Original Research Article

Nano-enabled drug delivery research: A scientometric assessment of Indian publications during 1995–2018

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Abstract

Aim: The present study is aimed on to perform Scientometric assessment of global publications output of research on nano-enabled drug delivery (NEDD) during 1995–2018.

Materials and Methods: A quantitative and qualitative description of NEDD research in India is presented here based on measures such as growth rate, global publications share, share of international collaborative papers, citations per paper, and highly cited papers. It was examined India's research output on NEDD on a series of bibliometric indicators.

Results: India published a total of 5897 publications in 24 years during 1995–2018, registering an average annual growth rate of 42.99%, citation impact of 22.90 citations per paper, global publication share of 11.11%, and international collaborative publication share of 20.35%. Profiles global publication output and share of top 10 most productive countries in NEDD research, 20 most productive Indian organizations and 20 most productive Indian authors on a series of indicators including publications output, number of citations, the relative citation index, citations per paper, h-index, and share of international collaborative papers during 1995–2018.

Conclusion: This study describes the scattering of research output of India across source journals and distribution of research by subject areas that intersect with NEDD research. It suggests the need for India to develop specific plans of action and ensure its implementation at the national level and also prioritize national goals for NEDD research.

Keywords: Bibliometrics, Indian publications, nano-enabled drug delivery, Scientometrics

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INTRODUCTION

Drug delivery research has grown rapidly over the past two decades and has enabled drug development by designing suitable delivery systems that improve efficacy, lower dosing frequency, and encourage patient convenience and compliance.[1] Drug delivery is an important issue, especially with a new generation of therapeutics, which are either unstable in the biological environment, have poor transport properties across biological membranes, are insoluble in water, or have very low bioavailability. Within the last 10 years, nano-enabled drug delivery (NEDD) has drawn the attention of research and industry areas, as a key nanotechnology. Nanoparticulate drug-delivery vehicles have been developed using various nanomaterials and components. Such systems have the ability to encapsulate and carry the payload (therapeutics) and penetrate through biological membranes to deliver that payload to

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specific target disease sites. The outstanding advantage of NEDD is that the applicable nanoparticles can keep the pharmaceutical well protected from degradation and prolong the exposure of the pharmaceutical through controlled release. Thus, NEDD provides a novel approach to medical therapy, including treatment of chronic diseases and genetic disorders.[2]

In the last decade, several drug-delivery technologies have emerged for the development of nanoscale drug delivery devices. The enormous growth of nanotechnology paved ways for the development of advanced drug delivery systems having ultraprecision and control over the release of drugs. Different strategies are adopted to ensure targeted and controlled drug delivery, such as encapsulation, biomarkers, and artificial nanocarriers. Extensive types of nanocarriers (such as nanoparticles, nanowires, nanocages, nanoshells, and nanodiamonds) composed of an assortment of different sizes, shapes, and materials and with various chemical and surface properties, have already been constructed. These nanocarriers normally consist of biological materials or chemically synthesized materials or combination of both, such as dendrimers, protein, lipid, chitosan, lactic acid, polymers, magnetic, fullerenes, quantum dots, carbon, and silica are being developed for various drug-delivery applications.[3]

Literature review

Only a few scientometric studies are available on drug delivery technology, particularly the NEDD. Robert *et al.*[4] studied the growth of the drug delivery literature published during 1974–2015 from the journals indexed in the Science Citation Index Expanded Database. The growth of publications on drug delivery paralleled the total scientific publications for three decades (1974–2003); however, from 2004 to 2015, it exploded fourfold, while the total increased only 1.75-fold. Industrialized countries (the USA, UK, Germany, Japan, Italy, France, and Canada) were the most prolific during the first decades, but in 2014–2015, China, India, and South Korea ranked 1st, 3rd, and 4th, respectively, among the productive countries. The number of participating countries increased fivefold (from 19 to 96). During the last 15 years, the journals targeted by drug delivery research increased nearly 2.4-fold (416–1001) and three journals (Journal of Controlled Release, Advanced Drug Delivery Reviews and International Journal of Pharmaceutics) published nearly one-fifth of the drug delivery research in 2014–2015.

Zhou *et al.*[5] described the process of how to derive NEDD-related information from global research and patent databases in an effort to perform a comprehensive global analysis of research trends and directions, along with collaborative patterns. Yen-Chun *et al.*[6] studied the scientific literature of nanoparticle drug delivery technologies between 2005 and 2014 was reviewed. The visualized cocitation network of its knowledge domain was characterized in terms of thematic concentrations of cocited references and emerging trends of surging keywords and citations to references through a scientometric review. The combined dataset of 25,171 bibliographic records was constructed through topic search and citation expansion to ensure adequate coverage of the field. This study not only facilitated the connection of authors and research themes in the NEDD community, but also demonstrated how research interests and trends evolve over time, which greatly contributes to our understanding of the NEDD knowledge domains. Huang *et al.*[2] used bibliometric and social network analyses, at country, institution, and individual levels, to explore the patterns of scientific networking for a key nanoarea – NEDD. The data for this research come from a global compilation of research publication information on NEDD directed at brain cancer. The authors derive a set of indicators that address multiple facets of research collaboration and knowledge transfer patterns. The study results show that: (i) international cooperation is increasing, but networking characteristics change over time; (ii) highly productive institutions also lead in influence, as measured by citation to their work, with American institutes leading; and (iii) research collaboration is dominated by local relationships, with interesting information available from authorship patterns that go well beyond journal impact factors.

