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Mapping the Indian landscape of nanodrug delivery for cancer treatment : A bibliometric analysis

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In recent, increases of cancer cases in India indicating the urgent need for innovative treatment strategies. To address this growing demand, India must prioritize the development of advanced therapies. Nanodrug delivery systems (NDS) shown a promising potential in precisize way of cancer treatment. This study attempt bibliometric analysis to identify current research hotspots, trends, prolific authors and institute, and research clusters in the field of nanodrug delivery systems. The Scopus database has been used for data download between year 2001 to 2022. The data search string retrieved comprehensive bibliographic information and resulting a total of 11,127 documents in RIS and CSV formats.

The VOSviewer and R software (Biblioshiny) have been used to examine authors, institutions, international collaborations, keywords, research hotspots, leading sources, and citation patterns. The findings revealed a consistent growth in literature, indicating strong research activity in NDS. The data interpretation identified that USA, Saudi Arabia, and South Korea as a top collaborating countries with India in nanodrug delivery system research, reflecting the expanding global interest and partnerships in this emerging research domain.

Among Indian institutions, "Jamia Hamdard" (Deemed University) emerged as the leading research organization, followed by the "All India Institute of Medical Sciences (AIIMS)" and "Tata Memorial Hospital". The top trending author keywords identified were "cancer," "application," and "cancer therapy," while emerging topics included "polymer nanoparticles," "synthesized," and "internalization." "The Journal of Drug Delivery Science and Technology" ranked highest in productivity, whereas the "Journal of Controlled Release" led in total citations.

The findings suggest that India's collaborations, particularly with European and Asian countries, are expected to grow in the coming years. Between 2020 and 2022, key research areas in NDS included nanoparticles, neoplasm drug carriers, tumors, polymers, nanochains, and nanoparticle drug delivery systems. Most studies during this period

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focused on NDS supported by advanced technologies and materials. Keyword analysis in NDS research indicate a significant focus on cancer treatment, were contemporary technological advancements playing a critical role. Future research is anticipated to focus on more robust technologically advanced NDS for cure of cancer, aiming to optimize therapeutic outcomes.

Keywords: *Nano drug delivery, Bibliometric analysis, Cancer, Bibliographic coupling, Co-citation analysis, Targeted therapy.*

1. Introduction

Cancer treatments often result in long-term side effects due to the limitations of conventional therapies. The Nanoparticles, typically ranging in size from 1-100 nanometers, enable more precise drug delivery. They are specifically designed to monitor molecular changes, facilitate molecular interactions, and transport therapeutic compounds across biological barriers. Todays, nanoparticle-based drug support systems got attention while effective delivery both for small and large molecules. This target-based method enhances the level of cancer treatments and lower the negative effect. It is proving the nanotechnology as a highly advanced and promising field of research.

Once nanoparticles bind to cellular receptors, they are rapidly internalized through receptor-mediated endocytosis or phagocytosis, leading to the release of the encapsulated drug into the cell's cytoplasm [1]. The NDS development started in late 1970s with lipid vesicle-based systems. In year 1983 the first micellar drug approved by the "U.S. Food and Drug Administration" for systemic nanoparticle injection in humans. In 1990, Adagen became the first polymer-drug nanoconjugate approved for its clinical use [2]. Since then, various nanostructures, including liposomes and polymer-based systems, have been extensively explored in drug delivery research to improve treatment outcomes reported in study [3].

According to Mohammed and Al-Gawhari [4], the surface properties of gold nanoparticles play a critical role in enhancing their effectiveness as carriers for various drug molecules, particularly in cancer therapy. Rizvi & Saleh [5] mention that advances in nanotechnology have significantly improved diagnostic testing and hold great potential for the treatment of AIDS, cancer, and several other diseases. Chen [6] has proposed combining biological materials with nanomaterials to increase their biocompatibility and enable more controlled drug release. The small size, large surface area, and high permeability of nanomaterials facilitate their efficient integration into therapeutic applications [7]. Consequently, NDS can reduce systemic toxicity, improve targeted drug delivery, protect encapsulated drugs from degradation in circulation, optimize drug pharmacokinetics, and enhance therapeutic efficacy discuss in study [8].

The common techniques for preparing polymeric and lipid-based nanoparticles include solvent emulsification, gelation, sonication, salting out, extrusion, supercritical fluid technology, nanoprecipitation, and high-pressure homogenization [9]. Since the advent of nanotechnology, significant advancements have been made in nanomedicine, particularly in the study and treatment of cancer [10]. A deeper understanding of the properties of nanoparticles and their interactions with biological systems could lead to innovative approaches for diagnosing, preventing, and treating various diseases, especially those that are currently incurable [11].

One of the ongoing challenges in the pharmaceutical industry is addressing poor solubility during drug development [12]. Researchers estimate that up to 40% of newly discovered chemical entities exhibit poor solubility. Specially designed carriers have the potential to attach to medications, enabling cell-specific targeting [13]. Numerous nanostructures have been explored as carriers in drug delivery systems, including liposomes, polymers, dendrimers, silicon or carbon materials, and magnetic nanoparticles [14].

Faraji and Wipf [15] discussed several nanoscale drug delivery methods capable of transporting both small drug molecules and larger therapeutic agents like proteins, peptides, and nucleic acids [16]. Furthermore, Liu, Shah, and Tan [17] anticipate that future advancements in computer modelling will enhance the prediction of drug delivery efficiency, optimizing the design of drug carriers for individual patients' vascular environments.

Bibliometrics has emerged as a vital research tool, enabling scholars to predict research hotspots, analyze trends, and efficiently identify the latest developments within specific fields. Recently, researchers have employed bibliometric analysis to monitor trends in nanomaterials research [18]. Current areas of focus include hotspot research topics such as photothermal therapy for cancer treatment [19], magnetic nanoparticles for drug delivery, and ultrasonic microbubbles [20].

