RESEARCH PAPER

A Bibliometric Analysis on Next – Generation Polymers for Drug Delivery: Conductive, Bioresorbable, and Biodegradable Polymers

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1. Abstract

Objective: This bibliometric study presents a detailed research trends of current state on next generation bioresorbable, biocompatible and conductive polymeric drug delivery systems have evolved. By evaluating global research scientific output, this paper tracks how research area evolved from fundamental core-shell drug delivery architectures that have passive drug-encapsulating mechanics towards complex polymer-based structures that are highly responsive to their local biological environment. Methods: Studies from 2008-2026 were collected from Scopus database and analysed using Microsoft Excel, VOSViewer 1.6.20 and BiblioShiny - Bibliometrix R 4.6.0 to evaluate patterns in publication and citation and various knowledge networks. Results: Upon analysis of 1283 papers, we find that research has steadily grown from 2008-2021. There have been two major milestones, one at 2013 and one between 2016 and 2019 as citations peaked in these years. Further, the top influential papers that caused these and what journals are most interested in this research area peaks have been shown. Demographic indexing also shows the leading females and their footprint and weight in the field. Localized mapping shows Indian institutions that have published most in this field and globalized mapping have identified distinct eastern and western hubs. Conclusion: The formulation of effective drug delivery techniques have gained steady traction over the globe and have given rise to cross disciplinary research in this field with significant results that are being applied in therapeutic procedures.

Keywords: Bibliometric analysis, Next-generation polymers, Drug delivery, Conductive polymers, Bioresorbable polymers, Biodegradable polymers.

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2. Introduction:

Drug delivery is a wide field of research on developing novel materials and carrier systems for better efficacy of therapeutic delivery in humans and animals[1]. Conventional methodologies like lotion, cream, ointments, suspensions, powders, immediate release of capsules and tablets etc are used to administer drugs to a target site. These methods may have multiple disadvantages like systemic toxicity, rapid degradation and poor solubility[2].Thus, it became essential that specialized approaches and technologies be formulated to transport a pharmaceutical compound safely to its target without inadvertently harming other organs in the process.

The earliest milestone in this effort was in the mid-1990s when researchers explained the thermodynamic principles that govern the **amphiphilic block copolymer** that can self-assemble into nanoscale core-shell structures, demonstrated in Zhang and Eisenberg's pioneering work on crew-cut micelle formation in 1995[3].

These principles were further applied on engineering nanocarriers of size 10mm -100mm like **PLGA-PEG micelles** that form when the concentration of amphiphillic copolymer exceeds the Critical aggregation concentration(or CAC) through primary hydrophobic interactions between hydrophobic chains. These carriers can encapsulate hydrophobic chemotherapeutics like doxorubicin and allowed modulation of their release kinetics[4]. The next transformative shift was moving beyond passive encapsulation to dynamic control through stimuli responsive systems that react to local biological cues by sensing them[5]. In this same period, we also find an architectural pivot towards complex, naturally derived hydrogels (biopolymers) including chitosan because of their biocompatibility, pH responsive behaviour and functional versatility[6].

The recent research hotspots feature an intersection of oncology, cardiovascular medicine and bioelectronics. In cancer therapy specifically, a combination of therapies are being utilized, integrating photothermal ablation using Near Infrared radiation- responsive polymer vesicles to fight chemoresistance and increase effectiveness of treatment[7]. On the parallel, the domain of cardiac regeneration intersects with the domain of drug delivery as researchers are deploying injectable hydrogels that are responsive to post-infarction cues and simultaneously deliver drugs, stem cells, and therapeutic micro-RNAs to ischemic myocardium[8]. Another interesting emerging field is the bioelectronic interfaces where conducting polymers such as PEDOT:PSS polyaniline are integrated into soft hydrogel matrices that can coordinate with the

*Author for Correspondence: poojabhati@igdtuw.ac.in electrical activity of cardiac and neural tissues[9].

A distinctive feature of this domain is its highly cross disciplinary nature. Research advancements often bridge chemistry, nontechnology, electrophysiology, tissue engineering, and clinical oncology[10].

