Nanomedicine Research in India: A Bibliometric Assessment of Publications Output during 2002-20

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ABSTRACT

The paper describes quantitative and qualitative dimensions of nanomedicine research studies in India. The study is based on research publications data in nanomedicine research (1491 publications) as covered in Scopus data basefor the period 2002-20. The study finds that nanomedicine research in India registered a high 73.7% growth with an average of 22.93 citations per paper. The nano-oncology subfield accounted for the highest share (48.49% share) in the national output, followed by seven other nanomedicine subfields. Jamia Hamdard University, Delhi, Panjab University, Chandigarh and Banaras Hindu University, Varanasi lead as the most productive organizations in the country. The paper also lists the most productive authors in nanomedicine research. The most productive research journals that reported nanomedicine research in India include *Nanomedicine, International Journal of Nanomedicine* and *Current Pharmaceutical Design*. In addition, *International Journal of Pharmaceutics, International Journal of Nanomedicine* and *Drug Delivery Today* topped in the list of most cited research journals.

Key words: Nanomedicine, Nanotechnology, Medicine, India, Research, Publications, Scientometrics, Bibliometrics.

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INTRODUCTION

Nanomedicine is one of the applications of nanoscience and nantechnology in the field of medicine involving the use of nanoscale materials and devices for diagnosis, treatment, and prevention of diseases. In other words, nanomedicine is a technology that treats and manipulates biological processes using nanomaterial's at nanoscale, the level at which diseases originate and progress. Nanomaterials due to their small size are sensitive to diseased cells, and hence are easily attracted to the target cells compared to their bulk chemical equivalent. They (nanomaterials) do play a very crucial role in drug development designed to enable benefits such as site specific drug delivery, safer imaging of diseased tissues, reduced side effects and better results compared to standard therapies.

The term "nanomedicine" was coined by the American engineer Eric Drexler (1955) and Robert Freitas Jr. (1952) in the nineties,[1] with the publication of the multi-volume textbook entitled "Nanomedicine", released in October 1999. Nanomedicine technology uses structured nanomaterials in the treatment of diseases such as neurological diseases, infectious diseases, cardiology, oncology, orthopaedics, and others, not possible before. Nanomedicine potentially enables physicians to detect a disorder early, before the insurgence of its clinical manifestations and symptoms, as well as to provide drugs in a rational, precise, and targeted way, thereby minimizing the risk of the occurrence of side-effects as much as possible.[2]

Nanomedicine research has already branched out into sub-areas like drug development, diagnostic imaging, vaccines, regenerative medicines, implants, and in tissue engineering at cellular level. Research in this area is also aimed at developing key insight into techniques and technology needed to create structured nanomaterials and devices as per needs in the practice of medicine.[3] The other topics in nanomedicine research are how to develop medicines and implants that are biodegradable, how to ensure that nanomedicines are safer with fewer side effects, and also that they are cost-effective compared to conventional therapies.

India had launched a Nanotechnology Mission in 2007 involving participation of multiple research agencies and organizations such as the DBT, DST, ICMR, DRDO, CSIR with the aim to harness the benefits of nanotechnology applications in the country. This Mission had helped India to promote basic research, develop necessary infrastructure, build capacity, and engage in international collaborative research in nanotechnology and its applications including nanomedicine.[4] Though top level several research institutes and universities in India have started degree programmes in nanoscince and nanotechnology, but none is offering a degree programme *per se* in nanomedicine. The leading institutes/universities in nanotechnology area include IISC Bangalore, Indian Institutes of Technology, Delhi Technology University, and National Institutes of Technology. The Government of India has issued 'Guidelines for Evaluation of Nanopharmaceuticals in India, in Oct 2019 to ease research in clinical testing and commercial manufacturer of nanomedicines.[5] The pharmaceutical industries are seeing business opportunities in manufacturing next-generation nanopharmaceuticals. The global market size in nanomedicine is growing, it is projected to reach $261.063 billion by 2023. According to AMC report, India's market size in nanomedicine in expected to grow at 13.4% CAGR between 2016 and 2023, which is marginally above the global CAGR of 12.4%.[6]

Given the huge potential of nanomedicines to address unmet medical needs, and their growing impact on nanopharmaceutical market, it is important and desirable that a bibliometric study be undertaken in

nanomedicine research in India. Such an evaluative study - to be undertaken based on research publications output in the subject - will help stakeholders understand the performance status of nanomedicine research in the country at the global, national, institutional, and individual author level.

Literature Review

Bibliometric/scientometric studies in the past related to "Nanomedicine" research are quite limited in number. Amongst the available studies, Bhatia *et. al*[7] studied India's status of research and innovation in nanomedicine. The study evaluated India's innovations on the basis of five indicators: financial ecosystem, technology source, research translation, bibliographic data (patents and publications 2010-15). Bragazzi[8] studied a total of 6696 global articles published during 2003-19 on nanomedicine. The publications data was sourced from PubMed/MEDLINE database The author identified six thematic clusters (first cluster: molecular methods; second cluster: molecular biology and nano-characterization; third cluster: nano-diagnostics and nano-theranostics; fourth cluster: clinical applications, in the sub-fields of nano-oncology, nano-immunology and nano-vaccinology; fifth cluster: clinical applications, in the sub-fields of nano-oncology and nano-infectiology; and sixth cluster: nanodrugs). Most productive countries were the USA and European countries, with China as an emerging region. Hot topics in the last few years of the study were nano-diagnostics and nano-theranostics and clinical applications in the sub-fields of nano-oncology and nano-infectiology. Parameswaran[9] studied a total of 11255 global publications during 1999-2016 on nanomedicine. The data was analyzed using bibliometric indicators such as country- wise distribution of publications, year wise, source wise, and subject wise distribution of publications. Makkizadeh[10] examined the intellectual structure of knowledge in the field of nanomedicine (2798 records) during the period of 2009 to 2018 by using co-word analysis. The Co-word analysis helped to identify the intellectual structure of knowledge in a research domain and revealed its subsurface research aspects. Biglu and Riazi[11] analyzed and visualized the co-authorship network of all papers in the field of nanomedicine (3092) published through 2002-2014 in journals and indexed in the Web of Science database. However, not a single bibliometric study specificto only to India discovered in this survey. Hence, it was decided to undertake such a study that analyses India's research publications in the field of nanomedicine covering the publication period 2002-20.

OBJECTIVES

The study seeks to examine qualitative and qualitative aspects of India's overall research in the field of nanomedicine. The publications data for India was sourced from Scopus database during 2002-20. The specific objectives of this study are: (i) To analyze India's research in the subject in terms of publications growth publications output, its distribution by document types, source publication types, broad subject areas, research collaboration at international level, and type of research (ii) To analyze nanomedicine research in India in terms of citation impact and describe bibliographic features of highly-cited papers, and (iii) To Identify most productive organizations and authors and most productive source journals in nanomedicine research in India.