In studies of nanomedicine [21], nanotechnology [22], and magnetic nanoparticles [23], researchers have investigated current challenges and potential future directions for developing high-performance drug carriers for cancer therapy. To construct the conceptual framework of research topics, scholars frequently use tools like RStudio and VOSviewer [24], [25]. A comprehensive understanding of emerging trends and developments in any field is essential for informed decision-making in research funding and policymaking [26].

Bibliometric analysis of NDS (National Digital Services) research in India has not been conducted before. Additionally, no existing study focuses on the bibliometric evaluation of the available body of research on this topic. To address this gap, a comprehensive bibliometric analysis and visualization of NDS research in India was undertaken. This study explores research trends and citation patterns among Indian institutions and authors and identifies prominent keywords related to NDS literature. Tools such as VOSviewer and R (Bibliometrix) have been employed to perform the analysis, providing insights into the academic landscape of NDS in India. Two research questions have been formulated and are outlined below:

RQ1. What areas of research on nanodrug delivery systems does India's literature cover?

RQ2. What emerging and underexplored topics warrant further investigation in future studies?

2. Methodology

Sweileh [27] and Saleem et al. [28] emphasized that bibliometrics is a reliable and efficient method for identifying significant and emerging research trends across various fields. This approach was chosen due to its objective and reproducible nature, made possible by quantitative bibliometric techniques [29]. It allows for a comprehensive analysis and evaluation of publication success while revealing the structural dynamics of research subjects [30]. As a quantitative tool, bibliometrics has increasingly been applied across disciplines, offering researchers a way to track both current and emerging trends.

2.1 *Data acquisition and search terms*

This study focuses a comprehensive review of research on NDS, encompassing scholarly works published between 2001 and 2022. Data were retrieved from Elsevier's Scopus abstract and citation database [31], a renowned repository of scientific literature launched in 2004. Specifically, the data were extracted from Scopus's Core Collection on March 20, 2023.

Figure 1 depicts the data extraction process from the Scopus bibliographic database using specific keywords and the database's filtering features. The Scopus database provides comprehensive metadata, including citation counts, affiliation details, abstracts, keywords (both indexed and author-assigned), funding information, and references, ensuring thorough coverage of research output. This data forms the foundation for analyzing

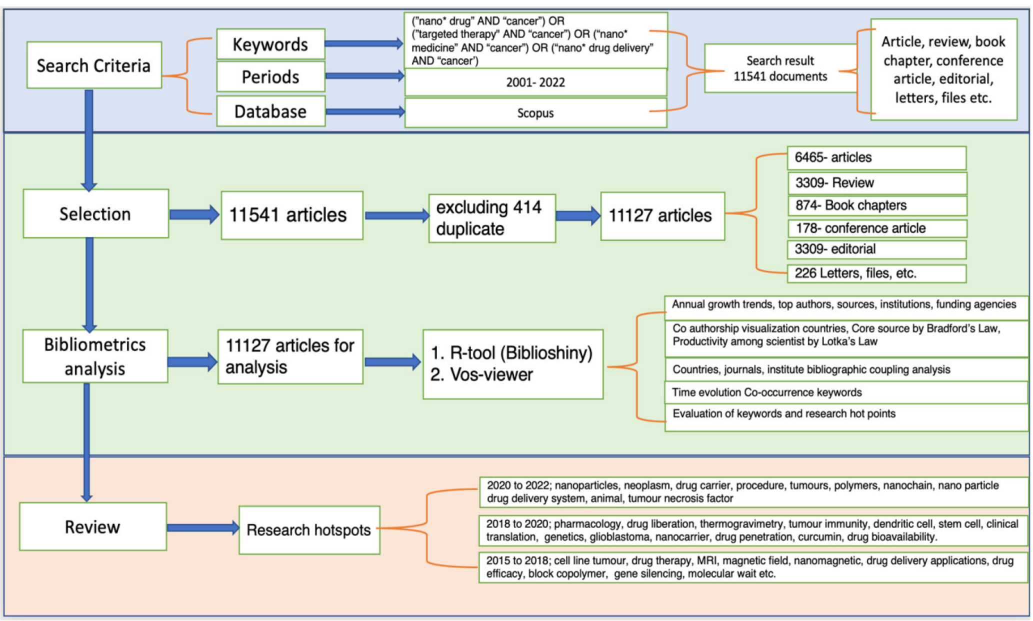

Figure 1

Research Flow chart of NDS research in India

publication trends, research productivity, and citation patterns. To optimize the retrieval of relevant materials for this study, search terms have been meticulously crafted through review papers extracted from Scopus and Google Scholar databases. Subsequently, data retrieval was conducted using the following search strings, (nano* AND drug AND cancer) OR (targeted treatment AND cancer) OR (nano* AND medicine AND cancer) OR (nano* drug delivery AND cancer).

For analysis, data were retrieved both in RIS and CSV formats, focusing exclusively on publications from India, excluding other countries. The Scopus search query yielded 11,541 results. Using R version (4.2.2), 414 duplicate documents were removed from the combined dataset. The resulting dataset comprised 6,465 articles, 3,309 reviews, 874 book chapters, 178 conference papers, 75 editorials, and 226 other records. After removing duplicates, 11,133 records were extracted to a single RIS file. The downloaded Scopus RIS format converted to Web of Science text format by using CiteSpace software. Subsequent analysis employed R software with VOSviewer. Following data cleaning, 11,127 documents remained for examination. As illustrated in Figure 1, this study encompasses 11,127 papers, encompassing all data published up to 2022 in English language only.