MATERIALS AND METHODS

Objectives

NEDD systems are rapidly emerging as a key area for nanotechnology application. Understanding the status and developmental prospects of this area around the world and India, in particular, is important to determine research priorities and to evaluate and direct progress. Global research publication and patent databases provide a reservoir of information that can be tapped to provide intelligence for such needs. The present study is aimed at making a scientometric assessment of India's publications in NEDD systems, indexed in the Scopus database during 1995–2018. The specific objectives are to study:

- The growth and distribution of world and top 10 countries publications
- Indian literature on NEDD research, with particular reference to its publication output, its global publication share, and citation impact

- International collaboration and identification of major collaborators with India
- The distribution of India's publication output by broad subject areas and the identification of significant keywords
- The scientometric profile of 10 most productive countries, 20 most productive Indian organizations, and 20 most productive Indian authors
- The leading medium of communication in India and the bibliographic characteristics of highly cited publications by India on NEDD research.

Methodology

The global publications and of world and of top 10 countries in NEDD research were sourced from the Scopus international database (http://www.scopus.com) using a keywords, "drug delivery" and "Nano*" for the years 1995–2018. The "Article title" or "Keyword" (As shown in the search string below) tags were searched for the keyword restricting the hit to the period 1995–2018 in "date range tag." This statement became the main search string. The main search string was further restricted to 10 countries one by one in "country tag" for obtaining publication information of these countries (as shown below for India). On further restricting India's main search string (as provided in analytical functions of Scopus database) by "subject area tag," "country tag," "source title tag," "journal title name" and "affiliation tag," statistics on distribution of publications by subject, collaborating countries, author-wise, organization-wise, and journal-wise were citation data was obtained from the date of publication till December 22, 2018.

- KEY ("drug delivery" and "Nano*") OR TITLE ("drug delivery" and "Nano*") AND PUBYEAR > 1994 AND PUBYEAR < 2019
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Analysis

NEDD research output consisting of 53,079 global and 5897 Indian publications were derived from Scopus database and studied during 24 years (1995–2018). The annual and cumulative publication output of world and India increased from 48 and 1 in the year 1995 to 95 publications in the year 2018, averaging 25.67% and 42.99% annual growth rate, respectively. The global and Indian cumulative output (computed in 12 years) in NEDD research increased from 3343 and 151 (during 1995–2006) to 49,736 and 5746 (during 2007–2018), registering 1387.77% and 3705.30% growth rates, respectively. India's global share in NEDD research averaged to 11.11% during 1995–2018, which increased from 4.52% during 1995–2006 to 11.55% during 2007–2018. The citation impact of Indian publications on in NEDD research averaged to 22.90 citations per publication (CPP) during 1995–2018, which declined from 150.66 CPP during 1995–2006 to 19.54 CPP during 2007–2018 [Table 1]. Of the total Indian publications output, 66.32% (3911) was published as articles, 24.42% (1440) as reviews, 4.49% (265) as book chapters, 2.63% (155) as conference papers, 0.58% (34) as editorials, 0.56% (33) as articles in press and the rest as short surveys (19 and 0.32%), books and letters (14 and 0.24% each), notes (6 and 0.10%), erratum (4 and 0.07%), and retracted (2 and 0.03%) during 1995–2018.

International collaboration

About 20.35% (1200) of the total research output by India in NEDD research was published as international collaborative papers during 1995–2018. India's collaborative output increased from 14.57% during 1995–2006 to 20.50% during 2007–2018. The 1200 international collaborative papers by India together received 34013 citations, averaging to 28.34 citations per paper. The leading foreign countries that collaborated with India in NEDD research were: the USA (33.75% publication share), followed by Saudi

Table 1: Annual publications output by world and India on nano-enabled drug delivery research during 1995-2018

Period	World TP	India				
		TP	TC	CPP	Percentage TP	ICP (%)
1995	48	1	21	21	2.08	
1996	56	3	103	34.33	5.36	
1997	74	3	28	9.33	4.05	
1998	72	4	50	12.50	5.56	
1999	106	2	48	24.00	1.89	
2000	97	4	2853	713.25	4.12	
2001	140	4	2882	720.50	2.86	1 (25.00)
2002	211	5	316	63.20	2.37	0 (0.00)
2003	284	10	1461	146.10	3.52	1 (10.00)
2004	505	27	6467	239.52	5.35	6 (22.22)
2005	753	35	3526	100.74	4.65	7 (20.00)
2006	997	53	4994	94.23	5.32	7 (13.21)
2007	1286	82	7536	91.90	6.38	12 (14.63)
2008	1772	121	8296	68.56	6.83	18 (14.88)
2009	2217	183	9422	51.49	8.25	35 (19.13)
2010	2863	298	17,239	57.85	10.41	53 (17.79)
2011	3262	428	12,057	28.17	13.12	70 (16.36)
2012	3995	455	13,116	28.83	11.39	68 (14.95)
2013	4579	567	12,052	21.26	12.38	98 (17.28)
2014	5017	591	12,458	21.08	11.78	106 (17.94)
2015	5453	662	8644	13.06	12.14	143 (21.60)
2016	5943	797	7243	9.09	13.41	172 (21.58)
2017	6340	754	3255	4.32	11.89	189 (25.07)
2018	7009	808	976	1.21	11.53	214 (26.49)
1995-2006	3343	151	22,749	150.66	4.52	22 (14.57)
2007-2018	49,736	5746	112,294	19.54	11.55	1178 (20.50)
1995-2018	53,079	5897	135,043	22.90	11.11	1200 (20.35)

TP: Total paper, TC: Total citation, CPP: Citations per paper, ICP: International collaborative paper

Arabia (13.42%), Malaysia and South Korea (7.58% each), Australia (6.33%), Japan, Canada, Germany, the UK, and South Africa (from 3.33% to 4.67%) during 1995–2018. India's international collaborative publications (ICP) share showed increase in Saudi Arabia, Malaysia, South Korea, the UK, South Africa, and Australia (from 1.82% to 13.67%), as against decrease in the USA, Canada, Germany, and Japan (from 4.51% to 21.18%) from 1995–2006 to 2007–2018 [Table 2].