MATERIALS AND METHODS

In order to analyze India's contribution in the "Nanomedicine Research", the study sourced publications data from the Scopus database (http://www.scopus.com) covering the period 2002-20. A number of keywords shown below were tagged to "Keyword tag" for retrieval on the subject. The search output was subsequently restricted to period "2002-20" in the "period tag", and to 'India' in the affiliation tag. The search retrieved a total of 1491 records. The search strategy was further refined to get statistics on India's output by subject, collaborating country, organization, author and journal. Citations to publications were counted from date of their publication till 28 January 2021. A complete counting method, wherein every contributing author or organization covered in multiple authorship papers was fully counted and used. All type of publications have been used in conducting this study.

((KEY(nanomedicine or nano-medicine)) or ((KEY(nanoneurology or nano-neurology or nano-surgery or nano-surgery) OR KEY(nanoneurosurgery or nano-neurosurgery))) or ((KEY(nanootor* or nano-otor* or nano-dentist* or nano-dentist*) OR KEY(nanoopthal* or nano-opthal*))) or ((KEY(nanocardio* or nano-cardiol* or nanoortho* or nano-ortho*) OR KEY(nanoinfect* or nano-infect* or nano-oncology or nanooncology) OR KEY (nanonutrition or nano-nutrition)))) AND (LIMIT-TO (AFFILCOUNTRY, "India")) AND (EXCLUDE (PUBYEAR, 2021))

ANALYSIS

Publication Growth

In the domain of "Nanomedicine Research" India published a total of 1491 publications in 19 years during 2002-20, an average of 93.19 publications per year. The first paper by India in the subject was published in the year 2002. During the period, India registered a 73.70% annual average growth. Between 2002-12 and 2013-20 India's output in the subject increased by 560.71%. This implies that India registered a high level of research productivity in the second-half of the study period 2013-20. India's citation performance in the domain of "nanomedicine research" was 22.93 citations per paper (CPP) since publication in 2002-20. It was comparatively much higher for research output in 2002-12, an average of 55.37 CPP, but it dropped to 18.02 CPP for research output

Table 1: "Nanomedicine Research in India" - Publications Growth during 2002-20

Publication Year	TP	TC	CPP	ICP	%ICP	FRP
2002	1	2	2.00	1	100.00	0
2006	5	227	45.40	0	0.00	1
2007	9	1430	158.89	2	22.22	2
2008	5	473	94.60	1	20.00	1
2009	25	1656	66.24	7	28.00	3
2010	39	2323	59.56	7	17.95	7
2011	53	2700	50.94	14	26.42	10
2012	59	2041	34.59	20	33.90	9
2013	82	2385	29.09	26	31.71	11
2014	111	3446	31.05	29	26.13	26
2015	144	4369	30.34	46	31.94	30
2016	136	3654	26.87	38	27.94	40
2017	140	2749	19.64	44	31.43	44
2018	187	3806	20.35	63	33.69	69
2019	250	2066	8.26	84	33.60	97
2020	245	857	3.50	101	41.22	42
2002-12	196	10852	55.37	52	26.53	33
2013-20	1295	23332	18.02	431	33.28	359
2002-20	1491	34184	22.93	483	32.39	392

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; ICP=International Collaborative Papers; FRP=Funded Research Papers

Table 2: India's Nanomedicine Research in Collaboration with Most Productive Collaborating Countries during 2002-20

S.No.	Collaborative Country	International Collaborative Papers (ICP)			Share of ICP		
		2002-12	2013-20	2002-20	2002-12	2013-20	2002-20
1	USA	20	147	167	38.46	34.11	34.58
2	Saudi Arabia	1	85	86	1.92	19.72	17.81
3	South Korea	2	43	45	3.85	9.98	9.32
4	Australia	3	37	40	5.77	8.58	8.28
5	Malaysia	0	39	39	0.00	9.05	8.07
6	China	0	32	32	0.00	7.42	6.63
7	Singapore	7	18	25	13.46	4.18	5.18
8	U.K.	2	22	24	3.85	5.10	4.97
9	France	0	20	20	0.00	4.64	4.14
10	Italy	2	13	15	3.85	3.02	3.11
	Total India's ICP output	52	431	483	100.00	100.00	100.00

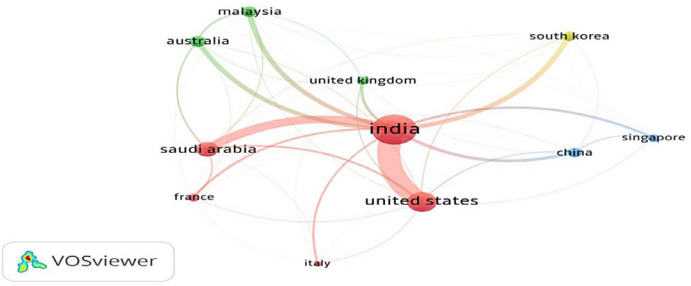

Figure 1: Bibliometric collaborative countries network chart in Nanomedicine Research in India

in 2013-20 (Table 1). Of the total publication output by India, a 45.88% share (684) appeared as articles, 40.91% (610)% as reviews, 7.18% (107) as book chapters, 2.41%(36) as editorials, 1.27% (19) as conference papers, 2.08% as reviews, 1.33% as book chapters, and less than 1.0% each for other publication types.

Sponsored Research

Of the total publication output (1491) by India in "nanomedicine research", 442 publications (29.64%) resulted from research projects funded by 100+ research agencies. These 442 papers from research projects received 12080 citations, averaging to 27.33 CPP since publication in 2002-20. The output from research projects increased from 33 papers in 2009-12 to 359 in 2013-20.

India's International Collaboration

Of the total publication output by India in "nanomedicine research", a 32.39% share (483 papers) appeared as international collaborative papers. The international collaborative papers received an average of 30.77 CPP since publication in 2002-20. India's output through international collaboration with 10 top countries varied from 3.11% to 34.58% as a share of its collaborative output (483). India collaborated the most with the the USA (accounting for a 34.58% share of India's ICP output), followed by Saudi Arabia (17.81%), South Korea (9.32%), Australia (8.28%), Malaysia (8.07%), and China (6.63%). (Table 2, Figure 1).

Subject-Wise Distribution of India's Research Output

As per Scopus database classification, "nanomedicine research" in India intersected with 9 broad disciplines. Of these, Pharmacology, Toxicology & Pharmaceutics have been the most favored area of research pursuit (with a 50.44% share), followed by Biochemistry, Genetics & Molecular Biology, Materials Science, Medicine, Engineering and Chemical Engineering (between 23.54% and 33.87% national publications share respectively). In other three disciplines, national publications share ranged between 3.15% and 15.96% (Table 3).