This convergence has led to a rapid expansion in literature which can be seen in the growing number of bibliometric studies mapping research in hydrogel and nanocarriers[11], [12], [13]. However, there does not exist a comprehensive bibliometric analysis that systematically maps the knowledge structure, its evolution over time, and the co-occurrence keyword patterns within the specific domain of next-generation polymers for drug delivery covering bioresorbable, biodegradable and conductive systems as an integrated whole. Thus, this study bridges that gap through a bibliometric analysis of publication trends, citation trends, co- occurrence networks and clustering of countries, aiming to dissect the key research frontiers, interdisciplinary bridges and future direction in this rapidly evolving field.

3. Methodology

Data was extracted from Elsevier's scopus database. The main query generated a very general and noisy data which was refined using a multi-iterative refinement strategy.

Further, to remove irrelevant noise, a controlled exclusion query was used before applying other technical filters like year ranges. Finally the data was cleaned using a Python script and manual screening. Below, **Figure 1** maps the data extraction and cleaning as recommended in [14].

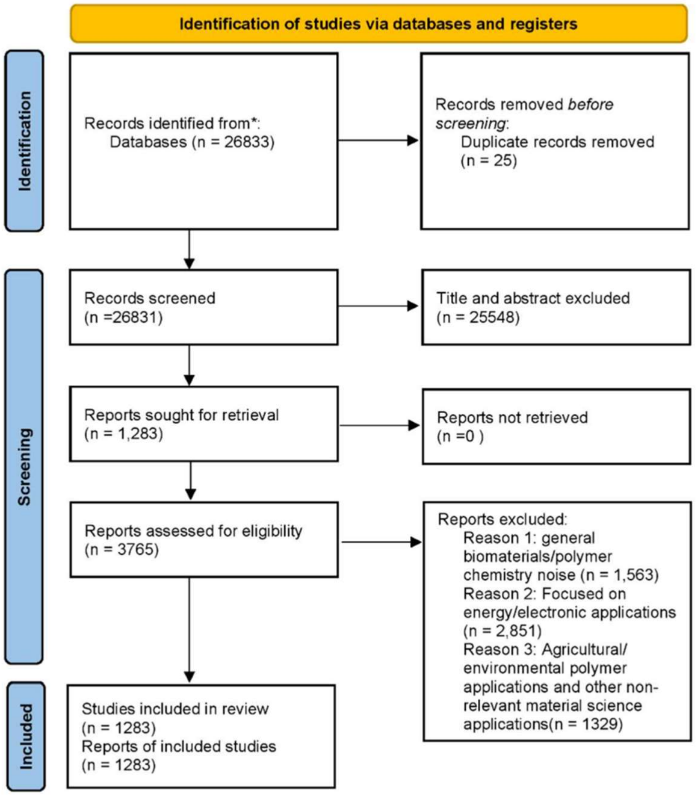


Figure 1 PRISMA flow diagram for the steps of document search. The asterisk (*) indicates that literature was taken exclusively from Scopus database.

3.1. Extraction of Data:

The primary source of data retrieval is Elsevier's Scopus, due to its multidisciplinary coverage and ease of use. Apart from that, it also includes strong filters into different domains like chemical engineering, material science, chemistry and more. The dataset thus obtained also has high quality citation metadata, which has been useful for several insights. To prevent discrepancies due to daily updates, data retrieval process was completed in a single day.

3.2. Data Retrieval Search Strategy

Our bibliometric study starts with a multi- stage iterative query refinement strategy, designed to narrow down a broad polymer drug-delivery domain, step-by-step, into a focused dataset that represents our study. The keywords used were specifically matched with only Title, abstracts and author/indexed keywords.

This ensured that the papers were of both conceptual relevance and query sensitive enough to retrieve most of the relevant documents related to the topic.

The preliminary query included generic terms which produced an excessively broad and noisy dataset of 26,000+ documents. Refining polymeric and hydrogel gave us 9,238 documents. The next step was to remove documents related to general biomaterials and chemistry polymers (instead of polymers related to delivery). This removed a big chunk of the dataset which still left us with 7,675 documents. The next step was to move the dataset towards carrier-focused delivery systems. This landed us at 4,175 documents. The next step focused on the 'next-generation' aspect of our study, which meant adding advanced functional descriptors. Inclusion of these specialized keywords resulted in 3,882 documents.