2.2 *Data management and analysis*

This study employed the Bibliometrix program, previously used by Aria and Cuccurullo [32], to conduct a scientific mapping analysis. This method facilitated the creation of category maps, identification of influential research and publications, discovery of current and emerging research trends, and visualization of the subject framework. Additionally, bibliometric networks, co-citation, and bibliographic coupling analyses were conducted using VOSviewer [33], [34], [35]. According to Mao et al. [36] and Du et al. [37], a standard bibliometric approach involves keyword extraction and frequency analysis. Author-specified keywords were extracted from the database using VOSviewer, which provided a more comprehensive description of the topic compared to Keywords Plus. Co-citation analysis, as described by Van Eck and Waltman [38], was used to measure links between articles, generating document clusters and visualizing connections between authors, as applied in earlier studies [39], [40], [41]. The co-citation study by Phan, [42] was employed to explore key works and unique ideas, building on prior research [43], [44]. Bibliographic coupling analysis in year 1963 Kessler, [45] examines overlaps in publication reference lists, identifying potential research themes.

3. Results and discussion

This study compiled a comprehensive dataset of 11,127 documents, comprising research articles, reviews, book chapters, conference proceedings, editorials, books, surveys, and correspondence, published over the last two decades on NDS research in India. A total of 28,346 authors contributed in 11,127 documents, sourced from 2,233 unique publications. The linguistic analysis revealed an overwhelming dominance of English-language publications (N = 11,125), with only two documents published in French

Table 1

Details of the primary data

MAIN INFORMATION ABOUT DATA	
Description	**Results**
Timespan	2001:2022
Sources (Journals, Books, etc)	2233
Documents	11127
Average years from publication	4.9
Average citations per documents	27.77
References	816397
Article	6465
Review	3309
Book Chapter	874
Conference Paper	184
Editorial	75
Keywords Plus (ID)	54863
Authors	28346
Author Appearances	62471
Authors of single-authored documents	277
Authors of multi-authored documents	28069
Single-authored documents	277
Documents per Author	0.393
Authors per Document	2.55
Co-Authors per Documents	5.61
Collaboration Index	2.6

(N = 2). This finding underscores the universal recognition of English as the primary language of scientific communication, despite calls to incorporate non-English languages more prominently in the literature [46]. Authorship analysis revealed a prevalence of multi-authorship (N = 10,850) over single-authorship (N = 277), indicating a collaborative research environment.

Notably, multi-author publications dominate the field, with a vast majority of authors opting for collaborative work (97.52%) over solo authorship (2.48%). This preference for cooperation is evident across all collaboration options. The dataset revealed a substantial citation footprint, with 8,16,397 references, 309,081 citations, and an average of 27.77 sources per document. Furthermore, authors employed 54,863 unique keywords, indicating a diverse and expansive knowledge base.

3.1 *Scientific publications by year and document type*

Cancer, a longstanding threat to human health, has become increasingly perilous in recent times. Figure 1 illustrates the trend in annual publications, revealing two distinct phases. The initial phase (2001-2011) witnessed a remarkable growth, from a mere 2 publications in 2001 to 270 in 2011, indicating a significant expansion in research. This surge in scientific inquiry underscores the gravity of cancer's impact and its rising prominence on India's healthcare agenda, as evidenced by numerous studies (list specific studies or references). The second phase (2012-2022) saw an exponential increase, with publication numbers swelling to four-fold, reaching fifteen times the volume of the first phase. Notably, 2019 marked a milestone, with publications exceeding 1,000 for the first time.

Figure 2 shows a consistent increase in the annual growth rate of publications, without any decline below the baseline level. Notably, the annual growth rate surpassed 200% in 2010. The years 2006, 2009, 2011, and 2013 experienced the most significant yearly publishing growth. The consistent upward trend in cumulative publications suggests sustained growth until 2022, indicating expanding interest and increasing relevance across multiple academic fields. The earliest reference in the downloaded database dates back to 1701, citing an article on "cytotoxic ribosome-inactivating lectins".