Research activity index in all of 9 disciplines fluctuated across 100 during the period between 2002-12 and 2013-20. The national average activity index of a discipline is 100. In three disciplines, activity index registered a significant rise, whereas and in six other disciplines it registered a significant decline. In two other areas, the decline in activity index was marginal. Research publications in Immunology & Microbiology recorded the highest citation impact per paper of 29.74 and Medicine the least (19.83) since publication in 2002-20 (Table 3).

Distribution by Sub-Fields of Nanomedicine

Nanomedicine has branched out in several different sub-fields. Of the total output by India in "nanomedicine research", Nano-Oncology (as a sub-field) accounted for the largest publication share (48.49%), followed by Nano-Infection (6.64%), Nano-Neurosciences (6.10%), Nan-Surgery (3.02%), Nano-Nutrition (2.75%), Nano-Cardiology (2.08%), Nano-Dentistry (1.54%), Nano-Opthalmology (1.41%), etc. During the period between 2002-12 and 2013-20, the national publication share in sub-fields such as Nano-Oncology, Nano-Neurosciences, Nano-Otorhinolaryngology, Nano-Cardiology, Nano-Nutrition & Food, Nano-Ortho and Nano-Dentistry registered a marginal increase. Whereas in sub-fields such as Nano-Surgery, Nano-Opthalmology and Nano-Infection it registered a decline during the period. In terms of citation impact per paper, Nano-Nutrition & Food registered the highest impact (36.29 CPP) and Nano-Otorhinolaryngology the least (17.17 CPP) (Table 4).

Significant Keywords in Nanomedicine

Keyword co-occurrence in research publications offers an alternative approach to identify and highlight key research trends in 'nanomedicine research'. A total of 51 keywords have been identified from literature on "Nanomedicine research" in India. The frequency of their occurrence varies from 67 to 1059 times. The keyword "Nanomedicine" showed the highest frequency (1059) of occurrence, followed by Nanoparticles (673), Drug Delivery Systems (616), etc. (Table 5). The keyword network

Table 3: Subject-Wise Breakup of Indian Publications in "Nanomedicine Research" during 2002-20

S.No	Subject*	Number of Papers (TP)			Activity Index		TC	CPP	%TP
		2002-12	2013-18	2002-20	2002-12	2013-200		2002-20	
1	Pharmacology, Toxicology & Pharmaceutics	96	656	752	97.11	100.44	17061	22.69	50.44
2	Biochemistry, Genetics & Molecular Biology	56	449	505	84.36	102.37	13322	26.38	33.87
3	Materials Science	83	334	417	151.41	92.22	12543	30.08	27.97
4	Medicine	66	335	401	125.20	96.19	7950	19.83	26.89
5	Engineering	59	310	369	121.63	96.73	9309	25.23	24.75
6	Chemical Engineering	88	263	351	190.72	86.27	11854	33.77	23.54
7	Chemistry	41	197	238	131.05	95.30	9035	37.96	15.96
8	Physics & Astronomy	29	123	152	145.14	93.17	4503	29.63	10.19
9	Immunology & Microbiology	3	44	47	48.56	107.79	1398	29.74	3.15
	India's Output	196	1295	1491					

There is overlapping of literature covered under various subjects

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper

Table 4: Distribution of India's Publications by Sub-Fields in Nanomedicine Research during 2002-20

S.No	Sub-fields	TP			%TP			TC	CPP
		2002-12	2013-20	2002-20	2002-12	2013-20	2002-20		
1	Nano-Oncology	90	633	723	45.92	48.88	48.49	17487	24.19
2	Nano-Surgery	8	37	45	4.08	2.86	3.02	1228	27.29
3	Nano-Neurosciences	11	80	91	5.61	6.18	6.10	1592	17.49
4	Nano-Otorhinolaryngology	0	12	12	0.00	0.93	0.80	206	17.17
5	Nano-Opthalmology	4	17	21	2.04	1.31	1.41	821	39.10
6	Nano-Cardiology	4	27	31	2.04	2.08	2.08	1070	34.52
7	Nano-Nutrition & Food	5	36	41	2.55	2.78	2.75	1488	36.29
8	Nano-Infection	15	84	99	7.65	6.49	6.64	2460	24.85
9	Nano-Ortho	0	2	2	0.00	0.15	0.13	61	30.50
10	Nano-Dentistry	3	20	23	1.53	1.54	1.54	730	31.74
	India's total output	196	1295	1491	100.00	100.00	100.00		

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper

Table 5: Most Co-occurring Keywords in Indian Literature on Nanomedicine during 2002-20

S.No	Name of the Keyword	Frequency	S.No	Name of the Keyword	Frequency	S.No	Name of the Keyword	Frequency
1	Nanomedicine	1059	18	Biocompatibility	181	35	Targeted Drug Delivery	117
2	Nanoparticles	673	19	Cancer	181	36	Silver Nanoparticles	111
3	Drug Delivery Systems	616	20	Therapy	180	37	Breast Cancer	110
4	Chemistry	396	21	*In-Vitro* Study	178	38	Pathology	105
5	Nanotechnology	385	22	Neoplasms	165	39	Nanostructures	104
6	Theranostics	385	23	Gold Particles	163	40	Chitosan	98
7	Liposome	250	24	Diseases	160	41	Cell Line, Tumor	89
8	Nanomedicine	247	25	Dendrimer	158	42	Controlled Drug Delivery	86
9	Nanocarriers	244	26	Drug Targets	154	43	Nanoemulsion	86
10	Medical Nanotechnology	233	27	Quantum Dots	138	44	Cancer Chemotherapy	83
11	Drug Delivery	216	28	Carbon Nanotubes	136	45	Polyglactin	75
12	Drug Carrier	212	29	Metal Nanoparticles	1398	46	Theranostics	72
13	Drug Formulation	194	30	Anti-neoplasm Activity	131	47	Macrogol	71
14	Doxorubicin	191	31	Paclitaxel	127	48	Magnetic Nanoparticles	71
15	Nanomaterials	189	32	*In Vivo* Study	124	49	Tissue Engineering	69
16	Polymers	196	33	Nanoencapsulation	124	50	Gene Therapy	65
17	Drug Release	183	34	Solid Lipid Nanoparticles	121	51	Cisplatin	67