3.3. Exclusion Strategy

Even after iterative filtering and building of the query, the dataset still had noise related to energy storage, electrode and battery related components. Thus, we built a very controlled exclusion criteria to remove this domain drift. This improved the thematic focus towards biomedical drug delivery applications landing us somewhere around 1000 documents.

3.4. Technical Filters

Final filters were of publication years, which was between 2008-2026. Articles and review articles are the only selected document types while source type was selected as journal only. Further, subject area selection was performed. This resulted in a dataset of 937 papers.

One catch here is that this query did not include conductive and electroactive polymers. This is because this is a very niche area of drug delivery and thus had to be queried separately in a similar iterative manner which gave 373 papers, only on conductive polymers.

Hence the combined dataset used for this study consists of 1,310 papers, which was exported in csv format that VOS Viewer supports. Upon removing duplicates, the final number of documents was 1,283.

3.5. Data Cleaning and Pre processing

This step focused on keyword normalization and cleaning. For this, raw keyword data exported from Scopus was processed through a multi-stage normalization pipeline. The pipeline was implemented in Python using the libraries SpaCy for linguistic processing, rapidfuzz for string similarity matching and pandas for data handling.

As a result of this, first, all keywords were converted to lowercase, removed punctuation, Unicode characters transliterated to ASCII equivalents. Further, Hyphens, en-dashes and em-dashes were replaced with spaces, and excess whitespace removed. This ensured that typographic variants of the same concept such as Drug Delivery, drug-delivery, and drug delivery are all treated as identical strings by VOS Viewer.

The second step is lemmatization. This step handles singular/plural variation. The third step is domain specific Synonym Mapping. This handled 3 categories: The British / American spelling variants, polymer nomenclature variants, and common abbreviation/full name pairs.

The fourth and final step is fuzzy string matching for variant clustering. This step automatically identifies and merges keywords that refer to the same concept but are written differently. Differences can arise due to word reordering, hyphenation differences, or abbreviated suffixes. In this step, only high confidence matches were merged automatically by setting a similarity threshold to avoid collapsing terms that appear similar as text strings but are chemically or conceptually different.

At the end of this preprocessing, the pipeline also generated a report of all the merges done through this process to have complete visibility on good or bad merges.

This introduces us to the next step, The Manual Blocklist All the bad merges from the report like, biological and medical misalignments, wrong chemical or material substitutions were identified and demerged through a new pipeline that also included a blocklist identifying merges that are not allowed. Thus, a new column of author and index keywords was made where all the keywords were correctly normalized.

4. RESULTS

4.1 Annual Publication Volume

As shown in Figure 2 , thegraphshowsa modest baseline of 27 publications in 2008. Over the next decade, the field experiences a sharp and steady rise, reaching its productivity peak in 2021 at 107 annual publications.

This growth highlights a sustained expansion of research interest over the globe in polymeric material synthesis and adaptation of structure[13]. After this peak, a visible retraction occurs from 2022 onward which transitions to a steep drop toward 2026. This apparent decline should be carefully interpreted as latency of databases to include new literature and not as a loss of academic interest.