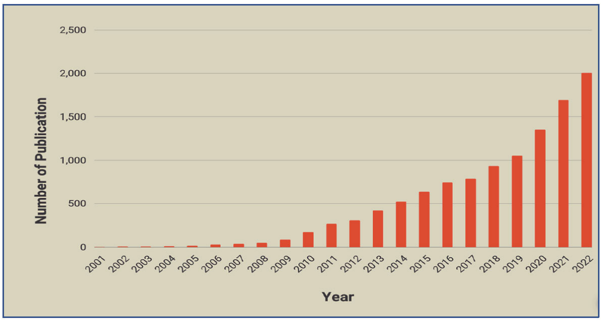

Figure 2

Year wise publication pattern in nano drug delivery

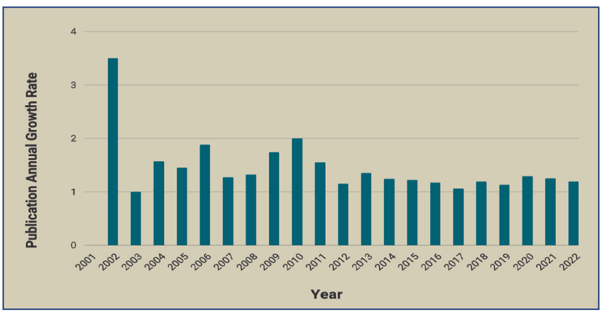

Figure 3

Annual scientific growth rate of publication in nano drug delivery

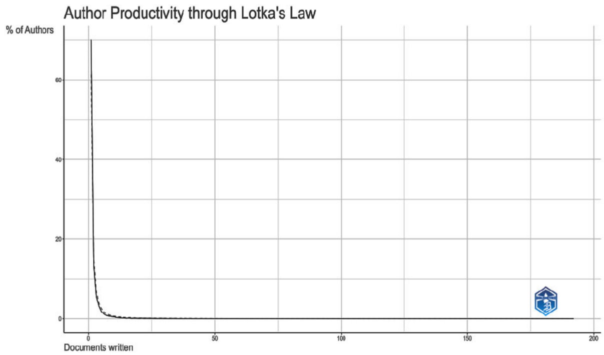

Figure 4

Productivity among scientists based on Lotka's Law

3.2 *Research Productivity among scientists*

Lotka's Law [47] is a fundamental principle governing scientific productivity, enabling analysis of production trends among scientists within specific subjects and timeframes. According to this law, approximately 60% of contributors are expected to produce a single item. Figure 4 illustrates the distribution of publications among 28,346 authors who contributed to 11,127 papers. The data reveals that 19,855 authors (70.04% of the total) had only one publication, exceeding Lotka's predicted ratio. Contrary to expectations of concentration among a few prolific authors, the distribution is characterized by author diversity. The author productivity distribution is as follows: 19,855 authors (70.04%) published one work, 3,815 authors (two works), 1,564 authors (three works), 886 authors (four works) 482 authors (five works), 358 authors (six works), 237 authors (seven works), 190 authors (eight works). Notably, a small number of single authors contributed more than 100 articles.190 authors with eight publications, and many single authors written more than a hundred article.

3.3 *Top ten prolific authors*

According to Table 2, Kesharwani, P. emerges as the most prolific author in NDS research, with a notable record of 123 publications and 62 h-index. The Hirsch Index (h-index) effectively measures this author's productivity and impact, highlighting their significant contribution to the field. Kesharwani's first publication year dates to 2002. The ranking of significant authors varies based on the indicator applied. Notably, Dua, K. (89 publications), Jain, S. (76 publications), Beg, S. (65 publications), and Jain, N.K. (65 publications) follow closely. Furthermore, author Sahoo, S.K. from the Institute of Life Sciences, India, Bhubaneswar, achieved the highest Citation Index (127.8) and total citations (7154), while Jayakumar, R. from Amrita Institute of Medical Sciences, India, Kochi, secured the second-highest CI (104.4). Table 2 presents the top ten NDS researchers affiliated with Indian universities, indicating that the most active and frequently cited authors hail from both public and private research institutions, which allocate substantial resources to developing NDS as a cancer treatment.

Table 2

Top ten authors with the highest publications, citations and h-Index

SN	Author	Affiliation	NP	TC	CI	h-index
1	Kesharwani, P.	Jamia Hamdard, New Delhi, India	123	5708	46.4	62
2	Dua, K.	University of Technology Sydney, Sydney, Australia	89	1808	20.3	21
3	Jain, S.	National Institute of Pharmaceutical Education and Research, Mohali, Mohali, India	76	3446	45.3	39
4	Beg, S.	Faculty of Clinical and Biomedical Sciences, Preston, United Kingdom	65	1420	21.8	23
5	Jain, N.K.	Dr. H. S. Gour Vishwavidyalaya Sagar, Department of Pharmaceutical Sciences, Sagar, India	65	4941	76.0	46
6	Chellappan, D.K.	International Medical University, Kuala Lumpur, Malaysia	63	1418	22.5	23
7	Gupta, G.	Indian Veterinary Research Institute, Bareilly, India	58	1498	25.8	22
8	Jayakumar, R.	Amrita Institute of Medical Sciences India, Kochi, India	56	5848	104.4	36
9	Sahoo, S.K.	Institute of Life Sciences India, Bhubaneswar, India	56	7154	127.8	31
10	Rahman, M.	Sam Higginbottom University of Agriculture, Technology and Sciences, Department of Pharmaceutical Sciences, Allahabad, India	53	1709	32.2	21

3.4 *Top Ten highest Cited Publications*

Table 3 indicates the highly cited, focuses on pivotal topics in NDS, including: Nanoparticle-based approaches; Hepatocellular carcinoma treatment using nanomaterials; Paclitaxel-based therapies; Photothermal tumor therapy; Human cancer therapy strategies; Macromolecular therapies; Innovative therapeutic techniques. These highly cited publications underscore the significance of these research areas in advancing nanodrug delivery systems for cancer treatment.

According to Table 3, the top-cited publications in nanodrug delivery systems include Ulbake et al.'s 2017 study in Pharmaceutics (N = 1216 citations) and Agnihotri et al.'s 2004 paper in Journal of Controlled Release (N = 2139 citations), holding the highest overall citation count. Notably, the most frequently cited papers often intersect multiple disciplines, including pharmaceuticals, nanomedicine, hepatology, oncology, cancer biology, and nanobiotechnology. Eight of the top ten works were published in cancer research journals. The most referenced authors are not necessarily the most prolific. This disparity may be

Table 3

Summary of the top ten selected publications

SR No.	Author	Title	DOI	Year	Total Citations	Article Keywords	Journal Name
1	Agnihotri S.A., Mallikarjuna N.N., and Aminabhavi T.M.	Recent advances on chitosan-based micro- and nanoparticles in drug delivery	10.1016/j.jconrel.2004.08.010	2004	2139	Microparticles, Chitosan Nanoparticles, Drug delivery Chemically modified chitosan	Journal of Controlled Release
2	Bulbake U., et al.	Liposomal formulations in clinical use: An updated review	10.3390/pharmaceutics9020012	2017	1216	clinical trials; drug delivery; liposome technology; liposomes; nanotechnology; therapeutics	Pharmaceutics
3	Omata M., D.A., et. al.	Asia–Pacific clinical practice guidelines on the management of hepatocellular carcinoma: a 2017 update	10.1007/s12072-017-9799-9	2017	1188	APASL; Asia–Pacific; Hepatocellular carcinoma; Treatment algorithm	Hepatology International
4	Parveen S., Misra R., Sahoo S.K.	Nanoparticles: A boon to drug delivery, therapeutics, diagnostics and imaging	10.1016/j.nano.2011.05.016	2012	1112	Nanotechnology Drug delivery Nanoparticles NPs Polymeric micelles Dendrimers	Nanomedicine: Nanotechnology, Biology, and Medicine
5	Jayakumar R., et al.	Biomedical applications of chitin and chitosan based nanomaterials - A short review	10.1016/j.carbpol.2010.04.074	2010	1005	Chitin, Chitosan Nanofibers, Nanoparticles Nanocomposite scaffolds Tissue engineering Drug delivery, Cancer diagnosis, Wound healing	Carbohydrate Polymers

Contd...