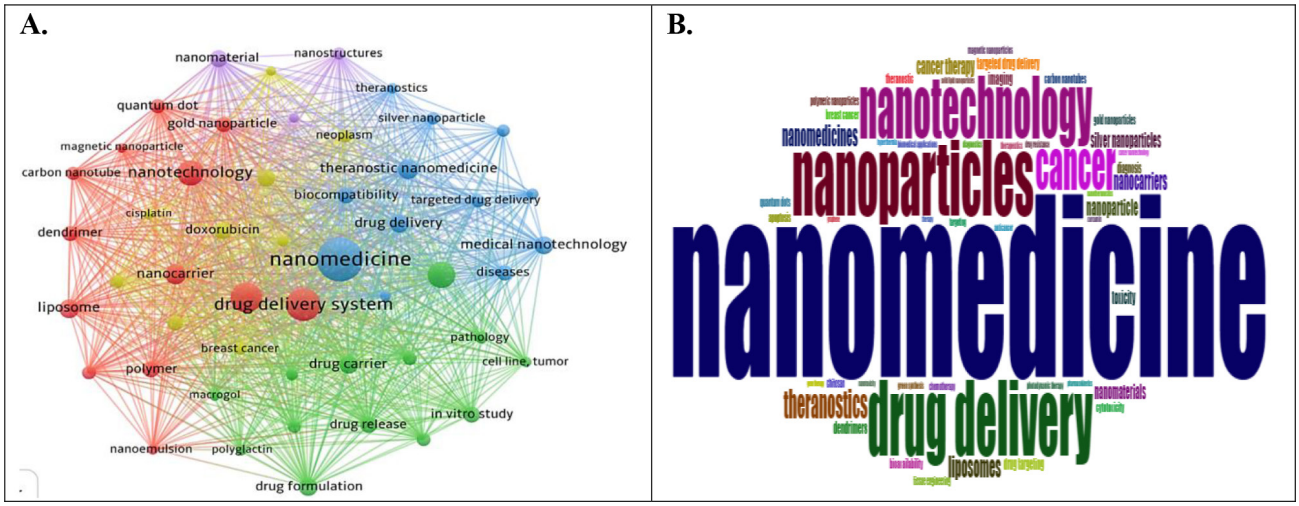

Figure 2: (A) Top 50 Keyword network chart and (B) WordCloud keyword co-occurrence chart

Table 6: Scientometric Profile of Top 25 Most Productive Indian Organizations in Nanomedicine Research during 2002-20

S.No	Name of the Organization	TP	TC	CPP	HI	ICP	%ICP	RCI	TCL
1	Jamia Hamdard University, Delhi	80	1555	19.44	21	46	57.50	0.85	222
2	Panjab University, Chandigarh	55	1057	19.22	17	18	32.73	0.84	145
3	Banaras Hindu University, Varanasi	54	2327	43.09	26	15	27.78	1.88	180
4	Academy of Sciences & Innovative Research, ACSIR, New Delhi	38	671	17.66	15	8	21.05	0.77	77
5	Amrita Institute of Medical Sciences, Coimbatore	36	871	24.19	17	6	16.67	1.06	40
6	Indian Institute of Technology, BHU, Varanasi	34	796	23.41	17	6	17.65	1.02	83
7	All India Institute of Medical Sciences, New Delhi	33	558	16.91	13	12	36.36	0.74	80
8	Amrita Vishwa Vidhyapeetham University, Kochi	32	811	25.34	16	6	18.75	1.11	45
9	Amity University, Noida	31	862	27.81	11	13	41.94	1.21	74
10	University of Delhi	31	1748	56.39	11	13	41.94	2.46	67
11	Lovely Professional University, Jalandhar	30	310	10.33	9	17	56.67	0.45	141
12	Indian Institute of Chemical Technology, Hyderabad	29	676	23.31	14	9	31.03	1.02	
13	Vellore Institute of Technology	26	377	14.50	8	7	26.92	0.63	
14	Birla Institute of Technology & Science, Pilani	24	99	4.13	5	4	16.67	0.18	
15	Institute of Chemical Technology, Mumbai	24	904	37.67	8	3	12.50	1.64	
16	Indian Institute of Technology, Bombay	23	289	12.57	10	1	4.35	0.55	
17	Indian Institute of Technology, Guwahati	22	483	21.95	12	3	13.64	0.96	
18	Indian Institute of Technology, Kharagpur	21	484	23.05	12	7	33.33	1.01	
19	Dr H.S.Gour Vishvidalaya, Sagar	21	546	26.00	13	3	14.29	1.13	
20	Saveetha Dental College & Hospital	21	247	11.76	5	1	4.76	0.51	
21	NIPER-Mohali	20	582	29.10	15	6	30.00	1.27	
22	Aligarh Muslim University	20	450	22.50	10	10	50.00	0.98	
23	Sam Higginbottom University of Agricultural Technology & Sciences	20	306	15.30	8	17	85.00	0.67	
24	Saveetha Institute of Medical & Technical Sciences	19	88	4.63	5	2	10.53	0.20	
25	Central Drug Research Institute, Lucknow	18	394	21.89	13	2	11.11	0.95	
	Total of 25 organizations	762	17491	22.95	12.44	235	30.84	1.00	
	India's total	1491	34184	22.93					
	Share of top 25 organizations in India's output	51.11	51.17						

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; HI=h-index; ICP=International Collaborative Papers; RCI=Relative Citation Index

analysis chart shows a starburst pattern in which some of the keywords such as 'nanomedicine', 'drug delivery system' and 'nanoparticle' appear as the central nodes Figure 2 (A & B). The network charts were generated through VOSviewer and Biblioshiny tools. The 50 keywords appear in 5 different clusters. Cluster 1 & 2 with 13 Keywords each, cluster 3 with 12 keywords, followed by cluster 4 with 9 keywords and cluster 5 with 3 keywords respectively.

India's Most Productive Research Organizations

In all, 306 organizations participated in Indian research on "Nanomedicine Research" during 2002-20, of which 180 organizations published 1-5 papers each, 63 organizations published 6-10 papers each, 43 organizations 11-20 papers each, 17 organizations 21-50 papers each and 3 organizations 54-80 papers each. The productivity of top 25 most productive organizations varied from 18 to 80 publications per organization;

together they contributed 51.11% (762) Indian publications share and 51.17% (17491) Indian citations share during 1992-20. The scientometric profile of the 10 most productive organizations and top 10 most cited organizations are presented in Table 6.