Top productive countries contribution in global nano-enabled drug delivery research

The global NEDD research witnessed the participation of 134 countries during 1995–2018, of which 80 countries contributed 1–50 papers each, 7 countries 51–100 papers each, 24 countries 101–500 papers each, 9 countries 501–1000 papers each, 12 countries 1001–5000 papers each, and 2 countries 12,092–13,244 papers each. However, the top 10 countries together alone accounted for 85.04% global publication share during 1995–2018, which showed increase from 82.08% during 1995–2006 to 85.24% during 2007–2018. Individually, the top 10 countries publications ranged from 1839 to 13244 and accounted for 3.46%–24.95% of global publication share during 1995–2018. The USA, among top countries, accounted for the largest publication share (24.95%), followed by China (22.78%), India (11.11%), Germany, the UK, South Korea, and Italy (from 4.00% to 4.58%) and Iran, Japan, and France (from 3.46% to 3.86%) during 1995–2018. Four countries which showed increase in their global publication share (from 0.08% to 115.28%) in 12 years were: China, India, Iran, and Italy, as against six countries, namely, the USA, France, Germany, Japan. The UK and South Korea showing decrease in their global publication share (from 1.27% to 6.80%) from 1995–2006 to 2007–2018 [Table 3].

Subject-wise distribution of Indian research on nano-enabled drug delivery research

NEDD research output from India published during 1995–2018 was classified under seven broad subjects (as defined by Scopus database) during 1995–2018. Pharmacology, toxicology, and pharmaceutics accounted for the largest publication share (53.72%), followed by biochemistry, genetics and molecular biology (27.51%), materials science (25.57%), engineering (22.01%), chemical engineering (20.89%), medicine (19.50%),

Table 2: Publication share of leading foreign countries in India's collaborative papers output in nano-enabled drug delivery research during 1995-2018

Serial number	Collaborative country	Number of ICP			Share of ICP		
		1995-2006	2007-2018	1995-2018	1995-2006	2007-2018	1995-2018
1	USA	12	393	405	54.55	33.36	33.75
2	Saudi Arabia	0	161	161	0.00	13.67	13.42
3	Malaysia	0	91	91	0.00	7.72	7.58
4	South Korea	0	91	91	0.00	7.72	7.58
5	Australia	1	75	76	4.55	6.37	6.33
6	Japan	2	54	56	9.09	4.58	4.67
7	Canada	4	50	54	18.18	4.24	4.50
8	Germany	2	48	50	9.09	4.07	4.17
9	UK	0	48	48	0.00	4.07	4.00
10	South Africa	0	40	40	0.00	3.40	3.33
Indian total		22	1178	1200			

ICP: International collaborative paper

Table 3: Publication output and global publication share (percentage) of top 10 most productive countries in nano-enabled drug delivery research during 1995-2018

Serial number	Name of the country	Number of papers			Share of papers		
		1995-2006	2007-2018	1995-2018	1995-2006	2007-2018	1995-2018
1	USA	1047	12,197	13,244	31.32	24.52	24.95
2	China	283	11,809	12,092	8.47	23.74	22.78
3	India	151	5746	5897	4.52	11.55	11.11
4	Germany	284	2147	2431	8.50	4.32	4.58
5	UK	206	2111	2317	6.16	4.24	4.37
6	South Korea	122	1183	1305	3.65	2.38	2.46
7	Italy	131	1990	2121	3.92	4.00	4.00
8	Iran	9	2038	2047	0.27	4.10	3.86
9	Japan	240	1608	1848	7.18	3.23	3.48
10	France	271	1568	1839	8.11	3.15	3.46
Total		2744	42,397	45,141	82.08	85.24	85.04
World total		3343	49,736	53,079			
Share of top 10 countries in world total		82.08	85.24	85.04			

and chemistry (19.31%) during 1995–2018. The activity index showed increase in publication activity in engineering, materials science, chemical engineering, biochemistry, genetics and molecular biology, medicine, and chemistry (from 14.66 to 59.40), as against decrease in pharmacology, toxicology, and pharmaceutics by 21.35 from 1995–2006 to 2007–2018. The average value of activity index is 100. Chemical engineering registered the highest citation per paper (28.43), followed by pharmacology, toxicology and pharmaceutics (24.08), biochemistry, genetics and molecular biology (27.51), chemistry (27.11), materials science (24.72), medicine (19.12), and engineering (18.05) during 2008–2017 [Table 4].

Significant keywords

Around 108 significant keywords have been identified from the literature which through light on the research trends in NEDD research, including different types of nanocarriers along with materials used, target therapies for different diseases, types of pharmaceuticals, and various medicines used. These keywords are listed in Table 5 in the decreasing order of the frequency of their occurrence in the literature during 1995–2018 [Table 5].