6	Singla A.K., Garg A., Aggarwal D.	Paclitaxel and its formulations	10.1016/S0378-5173(01)00986-3	2002	947	Paclitaxel Taxol Formulation Solubility	International Journal of Pharmaceutics
7	Von Maltzahn G., et al.	Computationally guided photothermal tumor therapy using long-circulating gold nanorod antennas	10.1158/0008-5472.CAN-08-4242	2009	944	Plasmonic nanomaterials polyethylene glycol photothermal	Cancer Research
8	Bisht S., et al.	Polymeric nanoparticle-encapsulated curcumin ("nanocurcumin"): A novel strategy for human cancer therapy	10.1186/1477-3155-5-3	2007	929	anti-cancer carcinogenesis bioavailability NIPAAM pancreatic cancer	Journal of Nanobiotechnology
9	Mundargi R.C., et al.	Nano/micro technologies for delivering macromolecular therapeutics using poly(d,l-lactide-co-glycolide) and its derivatives	10.1016/j.jconrel.2007.09.013	2008	898	PLGA Nanoparticles Microparticles Targeted drug delivery Proteins Peptides	Journal of Controlled Release
10	Vinay D.S., et al.	Immune evasion in cancer: Mechanistic basis and therapeutic strategies	10.1016/j.semcancer.2015.03.004	2015	888	Cancer Immune evasion T cells Therapy	Seminars in Cancer Biology

attributed to the "citation time lag" phenomenon, where older papers accumulate more citations over time highlighted in study [48]. Table 4 also highlights intriguing correlations between publication type and citation counts. Contrary to previous suggestions [49], [50] our analysis indicates that research articles can garner comparable attention and citation rates to review papers.

3.5 *Top productive sources*

Bradford's Law, 1934 [51] describes the distribution of journal productivity, categorizing publications into three zones based on their publishing frequency. According to this law, journal productivity can be divided into: A small core of highly productive journals (Zone 1); A moderate number of journals with moderate productivity (Zone 2); A large number of journals with decreasing productivity (Zone 3) [51]. In the field of traditional and ethnic medicine related to cancer, researchers often consider top publications in Zone 1 as highly relevant due to their frequent citations. Figure 5 illustrates the distribution of journals across these zones, with: Zone 1: 51 journals (2.28%); Zone 2: 247 journals (11.05%); Zone 3: 1936 journals (86.66%). The top four core journals in Zone 1 are: "International Journal of Biological Macromolecules"; "Colloids and Surfaces B: Biointerfaces"; "Journal of Drug Delivery Science and Technology"; International Journal of Pharmaceutics". Notably, all four journals are published by Elsevier and rank within the first quartile (Q1) in their subject area. To evaluate the influence and effectiveness of these sources, Table 4 presents the top 10 journals, including their: Total publications (TP); Impact factor (IF); Total citations (TC) and Citation Index (CI). The "Journal of Drug Delivery Science and Technology" leads with 216 articles, followed by the "International Journal of Biological Macromolecules" with 185 publications. The "Journal of Controlled Release" boasts the highest citation count (9634), Citation Index (99.32), and impact factor (11.467).

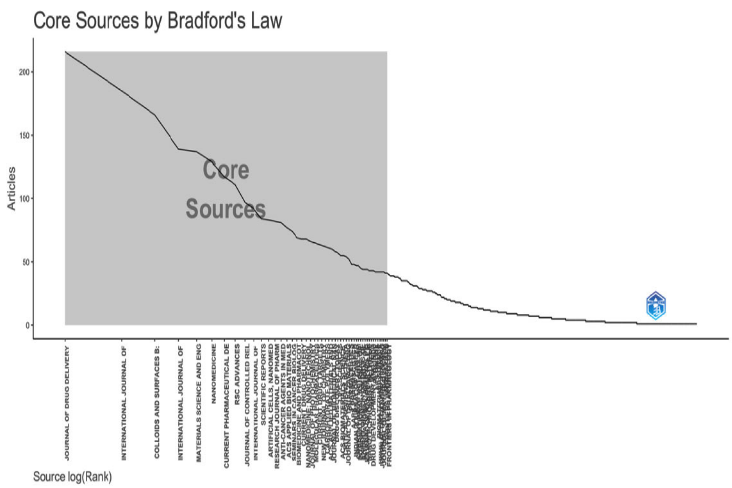

Figure 5

Core publication sources

Table 4

Top ten sources with highest citation, total publication, collaborative index and impact factor

SR No.	Journal	NP	TC	CI	IF
1	Journal of Drug Delivery Science and Technology	216	3551	16.44	5.062
2	International Journal of Biological Macromolecules	185	6385	34.51	8.025
3	Colloids and Surfaces B Biointerfaces	166	8976	54.07	5.999
4	International Journal of Pharmaceutics	139	7584	54.56	6.51
5	Materials Science and Engineering C	137	6441	47.01	8.457
6	Nanomedicine	129	4184	32.43	6.096
7	Current Pharmaceutical Design	117	2783	23.79	3.31
8	Rsc Advances	111	2634	23.73	4.036
9	Journal of Controlled Release	97	9634	99.32	11.467
10	International Journal of Nanomedicine	92	5674	61.67	7.033

The referenced sources examine nanomedicine delivery systems for cancer treatment, substantiating the notion that contemporary nanodrug delivery system (NDS) research primarily concentrates on cancer therapy. However, study emphasizes the necessity of an interdisciplinary approach to develop effective solutions and interventions. To optimize cancer treatment outcomes, researchers in nanodrug delivery should integrate expertise from diverse fields, leveraging knowledge and experience to combat the devastating effects of cancer.