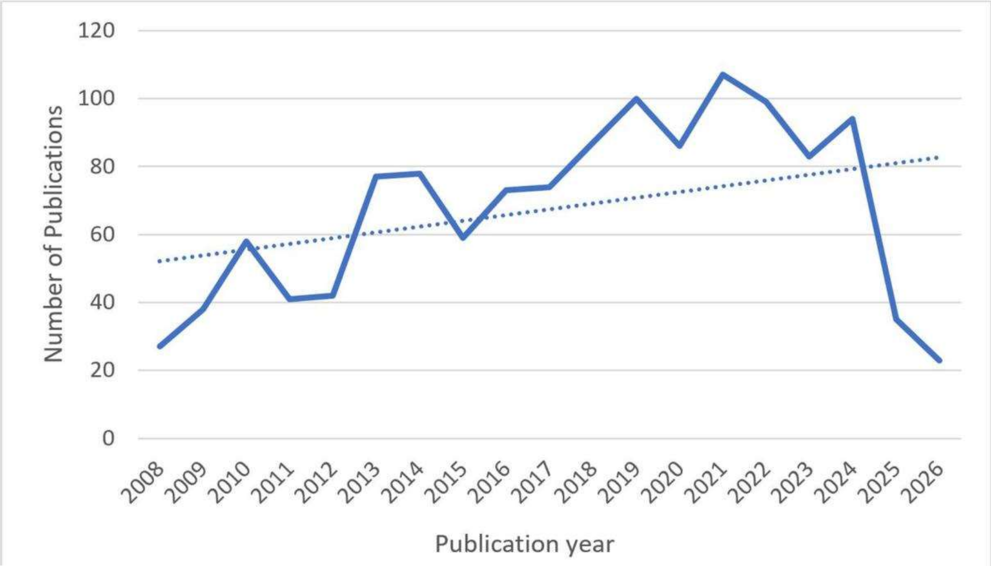


Figure 2 Annual Publication Volume from 2008 to 2026.

4.2 Citation Frequency

The distribution of total citations is an asymmetrical profile, demonstrating that the intellectual impact of the field is concentrated within specific landmark periods. A major historical milestone is visible in the year 2013 which generated an impressive spike of 7,545 citations despite possessing only moderate publication volume (refer 2013 year in Figure 2). This anomaly points towards seminal domain-shifting foundational papers. A secondary broader wave of high impact citations is spread between 2016 to 2019 where annual citation counts sustained levels above 3,400 to 5,200. On the contrary, the sharp tapering observed between 2023-2026 is a classic citation maturation curve since, newly published literature naturally requires a multi-year window to accumulate visibility and pull citations from the global network. **Table 1** Lists the top influential papers that have influenced citation numbers.