Contribution and citation impact of top 20 most productive Indian organizations

Six hundred and fifty-eight organizations participated in Indian NEDD research, of which 472 organizations contributed 1–10 papers each, 93 organizations 11–20 papers each, 34 organizations 21–30 papers each, 68 organizations 21–50 papers each, 22 organizations 51–100 papers each, 10 organizations 101–200 papers each, and 3 organizations 201–278 papers each. Of the 658 participating organizations, the 20 most productive organizations in NEDD research together contributed 2360 publications (40.02% share) and 70,329 citations (52.08% share) in India's output during 1995–2018. Individually, the top 20 organizations contribution varied from 67 to 304 in 24 years. Only four organizations registered productivity rate above the group average of 118 per organization: Jamia Hamdard University, Delhi (304 papers); Dr. Harisingh Gour University, Sagar, M.P. (278 papers); Panjab University, Chandigarh (169 papers); and University of Delhi (142 papers). Only ten organizations registered citation impact and Relative Citation Index above the group average of 29.80 CPP and 1.30: National Institute of Pharmaceutical Education and Research, Mohali (73.87 and 3.23); Indian Institute of Technology, Kharagpur (40.11 and 1.75); Dr. Harisingh Gour University, Sagar, M.P. (38.82 and 1.70); M.S. University of Baroda (36.18 and 1.58); Amrita Institute of Medical Sciences, Coimbatore (34.39 and 1.50); Institute of Chemical Technology, Mumbai (34.37 and 1.50); Amrita Vishwa Vidyalayam University, Kochi (33.99 and 1.48); Institute of Nuclear Medicine and Allied Sciences, Delhi (33.60 and 1.47); University of Delhi (30.39 and 1.33); and Banaras Hindu University, Varanasi (29.88 and 1.30). Ten organizations registered ICP above the group average of 21.95%: Indian Institute of Science, Bengaluru (38.81%); University of Delhi (32.39%), Indian Institute of Chemical Technology, Hyderabad (29.41%); Amrita Institute of Medical Sciences, Coimbatore (29.03%); Jamia Hamdard University, Delhi (28.29%); Banaras Hindu University, Varanasi (27.10%); National Institute of Pharmaceutical Education and Research, Mohali (26.73%); Amrita Vishwa Vidyalayam University, Kochi (25.32%); Indian Institute of Technology, Mumbai (24.11%); and Indian Institute of Technology, BHU, Varanasi (22.34%) during 1995–2018 [Table 6].

Contribution and citation impact top 20 most productive Indian authors

Eight hundred and eleven authors participated in Indian NEDD research, of which 743 authors contributed 1–10 papers each, 139 authors 11–20 papers each, 47 authors 21–50 papers each, 11 authors 51–100 papers each, and 1 author 101–109 papers. Of the 811 participating organizations, the top 20 most productive authors contributed 37–109 papers each and together they contributed 1157 papers (19.62%) and received 41,825 citations (30.97%) during 1995–2018. Nine authors registered publication productivity above the group

Table 4: Subject-wise breakup of India's publications on nano-enabled drug delivery research during 1995-2018

Serial number	Subject*	Number of papers (TP)			Activity index		TC	CPP	TP (%)
		1995-2006	2007-2018	1995-2018	1995-2006	2007-2018	1995-2018		
1	Pharmacology, toxicology, and pharmaceutics	98	3070	3168	120.81	99.45	76,279	24.08	53.72
2	Biochemistry, genetics, and molecular biology	35	1587	1622	84.27	100.41	44,066	27.17	27.51
3	Materials science	23	1485	1508	59.56	101.06	37,273	24.72	25.57
4	Engineering	14	1284	1298	42.12	101.52	23,431	18.05	22.01
5	Chemical engineering	24	1208	1232	76.08	100.63	35,028	28.43	20.89
6	Medicine	25	1125	1150	84.90	100.40	21,993	19.12	19.50
7	Chemistry	25	1114	1139	85.72	100.38	30,878	27.11	19.31
World output		151	5746	5897					

There is overlapping of literature covered under various subjects. TP: Total paper, TC: Total citation, CPP: Citations per paper

Table 5: List of significant keywords in Indian nano-Enabled drug delivery research literature, 1995-2018