3.6 *Collaboration of countries with India*

Bibliographic coupling phenomena can be identified when a research work cited by the two work in their bibliographies, indicating a high similarity in their research topics. In this study, bibliographic connectivity is established when two documents share one or more cited references. Table 5, generated using R software, presents the top countries by publication output, with the United States leading (N = 1184) in collaboration with India, followed by Saudi Arabia (N = 682), South Korea (N = 392), and Australia (N = 341).

Using VOSviewer software, a bibliographic coupling analysis of countries was conducted with a minimum threshold of five documents per country (N = 5), where 178 countries, 73 met this criterion. Figure 6 illustrates the results, revealing three distinct clusters: Cluster 1 (red): 41 countries, led by Singapore (148 documents, Total Link Strength (TLS) = 69,101), followed by Japan (141 documents, TLS = 66,319), Germany (136 documents, TLS = 64,042), Taiwan (122 documents, TLS = 59,645), and others. Cluster 2 (green): 26 countries, led by the USA (1184 documents, TLS = 164,310), followed by Saudi Arabia (682 documents, TLS = 94,201), South Korea (392 documents, TLS = 79,104), Australia (341 documents, TLS = 75,832), etc. Cluster 3 (blue): Six countries, with the United Kingdom leading (249 documents, TLS = 88,485), followed by Italy (140 documents, TLS = 69,209), Canada (114 documents, TLS = 55,213), and others. The bibliographic coupling analysis demonstrates

Table 5

Top ten countries with bibliographic coupling with India

SN	Country	Documents	TLS	Cluster
1	United States	1184	164310	2
2	Saudi Arabia	682	94201	2
3	South Korea	392	79104	2
4	Australia	341	75832	2
5	China	316	72982	2
6	Malaysia	276	72310	2
7	United Kingdom	249	88485	3
8	Singapore	148	69101	1
9	Japan	141	66319	1
10	Italy	140	69209	3

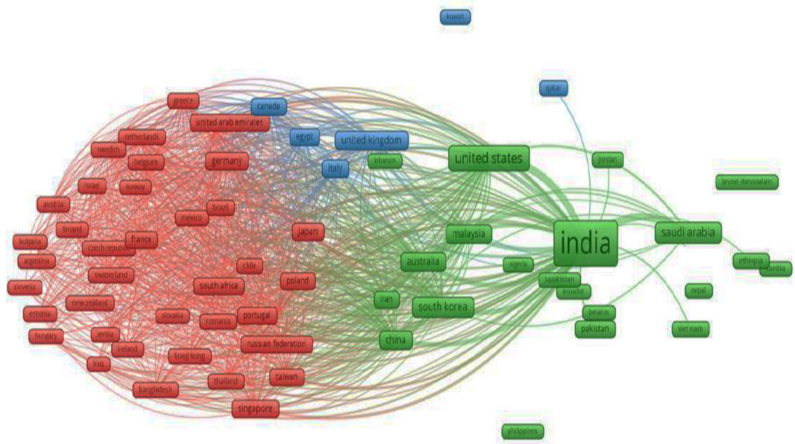

Figure 6

Bibliographic coupling of countries

India's robust collaboration and strong relationships with European and Asian countries in NDS.

3.7 *Institutions'/Universities' co-authorship pattern, publications and funding*

Co-authorship patterns among leading research institutions were analyzed using VOSviewer software (Fig. 7). Institutions with at least 25 publications were considered, yielding 162 institutions out of 1014. The link strength of co-authorship with other organizations was calculated for each institution. Figure 7 depict six different clusters, which are visible in distinguish colours. Cluster 1 (Red), 41 institutions, led by All India

Institute of Medical Science (255 documents, TLS = 158), Indian Institute of Technology (197 documents, TLS = 144), and Indian Institute of Science (137 documents, TLS = 83). Cluster 2 (Green): 31 institutions, dominated by Academy of Scientific and Innovative Research (155 documents, TLS = 102) and Homi Bhabha National Institute (106 documents, TLS = 79). Cluster 3 (blue): 31 institutions, including King Saud University (194 documents, TLS = 248) and Bharathiar University (133 documents, TLS = 82). Cluster 4 (Yellow): 26 institutions, featuring Panjab University (158 documents, TLS = 107), University of Delhi (156 documents, TLS = 56), and Banaras Hindu University (155 documents, TLS = 100). Cluster 5 (Magenta): 20 institutions, primarily from Middle Eastern countries, including King Abdul Aziz University (128 documents, TLS = 214) and Aligarh Muslim University (86 documents, TLS = 70). Cluster 6 (Sky blue): Top private universities and institutes in India, such as Lovely Professional University (117 documents, TLS = 329), International Medical University (88 documents, TLS = 272), and Sarda University (60 documents, TLS = 161). The analysis reveals: Homogeneous institutional types within each cluster, indicating local co-authorship patterns; Private universities have fewer publications but dominate in terms of total link strength; Collaboration relationships among institutions, represented by distance and link thickness in Fig. 7.; Institution size, publications, links, and total link strength are indicated by color disk size.