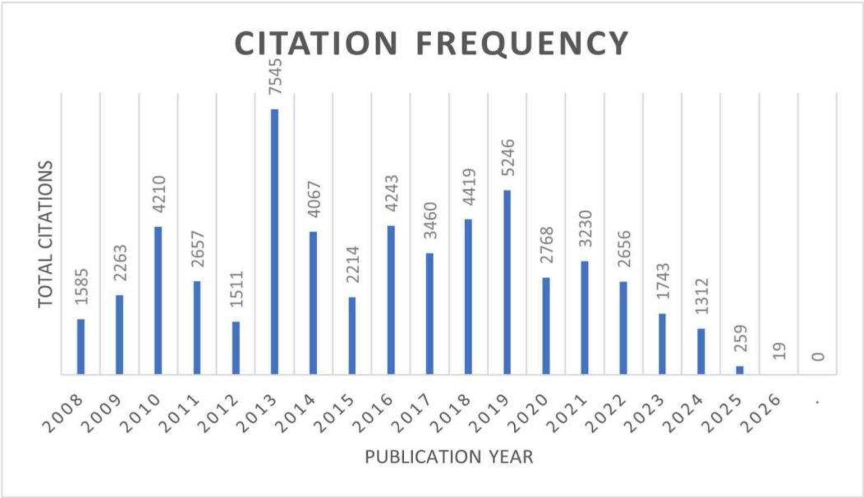


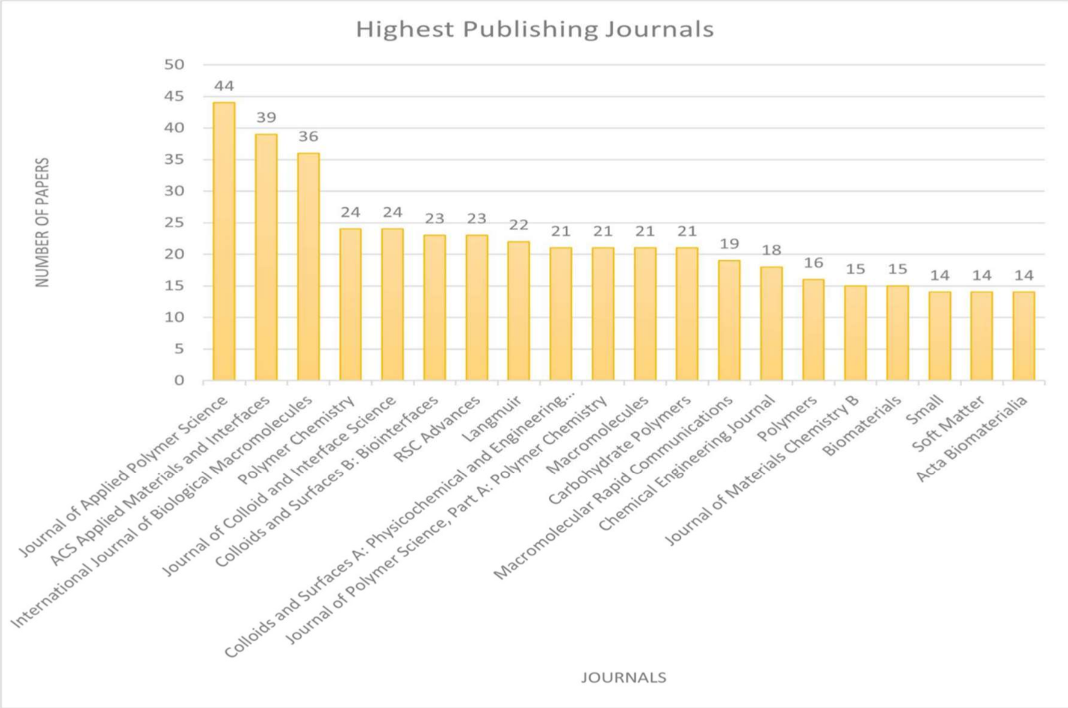
Figure 3 Total Citations for every year from 2008 through 2026

Table 1 A comprehensive table of Top 10 most influential papers listing Authors and titles of those papers along with the year they were published.

Authors	Title	Year	Source title	Cited by	Citation
Sheldon R.A.; van Pelt S.	Enzyme immobilisation in biocatalysis: Why, what and how	2013	Chemical Society Reviews	2544	[15]
Fernãndez-	Recent developments	2013	Biotechnology	587	[16]

Fernãndez M.; SanromÃ¡n M.T.; Moldes D.	and applications of immobilized laccase		Advances		
Esser-Kahn A.P.; Odom S.A.; Sottos N.R.; White S.R.; Moore J.S.	Triggered release from polymer capsules	2011	Macromolecules	564	[17]
	Self-Healing Conductive Injectable		ACS Applied Materials and Interfaces		[18]
Dong R.; Zhao X.; Guo B.; Ma P.X.	Hydrogels with Antibacterial Activity as Cell	2016		529	
	Delivery Carrier for				
	Cardiac Cell				
	Therapy				
	Supramolecular				[19]
	chemistry at				
Yang H.; Yuan B.; Zhang X.; Scherman O.A.	interfaces: Host-guest interactions for fabricating	2014	Accounts of Chemical Research	503	
	multifunctional				
	biointerfaces				
Qiu X.; Hu S.	"Smart" materials based on cellulose: A review of the preparations, properties, and applications	2013	Materials	472	[20]
Li M.-H.; Keller P.	Stimuli-responsive polymer vesicles	2009	Soft Matter	445	[21]
Qu J.; Zhao X.; Ma P.X.; Guo B.	Injectable antibacterial conductive hydrogels with dual response to an electric field and pH for localized “smart” drug release	2018	Acta Biomaterialia	443	[22]
Sharma N.; Madan P.; Lin S.	Effect of process and formulation variables on the preparation of parenteral paclitaxel-loaded biodegradable polymeric nanoparticles: A co-surfactant study	2016	Asian Journal of Pharmaceutical Sciences	442	[23]
Wandera D.; Wickramasinghe S.R.; Husson S.M.	Stimuli-responsive membranes	2010	Journal of Membrane Science	402	[24]