- Ten organizations registered their publications output above their group average (30.48): Jamia Hamdard University, Delhi (80 papers), Panjab University, Chandigarh (55 papers), Banaras Hindu University, Varanasi (54 papers), Academy of Sciences & Innovative Research, ACSIR, New Delhi(38 papers), Amrita Institute of Medical Sciences, Coimbatore (36 papers), Indian Institute of Technology, BHU, Varanasi (34 papers), All India Institute of Medical Sciences, New Delhi (33 papers), Amrita Vishwa Vidhyapeetham University, Kochi (32 papers), Amity University, Noida and University of Delhi (31 papers each);
- Eleven organizations registered their citations per paper and relative citation index above the group average (22.95 and 1.00) of all organizations: University of Delhi (56.39 and 2.46), Banaras Hindu University, Varanasi (43.09 and 1.88), Institute of Chemical Technology, Mumbai (37.67 and 1.64), NIPER-Mohali (29.10 and 1.27), Amity University, Noida (27.81 and 1.21), Dr H.S.Gour Vishvidalaya, Sagar (26.0 and 1.13), Amrita Vishwa Vidhyapeetham University, Kochi (25.34 and 1.11), Amrita Institute of Medical Sciences, Coimbatore (24.19 and 1.06), Indian Institute of Technology, BHU, Varanasi (23.41 and 1.02), Indian Institute of Chemical Technology, Hyderabad (23.31 and 1.02) and Indian Institute of Technology, Kharagpur (23.05 and 1.01).

Research Collaboration among top 25 Research Organizations

Twenty three of the 25 most productive research organizations have had one to many collaborative linkages (Table 7). The top three organizations with most collaborative linkages (43, 30 and 28) are - Jamia Hamdard University, Delhi, Banaras Hindu University, Varanasi and Amrita Institute of Medical Sciences, Coimbatore. The other such organizations with least collaborative linkages (1, 23 and 25) are - Aligarh Muslim University, Indian Institute of Technology, Kharagpur and Dr H.S.Gour Vishvidalaya, Sagar. The research collaboration at organization-to-organization level was the most between Amrita Institute of Medical Sciences, Coimbatore - Amrita Vishwa Vidhyapeetham University, Kochi (28 TCL), followed by collaboration between Banaras Hindu University, Varanasi - Indian Institute of Technology, BHU, Varanasi (24 linkages), Academy of Sciences & Innovative Research, ACSIR, New Delhi - Indian Institute of Chemical Technology, Hyderabad (21 linkages), etc. Universities from India such as Jamia Hamdard

Table 7: Collaborative Linkages among top 25 Indian organizations

S.No	Name of the Organization	Number of collaborative linkages with other organizations	TCL(NOO)
1	Jamia Hamdard University, Delhi	2(7), 9(2), 7(3), 9(2), 10(2), 11(3), 14(1), 21(2), 23(12), 25(2)	**43(10)**
2	Panjab University, Chandigarh	1(7), 3(1), 9(2), 10(2), 11(4), 14(2), 21(3), 23(6)	**27(8)**
3	Banaras Hindu University, Varanasi	2(1), **6(24)**, 7(2), 9(1), 10(1), 25(1)	**30(6)**
4	Academy of Sciences & Innovative Research, ACSIR, New Delhi	8(1), **12(21),** 17(1), 18(1)	**24(4)**
5	Amrita Institute of Medical Sciences, Coimbatore	8(28)	**28(1)**
6	Indian Institute of Technology, BHU, Varanasi	3(24)	**24(1)**
7	All India Institute of Medical Sciences, New Delhi	1(3), 3(2), 22(1), 25(1)	**7(4)**
8	Amrita Vishwa Vidhyapeetham University, Kochi	5(28)	**1(28)**
9	Amity University, Noida	1(2), 2(2), 10(1), 11(1), 17(1), 19(1), 25(2)	**10(7)**
10	University of Delhi	1(2), 2(2), 3(1), 9(1)	**6(4)**
11	Lovely Professional University, Jalandhar	1(3), 2(4), 13(1), 19(1), 20(1), 24(1)	**11(6)**
12	Indian Institute of Chemical Technology, Hyderabad	**4(21)**, 17(1), 18(1)	**23(3)**
13	Vellore Institute of Technology	11(1), 18(1), 20(3), 24(2)	**7(4)**
14	Birla Institute of Technology & Science, Pilani	1(1), 2(2), 17(1)	**4(3)**
15	Institute of Chemical Technology, Mumbai	Nil	**Nil**
16	Indian Institute of Technology, Bombay	Nil	**Nil**
17	Indian Institute of Technology, Guwahati	4(1), 9(1), 12(1), 14(1), 18(1)	**5(5)**
18	Indian Institute of Technology, Kharagpur	4(1), 13(1), 17(1)	**3(3)**
19	Dr H.S.Gour Vishvidalaya, Sagar	9(1), 11(1), 25(1)	**3(3)**
20	Saveetha Dental College & Hospital	11(1), 13(3), **24(18)**	**22(3)**
21	NIPER-Mohali	2(3), 25(1)	**4(2)**
22	Aligarh Muslim University	7(1)	**1(1)**
23	Sam Higginbottom University of Agricultural Technology & Sciences	1(12), 2(6)	**18(2)**
24	Saveetha Institute of Medical & Technical Sciences	11(1), 13(2), 20(18)	**21(3)**
25	Central Drug Research Institute, Lucknow	1(2), 3(1), 7(1), 9(2), 19(1), 21(1)	**7(5)**