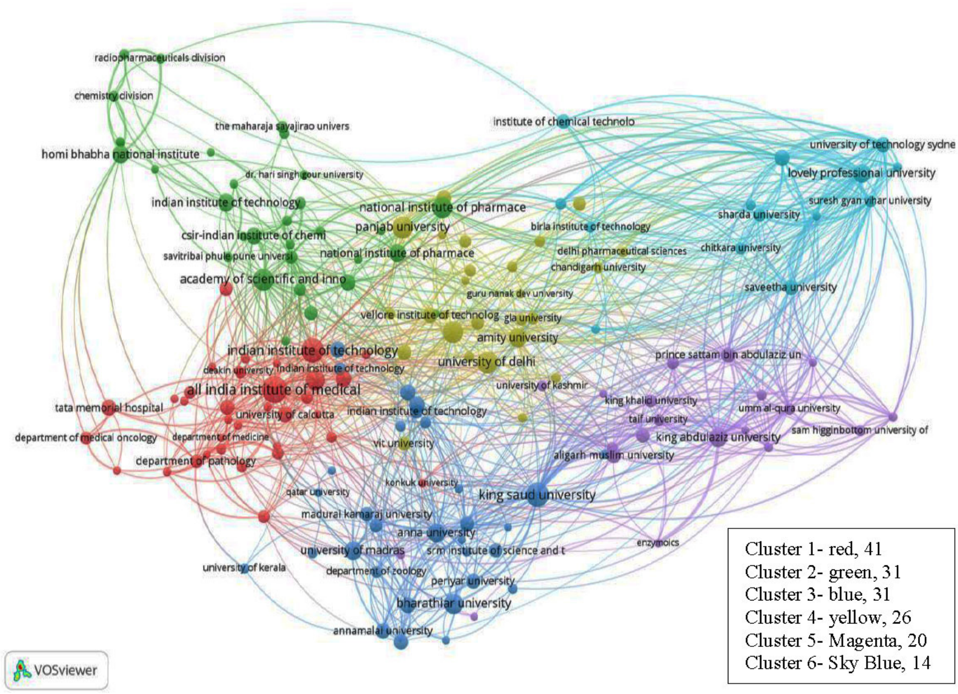

Figure 7

Bibliographic coupling among institutions

Table 6

Top 10 Organisation/institute/ research funding agency based on publications

SN	Name of Institute	Organisation type	TP	TC	CI	Publication share (%)
1	Jamia Hamdard	Deemed University	343	8893	25.9	3.08
2	All India Institute of Medical Sciences, New Delhi	Research Institute	255	4869	19.1	2.29
3	Tata Memorial Hospital	Research Institute	246	5250	21.3	2.21
4	Academy of Scientific and Innovative Research AcSIR	Research Institute	243	6240	25.7	2.18
5	King Saud University	Foreign University	202	5910	29.3	1.82
6	Manipal Academy of Higher Education	Private University	200	4009	20.0	1.80
7	University of Delhi	Central University	196	6323	32.3	1.76
8	Amity University	Private University	183	3220	17.6	1.64
9	Bhabha Atomic Research Centre	Research Institute	181	3845	21.2	1.63
10	Vellore Institute of Technology	Private Engineering Institute	177	3408	19.3	1.59

Table 7

Top ten research funding agency based on publications

SN	Name of Funding agency	TP	TC	CI	Publication share (%)
1	Department of Science and Technology, Ministry of Science and Technology, India	894	26380	29.51	8.03
2	Council of Scientific and Industrial Research, India	563	13922	24.73	5.06
3	Department of Biotechnology, Ministry of Science and Technology, India	551	15233	27.65	4.95
4	Science and Engineering Research Board	518	11239	21.70	4.66
5	University Grants Commission	511	16437	32.17	4.59
6	Indian Council of Medical Research	419	8490	20.26	3.77
7	Department of Science and Technology, Government of Kerala	276	10873	39.39	2.48
8	UGC Fellowship	217	5975	27.53	1.95
9	Department of Biotechnology, Government of India	202	7226	35.77	1.82
10	National Foundation for Cancer Research	190	16006	84.24	1.71

Table 6 presents the top ten high-yielding organizations based on publication count, total citations, Citation Index, and research sharing. The list comprises four research institutes, two private institutes, one deemed university, one central university, and one foreign university. Jamia Hamdard (deemed university) leads with 343 publications and 8,893 citations. The "All India Institute of Medical Sciences," New Delhi, ranks second with 255 publications and a 2.29% share of documents. University of Delhi boasts the highest Citation Index (32.3), followed by King Saud University (29.3). Table 7 lists the top ten funding agencies. The Department of Science and Technology (Ministry of Science and Technology), India, tops the list with 894 funded publications and 26,380 citations. The "Council of Scientific and Industrial Research," India, ranks second with 563 funded publications and 13,922 citations. The National Foundation for Cancer Research demonstrates the highest Citation Index (84.24) with 190 publications, indicating high-quality and contemporary research.

3.8 *Keywords evaluation and hot spot areas of research*

Table 8 presents the top 20 most very often used keywords, with its counts of occurrence and relevance scores. Total 20,546 keywords extracted from published articles, 213 terms with at least 25 occurrences have been selected for analysis. For each term keyword relevance score was calculated, with the top 60% being considered the most relevant. Top occurrence are, Cancer (N = 1757); Application (N = 647); Cancer therapy (N = 591) were Top relevance noted are Nanotechnology (N = 1.25); Diagnosis (N = 3.60); In vitro evaluation (N = 1.21). The analysis reveals that nano-drug delivery research for cancer treatment is closely associated with both subject (cancer) and object (nanotechnology). Key methodologies include drug delivery systems, silver nanoparticles, gold nanoparticles, anticancer activity, and nanomedicine. The relevant research areas identified including "lung cancer", "prostate cancer," "triple-negative breast cancer," and "cancer therapy". The evolution of highly occurred keywords provides valuable insights into research trends and potential gaps in NDS for cancer treatment.