4.3 Highest Publishing Journals



The analysis of publishing journalsin **Figure** *4* shows which journals are driving this research area. It revealed that most of the work comes from the top journals in polymer science and advanced interface science. The most popular journals in this area are thus, *Journal of Applied Polymer Science* (44 papers) followed closely by *ACS Applied Materials & Interfaces* (39 papers) and the *International Journal of Biological Macromolecules* (36 papers). A notable inclusion of specialized biomaterial and colloid focused journals such as *Polymer Chemistry*, *Colloids and Surfaces B: Biointerfaces*, and *Biomaterial,* confirms the strong alignment of this field toward soft-matter engineering and specialized biochemical translation matrices (biological systems that help convert or transfer biochemical signals from one form to another).

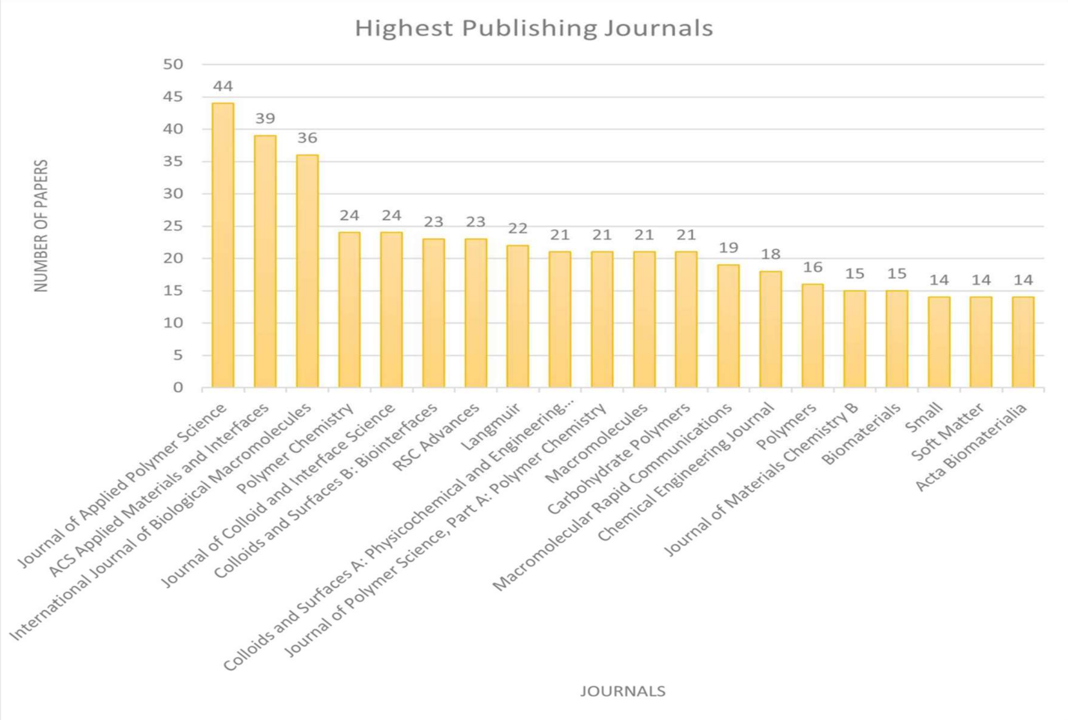


Figure 4 Highest Publishing Journals

4.4 Top Countries in the field

The Highest, giant contributor in this field is China, with 507 documents. The second place is currently secured by United States with 161 documents closely followed by India with 116 documents. In the fourth and fifth places are Germany and Iran with 67 and 58 publications respectively. Other smaller contributors by size are France (52), South Korea(46), Japan (41), Spain (40), United Kingdom (33), Taiwan(31),Australia (25), Brazil (24), Canada(22), Netherlands and Singapore (20), Saudi Arabia, Pakistan and Hongkong(18). Every country in Figure 5 has a minimum of 18 publications. China, being the main contributor of the field, suggests that it has pioneered several technologies and methodologies in this field. One single most active sub-domain in China is the NIR-triggered polymer vesicles that deliver chemotherapeutics and was pioneered by [25] at Sichuan University. And this is only one of many examples. Another technology that distinctly emerged in China is the aggregation-induced emission (AIE) phototheranostic nanoplatforms. AIE was discovered by Ben Zhong Tang's group at Hong Kong University of Science and technology[26]. Chinese researchers have since taken this concept forward into NIR-II phototheranostic polymer nanoparticles which enable deep-tissue imaging while providing photothermal and photodynamic therapy for image-guided cancer treatment and immunotherapy[27].

