articles accommodated by the journal/source title).

CR—cited rate (consider popularity—highlighting the percentage of articles received one or more citations).

ACPP—average citation per publication (consider the quality aspect of the article).

Table 5 provides the list of top ten sources that published most articles written by Indian authors or in collaboration with any Indian author. The list accommodated 3 journals from Elsevier Science, 2 each from the Royal Society of Chemistry and Springer, one each from American Scientific Publishers, Sphinx Knowledge House, and American Chemical Society. The *RSC Advances* published maximum articles, i.e., 37 in numbers but received STIR rank 4 with 1.420 points. The most preferred and venerable journal is *Nanoscale* of Royal Society of Chemistry that obtained STIR rank 1 with 1.490 points. The second most preferred journal is *Colloids and Surface B: Biointerfaces* of Elsevier Science that got 1.459 STIR points. The tenth rank was captured by the *International Journal of ChemTech Research* a journal of Sphinx Knowledge House of India that published 33 articles (third-most number of articles) but poor ACPP and cited rate the source journal received 0.964 STIR points and got placed at the last in the ranking.

Table 5 Top ten most preferred source titles

Source title	TP	TC	CR	ACPP	STIR	Rank
RSC Advances (UK)	37	284	97.30	07.68	1.420	4
Journal of Nanoscience and Nanotechnology (USA)	36	243	91.67	06.75	1.344	7
Int. Journal of Biological Macromolecules (Netherlands)	35	358	91.43	10.23	1.367	6
Int. Journal of ChemTech Research (India)	33	92	60.61	02.79	0.964	10
Nanoscale (UK)	33	529	100.00	16.03	1.490	1
ACS Applied Materials & Interfaces (USA)	27	511	96.30	18.93	1.422	3
Materials Science and Engineering C (Netherland)	27	489	96.30	18.11	1.414	5
Colloids and Surfaces B: Biointerfaces (Netherland)	24	525	100.00	21.88	1.459	2
Environmental Science and Pollution Research (Germany)	23	252	86.96	10.96	1.209	9
Journal of Nanoparticle Research (Netherland)	23	168	91.30	07.30	1.216	8

Most productive country

With the number of publications produced on nanotechnology, the top ten countries were identified and highlighted in Table 6. It shows that China has published the most number of articles (7978) in nanotechnology from 2014 to 2018. These articles attracted 135,365 citations with the cited rate of 83.27, followed by the USA by publishing 7718 publications and achieving a 90.71 cited rate. India produced a third most number of publications (2290) after China and the USA and achieved an 81.53 cited rate. It is followed by Germany with 1858 articles and 90.96 cited rate and South Korea with 1787 publications along with an 89.20 cited rate.

While assessing country-wise performance by computing average citation per publication, the USA dominated the list with the quality publications that achieved 20.89 ACPP. Germany recorded 19.15 citations per publication, followed by South Korea, and the UK that achieved 17.93 and 17.06 citations per publication respectively. Iran, with 9.69, placed in the last while assessed for average citations per publication. The quality aspect of Indian publications was also reported low that attained 10.25 citations per publication and remained slightly above to Iran.

Table 6 Most productive countries

Country	TP	TC	CR	ACPP
China	7978	135,365	83.27	16.97
USA	7718	161,249	90.71	20.89
India	2290	23,466	81.53	10.25
Germany	1858	35,572	90.96	19.15
South Korea	1787	32,041	89.20	17.93
UK	1632	27,841	89.77	17.06
Iran	1274	12,346	81.71	09.69
Italy	1257	18,939	90.61	15.07
Japan	1174	15,877	85.69	13.52
France	1146	17,510	88.83	15.28

International collaboration

Table 7 shows that the USA has published 69.05% of the country's nanotechnology research output in international collaboration. It has collaborated with China for 26.59% of international collaborated research output. The USA collaborated with 101 countries for nanotechnology research and remained the most preferred country for nanotechnology research by all listed countries.

It was found that Germany, the UK, Italy, and France were the countries that collaborated frequently with two or more countries for producing a single publication. It led to an increased number of international collaborations with countries than the total number of publications.