TCL - Total collaborative linkages NOA - Number of collaborating organizations

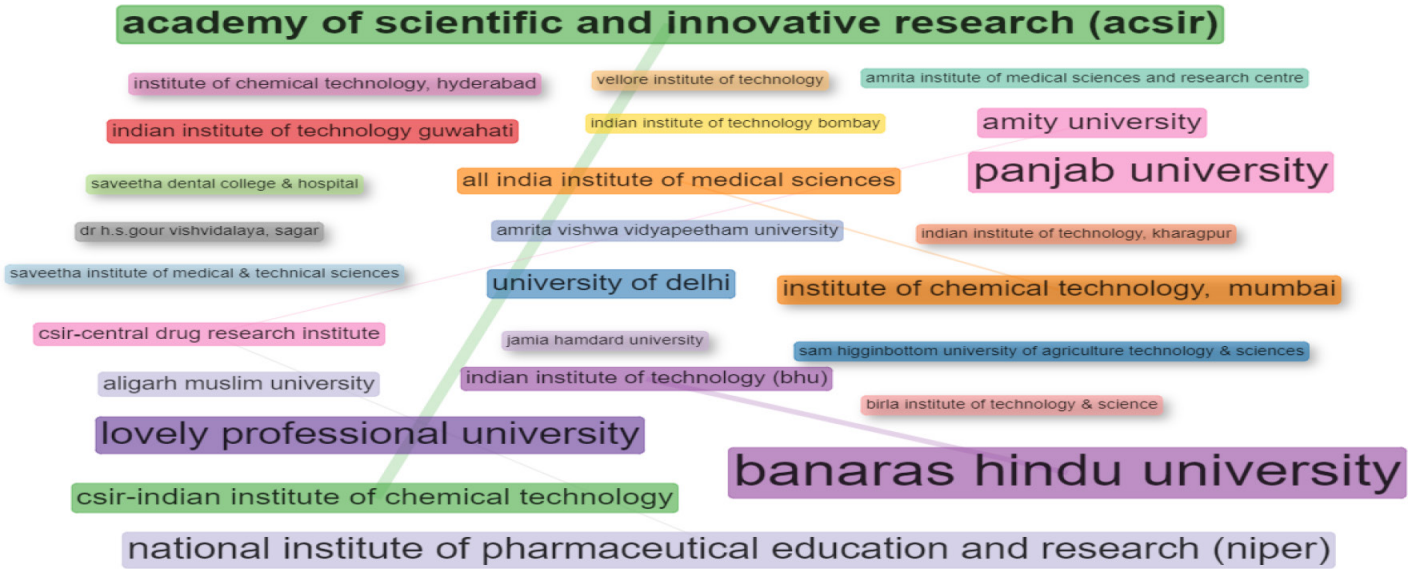

Figure 3: Bibliometric network of collaborative institutions in Nanomedicine Research

University, Panjab University and Banaras Hindu University were found to be the most productive institutions in collaborative research (Figure 3).

India's Most Productive Authors in Nanomedicine Research

A total of 517 authors participated in "Nanomedicine Research" in India during 2002-20. The distribution research by participating authors is highly skewed. Of these, 421 authors published 1-5 papers each, 68 authors 6-10 papers each, 23 authors 11-20 papers each and 5 authors 21-37 papers each. The research productivity of top 25 most productive authors varied from 10 to 37 publications per author. Together these 25 authors contributed a 27.97% (417) global publications share and a 39.11% (13369) global citations share during 2002-20. Their detailed scientometric profile is presented in Table 8.

- Seven of top 25 authors registered their publications output above the group average of 16.6: M.S. Mathu (37 papers), S. Beg (34 papers), F.J. Ahmad and M. Rahman (27 papers each), C.R. Patra (23 papers each), S. Akhter (20 papers) and S. Mukherjee (17 papers);
- Nine of top 25 authors registered their citation per paper and relative citation index above the group average (32.06 and 1.40) of all authors: S.K. Sahoo (178.45 and 7.78), M.S. Mathu (48.65 and 2.12), S. Singh (42.14 and 1.84), M.Z. Ahmad (38.27 and 1.67), R. Jayakumar (37.23 and 1.62), A.K. Barui (35.70 and 1.56), N.K. Jain (35.67 and 1.56), S. Akhter (34.6 and 1.51) and S,V. Nair (32.46 and 1.42).

Research Collaboration among top 25 authors

Of the 25 most productive authors in nanomedicine research, twenty have had one to many collaborative linkages (Table 9). The top three authors with most collaborative linkages (50, 46 and 44) are M. Rahman, S. Beg and F.J. Ahmad - and each had research collaboration with a maximum of 4-5 other authors. The authors with least collaborative linkages (1, 3 and 4) are R.K. Takade, N.K. Jain and V. Mishra - and each had research collaboration with a maximum of 1-2 other authors. The top authors also had one-one to collaboration in nanomedicine research. For instance, S. Beg - M. Rahman had registered the most collaborative linkages (19), followed by M.S. Mathu - S. Singh (13 linkages), M. Koyakutty - S.V. Nair (13 linkages), S. Akhter - M. Rahman (12 linkages, F.J. Ahmad - M.Z. Ahmad (12 linkages), F.J. Ahmad - M. Rahman (11 linkages), etc. The collaboration network chart (Figure 4) reveals that the top 25 authors are grouped into 11 clusters. The cluster 1 & 2 has four authors each - (Ahmad F.J., Ahmad M.Z., Akhter S. and Rahman M.) and (Jayakumar R., Koyakutty M., Menon D. and Nair S.V). The clusters 3 to 6 has three authors each and clusters 7 to 11 has one author each.

Medium of Research Communication

Of the total output in nanomedicine research in India, a 91.08% share (1358) appeared in research journals, followed by a 6.51% share (97) in books, 1.48% (22) in book series, 0.87% (!3) in conference proceedings and 0.07% (1) in trade journal. India's research output as articles in the subject is scattered across 294 national and international journals. Of these 294 journals (which reported 1358 articles), 246 published 1-5 papers each, 19 published 6-10 papers each, 18 published 11-20 papers each, 10 published 21-50 papers each and 1 published 69 papers during 2002-20. This implies that most productive research journals are not very many in number.

In the journal ranking by research productivity in nanomedicine research in India, it was seen that the top 24 most productive journals accounted for a 43.96% share during 2002-20. Nanomedicine is the top ranking productive journal (with 96 papers in nanomedicine), followed by International Journal of Nanomedicine (47 papers), Current Pharmaceutical Design (46 papers), Journal of Nanoparticle Research (44 papers), Colloid & Surfaces B.Biointerfaces (34 papers), Journal of Controlled Release and Journal of Drug Delivery Science & Technology (26 papers each), Journal of Biomedical Nanotechnology (23 papers), Delivery Today (22 papers), etc. In terms of research performance, International Journal of Pharmaceutics registered the highest citation per paper (53.0), followed by International Journal of Nanomedicine (47.38), Drug Delivery Today (47.23), Colloid & Surfaces B.Biointerfaces (43.15), Journal of Biomedical Nanotechnology (#6.09), Drug Delivery (35.58), Expert Opinion on Drug Delivery (34.27), Journal of Controlled Release (31.0), Nanomedicine (30.98), International Journal of Biomedical Macromolecules (29.86) and Current Drug Delivery (25.77) (Table 10).

Bibliometric network chart of top 25 productive journals (Figure 5) depicts that journals are grouped into 4 clusters. The cluster 1 holds eight journals, cluster 2 & 3 has six journals each and cluster 4 holds five journals. Such journals that cover closely related topics are placed closer

Table 8: Scientometric Profile of Top 25 Most Productive Indian Authors in Nanomedicine Research during 2002-20