Serial number	Name of keyword	Frequency	Serial number	Name of keyword	Frequency	Serial number	Name of keyword	Frequency
1	Drug delivery systems	4349	37	Nano-medicine	430	73	Biodegradability	233
2	Nanoparticles	3267	38	Cell line tumor	425	74	Quantum dots	217
3	Particle size	2216	39	Nanomaterial	418	75	Polyglycolic acid	207
4	Drug delivery	1607	40	Lipids	413	76	Silver nanoparticles	202
5	Drug formulation	1572	41	Drug penetration	406	77	Pegylate or PEG	178
6	Drug release	1479	42	Drug distribution	399	78	Polyglyactin	178
7	Drug carrier	1472	43	Anti-neoplastic activity	395	79	Polyglycolic acid	177
8	*In vitro* study	1469	44	Polyglactin	393	80	Cyclodextrin	172
9	Zeta potential	1066	45	Macrogol	385	81	Polylactic acid-polyglycolic acid copolymers	165
10	Polymer	986	46	Drug absorption	382	82	SiRNA or small interfering RNA	155
11	Nanotechnology	896	47	Surfactant	382	83	Polycaprolactone	149
12	Drug solubility	891	48	Metal nanoparticles	367	84	Magnetic nanoparticles	148
13	Liposomes	872	49	Controlled drug release	361	85	Chitin	143
14	Nano bioavailability	855	50	Gold nanoparticles	353	86	Alginic acid	126
15	Nano carrier	817	51	Dendrimer	352	87	Nanomagnetics	118
16	Chitosan	789	52	Nanostructure	345	88	Polymeric nanoparticles	112
17	*In vivo* study	784	53	Peptid	334	89	DNA	108
18	Biocompatibility	754	54	Polymerization	317	90	Hyaluronic acid	95
19	Scanning electron microscopy	706	55	Proteins	316	91	Colloid	9
20	Nano-encapsulation	680	56	Conjugation	316	92	Iron oxide particles	72
21	Encapsulation	668	57	Drug synthesis	316	93	Diagnostic imaging	70
22	Targeted drug delivery	650	58	Curcumin	313	94	Metal nanoparticles	70
23	Cytotoxicity	642	59	Pathology	310	95	Biodistribution	67
24	Drug efficacy	633	60	Hydrophobicity	306	96	PLGA	67
25	Doxorubicin	616	61	Nano pharmaceutics	304	97	Fluorescence imaging	59
26	Controlled drug delivery	607	62	Microemulsions	290	98	Superparamagnetic nanoparticles	59
27	Solid-lipid nanoparticles	545	63	Cancer therapy	284	99	Semiconductor quantum dots	59
28	Sustained drug release	538	64	Solid-lipid nanoparticles	250	100	Ligand	56
29	Nano-emulsion	527	65	Hydrogel	282	101	Polylactide	47
30	Solid-liquid nanoparticles	515	66	Neoplasms	276	102	Polymeric miscelles	38
31	Differential scanning caliometry	492	67	Nano encapsulation	265	103	Polypeptid	37
32	Bioavailability	487	68	Nanofabrication	264	104	Copolymers	26
33	Diseases	462	69	Breast cancer	257	105	Biomarkers	26
34	Encapsulation	458	70	Carbon nanotubes	254	106	Fullerenes	24
35	Anti-neoplastic agents	434	71	Glycol	234	107	Ceramics	13
36	Paclitaxel	434	72	PEGs	234	108	Silica	12

PEGs: Polyethylene glycols

average of 57.85: N.K. Jain (109 papers), J.Al (84 papers), F.J. Ahmad (76 papers), S.P. Vyas (70 papers), R. Jayakumar (68 papers), S. Baboota (67 papers), A.K. Goyal (66 papers), O.P. Katare (60 papers), and B. Singh (59 papers). Six authors registered impact and relative citation index above the group average of 36.15 CPP and 1.58: S.K. Sahoo (108.07 and 4.72), R.K. Khar (69.19 and 3.02), N.K. Jain (53.68 and 2.34), R. Jayakumar (49.29 and 2.15), A.K. Mishra (42.39 and 1.85), and J. Ali (37.64 and 1.64). Eleven authors registered ICP share more than the average ICP share (18.15%): P. Kesharwani (82.61%), S. Beg Jamia (30.0%), F.J. Ahmad (27.63%), A.K. Mishra (25.0%), S. Jain (21.82%), S. Baboota (20.90%), R. Jayakumar (20.59%), O.P. Katare (20.0%), N.K. Jain (19.27%), Z. Iqbal (18.92%), and B. Singh (18.64%) [Table 7].

Distribution of publications by source and channel of communication

Of the 5723 publications by India in Contribution and Impact research, 92.81% (3911) appeared in journals, 4. 41% (1440) as reviews, 1.49% (88) as conference proceedings, 1.03% (61) as book series and 0.25% (15) as

Table 6: Scientometric profile of the top 20 most Indian productive organizations on nano-enabled drug delivery research during 1995-2018

Serial number	Name of the organization	TP	TC	CPP	HI	ICP (%)	RCI
1	Jamia Hamdard University, Delhi	304	7428	24.43	43	86 (28.29)	1.07
2	Dr Harisingh Gour University, Sagar, M.P	278	10,792	38.82	56	41 (14.75)	1.70
3	Panjab University, Chandigarh	169	3766	22.28	32	36 (21.30)	0.97
4	University of Delhi	142	4315	30.39	31	46 (32.39)	1.33
5	Indian Institute of Technology, Kharagpur	113	4532	40.11	26	14 (12.39)	1.75
6	Indian Institute of Technology, Mumbai	112	1955	17.46	25	27 (24.11)	0.76
7	Banaras Hindu University, Varanasi	107	3197	29.88	29	29 (27.10)	1.30
8	M. S. University of Varoda	104	3763	36.18	34	12 (11.54)	1.58
9	Indo-Soviet Friendship College of Pharmacy	104	1741	16.74	24	13 (12.50)	0.73
10	National Institute of Pharmaceutical Education and Research, Mohali	101	7461	73.87	35	27 (26.73)	3.23
11	Central Drug Research Institute, Lucknow	98	2174	22.18	23	19 (19.39)	0.97
12	Indian Institute of Technology, BHU, Varanasi	94	2369	25.20	26	21 (22.34)	1.10
13	Amrita Institute of Medical Sciences, Coimbatore	93	3198	34.39	30	27 (29.03)	1.50
14	Institute of Nuclear Medicine and Allied Sciences, Delhi	92	3091	33.60	32	15 (16.30)	1.47
15	Institute of Chemical Technology, Mumbai	81	2784	34.37	23	14 (17.28)	1.50
16	Jadavpur University, Kolkata	79	1010	12.78	20	9 (11.39)	0.56
17	Amrita Vishwa Vidyalayam University, Kochi	79	2685	33.99	27	20 (25.32)	1.48
18	Indian Institute of Technology, New Delhi	75	893	11.91	17	16 (21.33)	0.52
10	Indian Institute of Chemical Technology, Hyderabad	68	1830	26.91	23	20 (29.41)	1.18
20	Indian Institute of Science, Bengaluru	67	1345	20.07	22	26 (38.81)	0.88
Total		2360	70,329	29.80	28.9	518 (21.95)	1.30
Total of India		5897	135,043	22.90			
Share of top 20 organizations in India's total output		40.02	52.08				