Utilizing R software (Biblioshiny), trend topics were identified by year for the entire study period. Recent research areas (2020-2022) include nanomedicine, cancer therapy, immunotherapy, malignant neoplasm, tumor microenvironment, internalization, and polymer nanoparticles. Notably, polymer nanoparticles found as effective nano-drug delivery agent for cancer treatment. The Overlay visualization of keyword co-occurrence based on title and abstract (nodes) using VOSviewer depicted in Figure 9. Time evolution analysis highlights research hotspots between 2015 and 2022. Node color (blue to red) represents the average year of appearance, while node size indicates occurrence frequency discussed in other studies [52], [53]. Color variation distinguishes newly introduced research from baseline research areas discussed in study [54]. Recent hotspots (2022) include: Nanoparticles (N = 518); Neoplasm (N = 208); Drug carriers (N = 173); Procedure (N = 169); Tumors (N = 149); Polymers (N = 87). Emerging hotspots (2021) are: Nanochain (N = 101); Nanoparticle drug and delivery system (N = 81). Long-term trends (2015-2022) reveal the evolution of nano-drug delivery research in India: Simple drug delivery system (2016, N =

Table 8
Top 20 most occurrence and relevant keywords (obtained by VosViewer)

SR No.	Term	Occurrence	Relevance	Term	Occurrence	Relevance
1	cancer	1757	0.49	nanotechnology	183	1.25
2	application	647	0.37	diagnosis	138	1.23
3	Cancer therapy	591	0.49	vitro evaluation	56	1.21
4	therapy	584	0.70	synthesis	488	1.17
5	treatment	492	0.73	Comprehensive review	61	1.13
6	synthesis	488	1.17	prostate cancer	73	1.13
7	approach	471	0.49	triple negative breast cancer	95	1.11
8	review	467	0.69	advancement	98	1.08
9	characterization	432	1.35	optimization	112	0.99
10	cell	397	0.69	biomedical application	180	0.94
11	evaluation	369	0.93	evaluation	369	0.93
12	cancer cell	351	1.64	lung cancer	193	0.92
13	effect	347	0.69	targeted therapy	89	0.92
14	role	332	0.59	recent advance	165	0.88
15	drug delivery system	276	0.61	gold nanoparticle	233	0.85
16	strategy	255	0.84	nanomedicine	214	0.84
17	silver nanoparticle	250	1.76	strategy	255	0.84
18	gold nanoparticle	233	0.84	nanomaterials	149	0.77
19	anticancer activity	215	2.18	expression	123	0.77
20	nanomedicine	214	0.84	Cancer treatment	206	0.73

7233); Targeted drug delivery (2018, N = 2922); Controlled drug delivery (2018, N = 2638). The Tumour necrosis factor - nanoparticle drug delivery system - nanochain-drug carrier-polymers - neoplasm identified as research chain, between 2001-2022. Keyword overlay visualization identifies research development stages: Early years (purple): foundational research areas, First decade (green and blue): emerging hotspots in NDS research in India.

4. Concluding remarks

Bibliometric analysis facilitates comprehensive evaluation of research domains. This study uncovers the invisible state and development of nanodrug delivery system (NDS) research in India for cancer treatment. Utilizing advanced data analysis and visualization

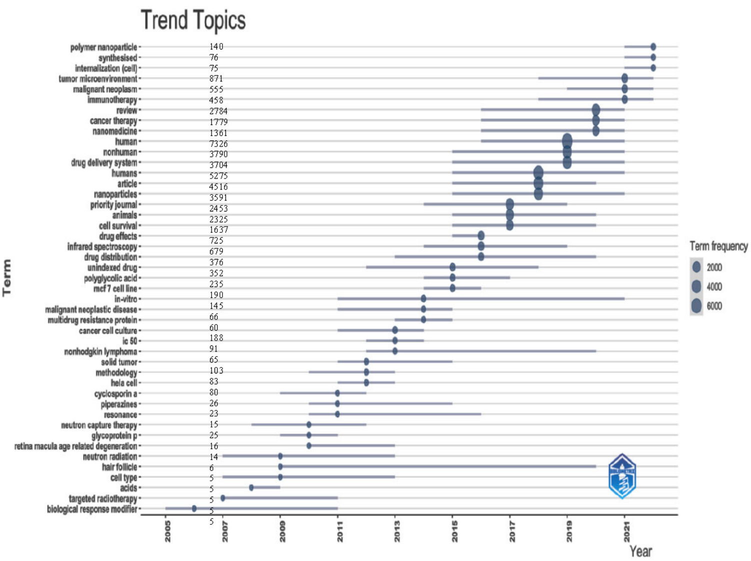

Figure 8

Year wise trend topics in NDS research in India

Figure 9

Time evolution of term cooccurrence.

software, this research reviews scientific literature on NDS for cancer cure. Findings indicate rapid growth in research since 2015, with increasing publication numbers. International collaboration analysis reveals the USA as India's primary partner, demonstrating a strong relationship in medical research. Study found that European and Middle Eastern countries are also emerging as key research collaborators in NDS research with India. This study presents the overall finding on Most productive countries, journals, authors, research institutions, and Research communities involved in NDS research. The Author-defined keyword analysis reveals the development of various NDS over 50 years. Latest research hotspots directed towards, optimization of nano-drug delivery for cancer cure, including nanoparticles, neoplasm, drug carriers, procedure, tumors, polymers, nanochain, and drug delivery systems. Time evolution analysis highlights: Emerging nano-drug carriers, Specific procedures as research focal points. Despite increased activity, NDS research remains underdeveloped, warranting further exploration.

The quality of data gathered significantly impacts the findings of bibliometric studies. This article endeavours' to comprehensively incorporate relevant materials on nanodrug delivery research for cancer treatment in India. However, limitations arise from logical operators and potential synonyms, making it challenging to ensure exhaustive record inclusion. Despite this, the database's margin of error is minimal, with negligible impact on study conclusions, and patterns in NDS cancer treatment. To further advance this field, we recommend: Thorough literature analysis to track qualitative development and investigation of intriguing research problems. The Notable study limitations include: Exclusive reliance on Scopus database, potentially omitting relevant literature; English-language search terms and keywords, overlooking non-English publications; and Exclusion of articles without titles, abstracts, and keywords indexed in Scopus. The future research directions are Bibliometric analysis incorporating multiple databases and languages, Examination of non-English literature and international collaborations and Utilization of alternative statistical programs to validate findings. Despite limitations, this study provides valuable insights and guidance on new directions in India's nanodrug delivery research for cancer treatment, serving as a catalyst for further investigation.

Data availability

All data generated or analyzed for this study are available from the corresponding author on reasonable request.

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