S.No	Name of the Author	Affiliation of the Author	TP	TC	CPP	HI	ICP	%ICP	RCI
1	M.S. Mathu	IMS-BHU, Varanasi	37	1800	48.65	24	12	32.43	2.12
2	S. Beg	Jamia Hamdard University, Delhi	34	740	21.76	14	20	58.82	0.95
3	F.J. Ahmad	Jamia Hamdard University, Delhi	27	680	25.19	15	18	66.67	1.10
4	M. Rahman	Jamia Hamdard University, Delhi	27	494	18.30	13	22	81.48	0.80
5	C.R. Patra	Indian Institute of Chemical Technology, Hyderabad	23	604	26.26	12	7	30.43	1.15
6	S. Akhter	Jamia Hamdard University, Delhi	20	692	34.60	15	19	95.00	1.51
7	S. Mukherjee	Academy of Science & Innovation Research AcSIR	17	504	29.65	12	10	58.82	1.29
8	B. Singh	Panjab University, Chandigarh	16	274	17.13	10	2	12.50	0.75
9	M.Z. Ahmad	Jamia Hamdard University, Delhi	15	574	38.27	12	14	93.33	1.67
10	R. Srivastava	Indian Institute of Technology, Bombay	15	204	13.60	9	1	6.67	0.59
11	R.K. Takade	NIPER, Ahmedabad	15	421	28.07	8	9	60.00	1.22
12	O.P. Katare	Panjab University, Chandigarh	14	215	15.36	7	3	21.43	0.67
13	M. Koyakutty	Amrita Institute of Medical Sciences, Coimbatore	14	262	18.71	9	1	7.14	0.82
14	S. Singh	Indian Institute of Technology, BHU	14	590	42.14	130	1	7.14	1.84
15	R. Jayakumar	Amrita Vidhyapeetham University, Kochi	13	484	37.23	11	3	23.08	1.62
16	P.K. Mishra	Tata Memorial Hospital, Mumbai	14	181	12.93	8	1	7.14	0.56
17	S,V. Nair	Amrita Institute of Medical Sciences	13	422	32.46	11	5	38.46	1.42
18	N.K. Jain	Dr H.S.Gour Vishwavidalaya, Sagar	12	428	35.67	12	4	33.33	1.56
19	V. Mishra	Lovely Professional University	12	268	22.33	8	8	66.67	0.97
20	S.P. Vyas	Dr H.S.Gour Vishwavidalaya, Sagar	12	348	29.00	8	1	8.33	1.26
21	D. Menon	Amrita Institute of Medical Sciences	11	334	30.36	9	3	27.27	1.32
22	S. Rajeshkumar	Saveetha Dental College & Hospital	11	234	21.27	5	1	9.09	0.93
23	S.K. Sahoo	Institute of Life Sciences, Bhubaneswar	11	1963	178.45	9	1	9.09	7.78
24	A.K. Barui	Indian Institute of Chemical Technology, Hyderabad	10	357	35.70	7	5	50.00	1.56
25	B. Koch	Banaras Hindu University	10	296	29.60	8	1	10.00	1.29
	Total		417	13369	32.06	15.44	172	41.25	1.40
	Total of India		1491	34184	22.93				
	Share of 25 Authors in Indian Output		27.97	39.11					

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; HI=h-index; ICP=International Collaborative Papers; RCI=Relative Citation Index

to one another, and those that cover fundamentally different topics are located far from each other. The visualization chart was generated through VOSviewer tool.

Highly - Cited Papers

Of the total output by India in "Nanomedicine Research" (1491 publications), a .53% share (comprising 58 papers and assumed as highly cited papers) received 100 to 942 citations per paper since their publication in 2002-20, averaging to 175.95 citations per paper (cumulative total 12772 citations). The distribution of these 58 highly cited papers is skewed. Thirty eight papers accumulated high-end citations in the range 100-192 per paper, 13 were in the citation range of 201-385 CPP and 7 in the citation range 482-730 CPP.

- Of the 58 highly cited papers, 23 were non-collaborative papers (each contributed by a stand-alone single organization) and 37 were collaborative papers (each contributed by two or more organizations per paper, 8 as national collaborative and 27 as international collaborative papers).
- Among highly cited papers, USA collaborated in most papers (10 papers), followed by Italy (6 papers), South Korea (5 papers), Singapore (4 papers), Germany, Greece, Slovenia and U.K. (3 papers), Brazil, China, Ireland, Spain, Hungary, Portugal, Sweden, Belgium, Turkey, France, Serbia, Switzerland, Israel, Norway, Austria and Finland (2 papers each), Tunisia, Saudi Arabia, Ukraine, Australia, Panama and Czech Republic (1 paper each).
- These 58 highly cited papers were contributed by 342 authors from 58 organizations.
- The leading organizations participating in highly-cited papers were: Institute of Medical Sciences, BHU (6 papers), Institute of Life Sciences, Bhubaneswar and Institute of Chemical Technology, Bombay (4 papers each), University of Delhi (3 papers), , Jamia Millia Islamia, Delhi, Panjab University, Chandigarh, Sant Baba Amravati University, Amravati, Jamia Hamdard, Delhi, DR H.S.Gaur University, Sagar, National Chemical Laboratory, Pune, JIPMER, Pondicherry, and Translational Health Science & Technology Institute, Faridabad (2 papers each) and 43 other institutions with 1 paper each.
- The leading authors participating in highly cited papers were: M.S. Muthu (IMS-BHU) (4 papers) and S.K. Sahoo (ILS-Bhubaneswar) (4 papers),

Table 9: **Collaborative Linkages among Top 25 authors**

S.No	Name of the Author	Number of collaborative linkages with other authors	TCL(NOA)
1	M.S. Mathu	14(13), 25(9)	22(2)
2	S. Beg	3(9), 4(19), 6(6), 8(8), 12(4)	46(5)
3	F.J. Ahmad	2(9), 4(11), 6(12), 9(12)	44(4)
4	M. Rahman	2(19), 3(11), 4(8), 6(12)	50(4)
5	C.R. Patra	7(11), 24(10)	21(2)
6	S. Akhter	2(6), 3(12), 4(12), 9(13)	43(4)
7	S. Mukherjee	5(11), 24(4)	15(2)
8	B. Singh	2(9), 3(1), 12(8)	18(3)
9	M.Z. Ahmad	3(12), 4(8), 6(13)	33(3)
10	R. Srivastava	Nil	Nil
11	R.K. Takade	19(1)	1(1)
12	O.P. Katare	4(1), 6(1), 7(4), 8(8)	14(4)
13	M. Koyakutty	17(4), 21(4)	8(2)
14	S. Singh	1(13), 25(6)	19(2)
15	R. Jayakumar	17(3), 21(2)	5(2)
16	P.K. Mishra	Nil	Nil
17	S,V. Nair	13(13), 15(3), 21(6)	22(3)
18	N.K. Jain	19(3)	3(1)
19	V. Mishra	11(1), 18(3)	4(2)
20	S.P. Vyas	Nil	Nil
21	D. Menon	13(4), 15(2), 17(4)	10(3)
22	S. Rajeshkumar	Nil	Nil
23	S.K. Sahoo	Nil	Nil
24	A.K. Barui	5(10), 7(4)	14(2)
25	B. Koch	1(9), 14(6)	15(2)