TP: Total paper, TC: Total citation, CPP: Citations per paper, HI: h-index, ICP: International collaborative paper, RCI: Relative citation index

Table 7: Scientometric profile of top 20 most productive Indian authors in nano-enabled drug delivery research during 1995-2018

Serial number	Name of the author	Affiliation of the author	TP	TC	CPP	HI	ICP (%)	RCI
1	N.K. Jain	Dr. Harisingh Gour University, Sagar	109	5851	53.68	42	21 (19.27)	2.34
2	J. Ali	Jamia Hamdard University, Delhi	84	3162	37.64	26	15 (17.86)	1.64
3	F.J. Ahmad	Jamia Hamdard University, Delhi	76	2356	31.00	22	21 (27.63)	1.35
4	S.P. Vyas	IFS College of Pharmacy, Moga	70	2177	31.10	29	3 (4.29)	1.36
5	R. Jayakumar	Amrita Vishwa Vidyalayam University, Kochi	68	3352	49.29	27	14 (20.59)	2.15
6	S. Baboota	Jamia Hamdard University, Delhi	67	2135	31.87	25	14 (20.90)	1.39
7	A.K. Goyal	Dr Harisingh Gour University	66	1612	24.42	23	0 (0.00)	1.07
8	O.P. Katare	Panjab University, Chandigarh	60	894	14.90	18	12 (20.00)	0.65
9	B. Singh	Panjab University, Chandigarh	59	1012	17.15	18	11 (18.64)	0.75
10	S. Jain	National Institute of Pharmaceutical Education and Research, Mohali	55	1677	30.49	21	12 (21.82)	1.33
11	S. Talegaonkar	Jamia Hamdard University, Delhi	55	1988	36.15	19	5 (9.09)	1.58
12	G. Rath	IFS College of Pharmacy, Moga	51	843	16.53	18	0 (0.00)	0.72
13	P. Kesharwani	Dr Harisingh Gour University, Sagar	46	1357	29.50	18	38 (82.61)	1.29
14	S.K. Sahoo	Institute of Life Sciences, Bhubaneshw.	45	4863	108.07	27	4 (8.89)	4.72
15	A.K. Mishra	Institute of Nuclear Medicine and Allied Sciences, Delhi	44	1865	42.39	24	11 (25.00)	1.85
16	R.K. Khar	Dr. Harisingh Gour University, Sagar	43	2975	69.19	22	5 (11.63)	3.02
17	T. Garg	IFS College of Pharmacy, Moga	41	828	20.20	17	0 (0.00)	0.88
18	C.P. Sharma	SCTIMST, Trivandrum	41	1414	34.49	19	5 (12.20)	1.51
19	S. Beg	Jamia Hamdard University, Delhi	40	816	20.40	15	12 (30.00)	0.89
20	Z. Iqbal	Jamia Hamdard University, Delhi	37	648	17.51	13	7 (18.92)	0.76
Total of 20 authors			1157	41,825	36.15	22.15	210 (18.15)	1.58
Total of India			5897	135,043	22.90			
Share of 20 authors in India's total			19.62	30.97				

TP: Total paper, TC: Total citation, CPP: Citations per paper, HI: h-index, ICP: International collaborative paper, RCI: Relative citation index

trade publications, and 1% as multivolume reference work during 1995–2018. Three hundred and seventy-six journals participated in Indian NEDD research, of which 282 journals contributed 1–10 papers each, 28 journals 11–20 papers each, 43 journals 21–50 papers each, 19 journals 51–100 papers each, and 4 journals 101–169 papers each. The cumulative output of top 20 journals accounted for 34.56% of total Indian journal output, which decreased from 40.35% during 1995–2006 to 34.43% during 2007–2018. The leading journals contributing to Indian research in NEDD research are listed in Table 6. Colloid and Surfaces B. Biointerfaces (169 publications), followed by Nanomedicine (147 publications), International Journal of Macromolecules (156 publications), International

Journal of Pharmaceutics (132 publications), etc., during 1995–2018 [Table 8].

Highly cited papers

Out of 5897 papers from the Indian scholars on NEDD research published during 1995–2018, there were 231 highly cited papers having received citations from 100 to 2802 citations per paper (153 in 100–200 citations range each, 49 in 200–399 citations range, 16 in 400–699 citations range, 3 in 700–100 citations range, and the remaining 7 papers in 1042–2802 citation range) during 1995–2018.

Together these 231 papers accounted for 58,559 citations, averaging 253.50 citations per paper. The 231 highly cited papers had participation from 20 countries: the USA (18 papers); Japan and Germany (7 papers); the UK, Italy, and Malaysia (4 papers each); France, Israel, Singapore, and South Korea (3 papers each); Brazil and Canada (2 papers each); and Austria, Belgium, China, Greece, Hungry, Ireland, Jordan, Norway, Oman, Portugal, Saudi Arabia, Slovenia, Serbia, South Africa, Spain, and Taiwan (1 paper each).