The table also shows that Iran has been reserved in collaborating with other countries and collaborated with 56 countries for producing 28.57% of its total nanotechnology research output. India has collaborated internationally with 65 countries to publish 36.59% of its total nanotechnology research output. Though China has produced a maximum number of nanotechnology publications, it could partially be treated as a reserved country for limited collaborative publications that come

Table 7 International collaboration on nanotechnology publications

Country	Total publications	International collaboration	No. of countries collaborated with	% of international collaboration*	Most collaborative country name	% share of collaboration
China	7978	3347	76	43.49	USA	40.84
USA	7718	5329	101	69.05	China	26.59
India	2290	838	65	36.59	USA	17.06
Germany	1858	2114	74	113.78	USA	16.13
South Korea	1787	993	63	55.57	USA	37.56
UK	1632	1896	75	116.18	USA	16.82
Iran	1274	364	56	28.57	USA	17.03
Italy	1257	1304	75	103.74	USA	14.49
Japan	1174	806	57	68.65	USA	17.74
France	1146	1262	77	110.12	USA	14.58

*% of international collaboration is higher when one publication collaborates with two or more countries; hence, the % computed to more than 100%

to 43.49% of its total nanotechnology publications collaborated internationally.

Prevalent research areas

The efforts were made to find out the most preferred subject areas in which nanotechnology research has been taking place. The subject categories were extracted from the Scopus database. There could be some multidisciplinary publications that got reflected independently in each subject or group of subjects listed in the table. Therefore, an extensive increase in numbers or percentages has been recorded.

Table 8 highlights the most common subject areas in which nanotechnology research was taken place in the world and India. Since nanotechnology emerged as core areas of material science, hence, most of the nanotechnology research has been carried out in material science. Out of total nanotechnology research in the world, 45.74% has taken place in material science whereas 37.55% of total Indian nanotechnology research happened in this subject only. The world's contribution to nanotechnology research in engineering subjects was 34.67% and India contributed 31.27% of its nanotechnology research to engineering. The 5.03% share of the world's nanotechnology research happened in medicine whereas India contributed 11.57% of its nanotechnology research to the medicine filed.

The data indicates that nanotechnology research is not merely taking place in material science or physics but it is also happening in other subject areas like environmental science, medicine, biology, and engineering too.

Conclusion

A remarkable growth was reported in the nanotechnology development in the first decade of the

Table 8 Prevalent nanotechnology research areas

Subject	World		India	
	Total publications	% share*	Total publications	% share*
Material science	13,780	45.74	860	37.55
Engineering	10,445	34.67	716	31.27
Chemistry	9493	31.51	549	23.97
Physics and astronomy	8995	29.86	545	23.80
Chemical engineering	6373	21.15	489	21.35
Biochemistry, genetics, molecular biology	5652	18.76	498	21.75
Environmental science	2708	08.99	212	09.26
Pharmacology, toxicology, pharmaceutics	2586	08.58	418	18.25
Medicine	2440	08.10	265	11.57
Energy	1516	05.03	114	04.98

*Percentage of share may be higher as one publication can envelop multiple subject areas

twenty-first century. A negative growth was observed in scholarly publications of nanotechnology literature after the year 2016. A similar trend was found in the Indian nanotechnology research output as well. It is also believed that many countries are not sharing their nanotechnology research output to the world; hence, a negative growth in publications is visible and it may continue some more time. The multi-authored pattern was more prevailed and well accepted by the readers as publications having two or more authors achieved more citations than the publications written in single authorship. The study revealed that the scholars prefer collaborated research in the areas of nanotechnology.

The potential of nanotechnology brought the whole world to an undefined race of nanotechnology development. The USA dominance of nanotechnology development has been well challenged by China by becoming a world leader in terms of nanotechnology publications. It was established that China has restricted international collaboration as compared with the USA and other developed countries. The USA has been the most favored country for collaborating on nanotechnology research output. India has been reported the third most productive country of nanotechnology publications but found with very low international collaboration. The quality of Indian nanotechnology publications also needs to be improved as the study found 10.25 average citations per publication that were slightly above Iran (9.69). Furthermore, it was found that the "nanoscale" journal published by the Royal Society of Chemistry has been the most advisable source for Indian authors to publish nanotechnology research. Environment, energy, and pharmaceutics were some of the subject areas that have reported low use of nanotechnology. Since these areas are directly related to society, it is expected that in due course of time, the use of nanotechnology research would be more in these fields.

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Compliance with ethical standards

Conflict of interest The author declares that he has no conflicts of interest.

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