TCL - Total collaborative linkages NOA - Number of collaborating authors

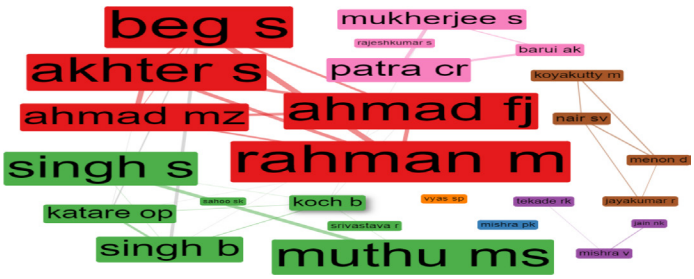

Figure 4: Collaboration network chart showing top authors in Nanomedicine Research in India

- Of the 58 highly cited papers, 21 were published as articles, 36 as review papers and 1 as short survey.
- These 58 highly cited papers appeared across 35 journals. International Journal of Nanomedicine published 6 papers, followed by 4 papers in Colloid & Surfaces B, 3 papers each in Nanomedicine, International Journal of Pharmaceutics and Biomaterials, 2 papers each in Advanced Drug Delivery Review, Drug Discovery Today, Theranostics, Proceedings of NAS of USA, ACS Nano,, Chemical Society Reviews, Journal of Controlled Release and Journal of Biomedical Nanotechnology, and 21 other journals with 1 paper each.

CONCLUSION

This paper provides a quantitative and qualitative description of India's research output in the domain of "Nanomedicine Research" based on 19-year research published during 2002-20 using bibliometric methods. The study has sought to highlight its institutional and individual researcher level performance in research. India published a 32% of its national output as a share of international collaborative papers, collaborating most with the USA (with a 34.58% share of total international collaborative papers), followed by Saudi Arabia (17.81%), South Korea (9.32%), Australia (8.28%), Malaysia (8.07%), China (6.63%), etc.

In terms of quantitative performance in nanomedicine research, India' productivity figures has been low and insignificant during the period under study. Over the last 19 years, the country published a total of 1491 papers, an average of just 4.87 papers per organization, just 2.88 papers per author, and barely 78.47 papers per year. These productivity figures indeed look very very small and insignificant, despite the fact that India had registered a high 73.7% annual average growth, contributed a good 29% share of its output through sponsored research projects. India attracted a high-end institutional and individual level participation in

Table 10: Most Productive Journals in Neuromedicine Research in India during 2002-20

S.No	Name of the Journal	Number of Papers			TC	CPP
		2002-12	2003-20	2002-20		
1	Nanomedicine	23	73	96	2974	30.98
2	International Journal of Nanomedicine	12	35	47	2227	47.38
3	Current Pharmaceutical Design	2	44	46	475	10.33
4	Journal of Nanoparticle Research	17	27	44	1127	25.61
5	Colloid & Surfaces B.Biointerfaces	5	29	34	1467	43.15
6	Journal of Controlled Release	1	25	26	806	31.00
7	Journal of Drug Delivery Science & Technology	0	26	26	171	6.58
8	Journal of Biomedical Nanotechnology	13	10	23	830	36.09
9	Drug Delivery Today	1	21	22	1039	47.23
10	International Journal of Biomedical Macromolecules	1	20	21	627	29.86
11	Critical Reviews in Therapeutic Drug Carrier System	1	19	20	306	15.30
12	ACS Biomaterials Science & Engineering	0	19	19	267	14.05
13	Expert Opinion on Drug Delivery	4	15	19	653	34.37
14	International Journal of Pharmaceutics	2	16	18	954	53.00
15	Current Drug Metabolism	0	17	17	127	7.47
16	Materials Science & Engineering C	0	17	17	421	24.76
17	Drug Delivery Translational Research	1	13	14	119	8.50
18	Therapeutic Delivery	2	12	14	108	7.71
19	Current Drug Delivery	0	13	13	335	25.77
20	Recent Patents on Drug Delivery & Formulations	2	11	13	66	5.08
21	Research Journal of Pharmacy & Technology	1	12	13	47	3.62
22	ACS Applied Materials & Interfaces	0	12	12	270	22.50
23	Drug Delivery	0	12	12	427	35.58
24	Artificial Cells Nanomedicine & Biotechnology	0	11	11	235	21.36
	Total of 24 journals	88	509	597	16078	26.93
	Total Indian	179	1179	1358		
		49.16	43.17	43.96		

TC - Total Citations, CPP - Citations per paper

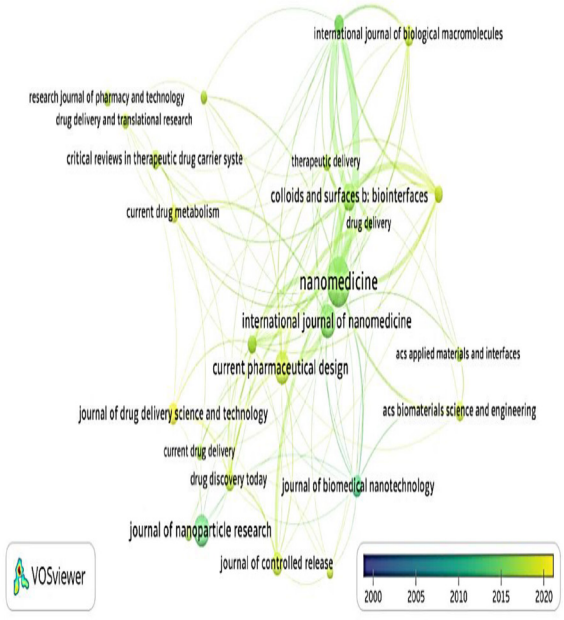

Figure 5: Bibliometric network chart of most productive Journals in Nanomedicine Research

'nanomedicine' research by as many as 517 authors from a total of 309 organizations from across the country during the period.

In terms of citation performance, India registered merely a 1.53% share of its output as highly cited papers, with each highly cited paper receiving at least 100+ citations per paper since publication. Compared to its national average of 22.93 citations per paper, India's sponsored research papers received citations at a higher average rate of 27.33 CPP, and its international collaborative papers received citations at a still higher rate of 30.77 citations per paper, both types registered citations rates above the national average. In overall, India's performance in qualitative research has been marginal.

The top 10 centers of excellence in the domain of nanomedicine research in India are mainly from the higher education sector, and none from the R&D sector. These centres include include Jamia Hamdard University, Panjab University, Banaras Hindu University, Academy of Sciences & Innovative Research, ACSIR, Amrita Institute of Medical Sciences, Indian Institute of Technology, All India Institute of Medical Sciences, Amrita Vishwa Vidhyapeetham University, Amity University, and University of Delhi.

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