One hundred and eleven Indian organizations participating in these 231 highly cited papers, including Dr. H.S. Gour University, Sagar (27 papers), National Institute of Pharmaceutical Education and Research, Mohali and Institute of Life Sciences, Bhubaneswar (17 papers each), Jamia Hamdard University, Delhi (14 papers), M.S. University of Baroda (9 papers), University Institute of Chemical Technology, Mumbai and Bombay College of Pharmacy (8 papers each), Postgraduate Institute of Medical Education and Research, Chandigarh (7 papers), University of Delhi, National Chemical Laboratory, Pune and Indian Institute of Technology, Kharagpur (6 papers each), SCTIMST, Trivandrum and Amrita Institute of Medical Sciences, Cochin (5 papers each), Karnatak University, Dharwad, Kakatiya University, Warangal, Pt. Ravishankar Shukla University, Raipur and Indian Institute of Chemical Technology, Hyderabad (4 papers each), National Institute of Interdisciplinary Research, Trivandrum, Central Drug Research Institute, Lucknow, INMAS-Delhi, National Institute of Science, Education and Research, Bhubaneswar, Indian Institute of Technology, Guwahati, Institute of Medical Sciences, BHU, Varanasi and J.S.S. College of Pharmacy, Ooctacamud (3 papers each), Sri Krishnadevaraya University, University of Kerala, Institute of Himalayan Bioresource Technology, Palampur, Bhabha Atomic Research Centre, Mumbai, Indian Institute of Technology, Mumbai, Birla Institute of Technology and Science, Pilani, Institute of Technology, BHU, Varanasi and Barchana's Women's College, Jaipur (2 papers), and rest of the organizations contributed only 1 paper each.

If the 231 highly cited papers (135 articles, 94 reviews, and 2 conference papers), 129 have zero collaboration and 102 involve national and international collaboration (64 national collaboratives and 38 international collaboratives).

Table 8: Top 15 most productive journals reporting output from Indian scholars in nano-enabled drug delivery research during 1995-2018

Serial number	Name of the journal	Number of papers		
		1995-2006	2007-2018	1995-2018
1	Colloid and Surfaces B. Biointerfaces	1	168	169
2	Nanomedicine	1	146	147
3	International Journal of Macromolecules	0	156	156
4	International Journal of Pharmaceutics	9	123	132
5	Drug Delivery	0	119	119
6	Journal of Biomedical Nanotechnology	0	98	98
7	Journal of Drug Targeting	8	86	94
8	Artificial Cells Nanomedicine and Biotechnology	0	92	92
9	Expert Opinion on Drug Delivery	0	86	86
10	Journal of Controlled Release	8	74	82
11	Current Drug Delivery	2	79	81
12	Materials Science and Engineering C	0	79	79
13	RSC Advances	0	77	77
14	Drug Development and Industrial Pharmacy	3	72	75
15	International Journal of Pharmaceutical Sciences Review and Research	0	74	74
16	International Journal of Pharmacy and Pharmaceutical Sciences	0	72	72
17	Critical Reviews in Therapeutic Drug Carrier Research	3	65	68
18	AAPS Pharmacitech	6	61	67
19	International Journal of Nanomedicine	1	63	64
20	Current Pharmaceutical Design	4	55	59
Total of 20 journals		46	1845	1891
Total India journal output		114	5358	5472
Share of top 20 journals in Indian journal output		40.35	34.43	34.56

The 231 highly cited papers were published in 88 journals, including 17 papers in Journal of Control Release, 16 papers in Nanomedicine, 11 papers in International Journal of Pharmaceutics and Biomaterials, 8 papers in European Journal of Pharmaceutical Sciences, 7 papers each in and European Advanced Drug Delivery Review, AAPS Pharm Sci Tech and Journal of Pharmaceutics and Biopharmaceutics, 5 papers each in Carbohydrate Polymers and Journal of Drug Targeting, 4 papers each in Colloids and Surfaces. B. Interfaces, Drug Discovery Today, Journal of Pharmacy and Pharmacology, Journal of Pharmacy and Pharmaceutical Sciences and Pharmaceutical Research, 3 papers each in Acta Biomaterialia, Biotechnological Advances, Bio-macromolecules, Chemical Society Reviews, International Journal of Nanomedicine, Journal of Antimicrobial Chemotherapy and Tuberculosis and 2 papers each in AAPS Journal, ACS Nano, ACS Applied Materials and Interfaces, Current Pharmaceutical Design, Biological and Pharmaceutical Bulletin, Critical Review in Therapeutic Drug Carrier System, Chemistry – A European Journal, Expert Opinion on Drug Delivery, Journal of Colloid and Interface Science, Journal of Pharmaceutical Sciences, Nanoscale and Polymer Plastic Technology and Engineering and 1 paper each in other journals.

CONCLUSION

There is a wide range of nanoparticulate materials and structures being developed for the delivery of therapeutic compounds. Each has its own particular advantages, but as these nanoparticles become optimized for their specific application, the outcome will be better-controlled therapy as a result of targeted delivery of smaller amounts of effective drugs to the required sites in the body. This is being made possible through the use of advanced material, improved control of particle size, and better understanding of interface between the biological and material surfaces and their effects *in vivo*. Some nanoparticle-based products are already approved by the USFDA, and several others are currently under development and clinical assessment. The analysis presented above offers useful technical intelligence to help researchers for identifying potential collaborators and to help inform R and D management and science and innovation policy for such nanotechnologies. Finally, it is suggested that India needs to develop specific plans of action and ensure its implementation at national level and also prioritize national goals for NEDD research.

DISCUSSION

The global NEDD research output (53,079) originated in 134 countries during 1995–2018. The 85.04% of total global publication share, however, came from only 10 most productive countries during 1995–2018, which showed increase from 82.08% during 1995–2006 to 85.24% during 2007–2018. The USA, among top 10 countries, accounted for the highest publication share (24.95%), followed by China (22.78%), India (11.11%), Germany, the UK, South Korea and Italy (from 4.00% and 4.58%), and Iran, Japan, and France (from 3.46% to 3.86%) during 1995–2018. China, India, Iran, and Italy showed increase in their global publication share (0.08%–115.28%), as against decrease in the USA, France, Germany, Japan. The UK and South Korea (from 3.46% to 3.86%) from 1995–06 to 2007–2018.

India had published 5897 publications in NEDD research during 1995–2018, which showed increase from 1 in the year 1995 to 95 in the year 2018, averaging 42.99% annual growth rate. India's share in the global publication output in NEDD research was 11.11% during 1995–2018, which showed increase from 4.52% during 1995–2006 to 11.55% during 2007–2018. India's citation impact in NEDD research averaged to 22.90 CPP during 1995–2018, which dropped from 150.66 during 1995–2006 to 19.24 during 2007–2018. The share of India's international collaborative papers was 20.35% during 1995–2018, which showed increase from 14.57% during 1995–2006 to 20.50% during 2007–2018. Pharmacology, toxicology and pharmaceutics registered the highest publications share (53.72%), followed by biochemistry, genetics and molecular Biology (27.51%), materials science (25.57%), engineering (22.01%), chemical engineering (20.89%), medicine (19.50%) and chemistry (19.31%) during 1995–2018.

Six hundred and fifty-eight organizations and 811 authors participated in Indian NEDD research, of which the top 20 most leading organizations and authors together contributed 40.02% and 19.62% as their share of Indian publication output and 52.08% and 30.97% as their share of Indian citation output, respectively, during 1995–2018. Indian organizations, showing comparatively higher productivity in NEDD research were: Jamia Hamdard University, Delhi (304 papers); Dr. Harisingh Gour University, Sagar, M.P. (278 papers); Panjab University, Chandigarh (169 papers); and University of Delhi (142 papers). Similarly, Indian organizations showing comparatively higher citation impact per paper and relative citation index were: National Institute of Pharmaceutical Education and Research, Mohali (73.87 and 3.23), Indian Institute of Technology, Kharagpur (40.11 and 1.75), Dr Harisingh Gour University, Sagar, M.P. (38.82 and 1.70), M.S. University of Baroda (36.18 and 1.58), Amrita Institute of Medical Sciences, Coimbatore (34.39 and 1.50), Institute

of Chemical Technology, Mumbai (34.37 and 1.50), Amrita Vishwa Vidyalayam University, Kochi (33.99 and 1.48), Institute of Nuclear Medicine and Allied Sciences, Delhi (33.60 and 1.47), University of Delhi (30.39 and 1.33) and Banaras Hindu University, Varanasi (29.88 and 1.30) during 1995–2018.

Indian authors showing comparatively higher productivity in NEDD research were: N.K. Jain (109 papers), J. Al (84 papers), F.J. Ahmad (76 papers), S.P. Vyas (70 papers), R. Jayakumar (68 papers), S. Baboota (67 papers), A.K. Goyal (66 papers, O.P. Katare (60 papers), and B. Singh (59 papers). Similarly, Indian authors showing with comparatively higher citation impact per paper and relative citation index were: S.K. Sahoo (108.07 and 4.72), R.K. Khar (69.19 and 3.02), N.K. Jain (53.68 and 2.34), R. Jayakumar (49.29 and 2.15), A.K. Mishra (42.39 and 1.85), and J. Ali (37.64 and 1.64) during 1995–2018.

Of the 5897 publications by India in NEDD research, 92.81% (3911) appeared in 376 journals. The 20 most productive journals contributed 27.31% share to the Indian journal publication output during 1995–2018. The publication shares from top 20 journals decreased from 40.35% during 1995–2006 to 34.43% during 2007–2018. The leading journals contributing to Indian research in NEDD: Colloid and Surfaces B. Biointerfaces (169 publications), followed by Nanomedicine (147 publications), International Journal of Macromolecules (156 publications), International Journal of Pharmaceutics (132 publications), etc., during 1995–2018.

Two hundred and thirty-one highly cited papers, out of output of 5897 publications on NEDD research from India, received from 100 to 2802 citations per paper during 1995–2018. These 231 highly cited papers together received 58,559 citations, averaging to 253.50 citations per paper. The USA accounted for the highest number of papers (18) in the 231 highly cited papers, followed Japan and Germany (7 papers); the UK, Italy, and Malaysia (4 papers each); France, Israel, Singapore, and South Korea (3 papers each); Brazil and Canada (2 papers each), etc., The 231 highly cited papers were published in 88 journals, including 17 papers in Journal of Control Release, 16 papers in Nanomedicine, 11 papers in International Journal of Pharmaceutics and Biomaterials, 8 papers in European Journal of Pharmaceutical Sciences, 7 papers each in Advanced Drug Delivery Review, AAPS Pharm Sci Tech and European Journal of Pharmaceutics and Biopharmaceutics, 5 papers each in Carbohydrate Polymers and Journal of Drug Targeting, and 4 papers each in Colloids and Surfaces. B. Interfaces, Drug Discovery Today, Journal of Pharmacy and Pharmacology, Journal of Pharmacy and Pharmaceutical Sciences and Pharmaceutical Research, etc.

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Conflicts of interest

There are no conflicts of interest.

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