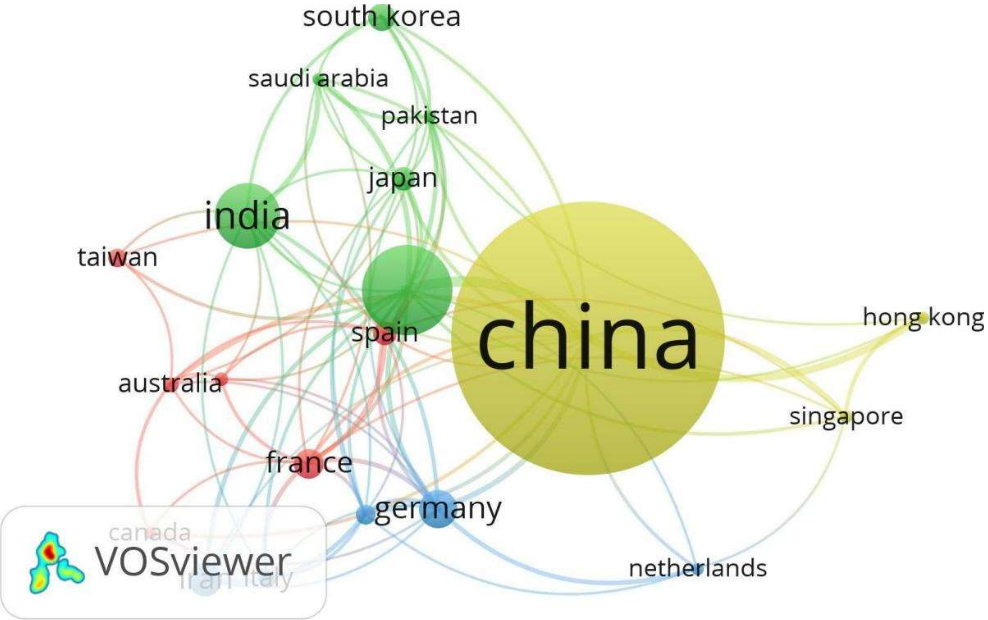


Figure 5 Top contributing countries in the field. Size of circle demonstrates number of publications. Greater the number of publications, bigger the circle.

4.5 Co-Authorship network analysis(unit analysis: authors):

In the co-authorship network analysis, Figure 6, with a minimum threshold of published articles as 3, we get 4 distinct clusters with 56 links and total link strength of 128. One point to be noted is that each cluster is connected to only one other cluster and connected by only one author from each cluster, which suggests that these are not institutionalized partnerships.

The single and important exception is the yellow zhang, jian node that is connected to almost all green authors. This directly points to the fact that Zhang, Jian is a key, either, interdisciplinary or more probably a key interinstitutional bridge.

Zooming into each cluster, the green cluster has the largest nodes which suggests highest citation weight and also is the densest in concentration of links that also overlap. This indicates that this group publishes most frequently and have a highly tight-knit team.

The most sparsely connected of these clusters is the red cluster where only one author is connected to four other authors and the rest are only connected with one other author.

The green cluster is thus, in stark contrast with the red cluster. On one hand, where the green cluster represents an institutionalized and collaborative team, the red cluster represents an individual-centric hierarchical team.

The blue cluster is like the green cluster except, its less dense and the yellow cluster is a mix of the green and red clusters. Liu Peng and Liu Lei are the biggest nodes in the yellow clusters with Liu Peng being a much bigger one. The other nodes are connected to at least one or two other nodes.

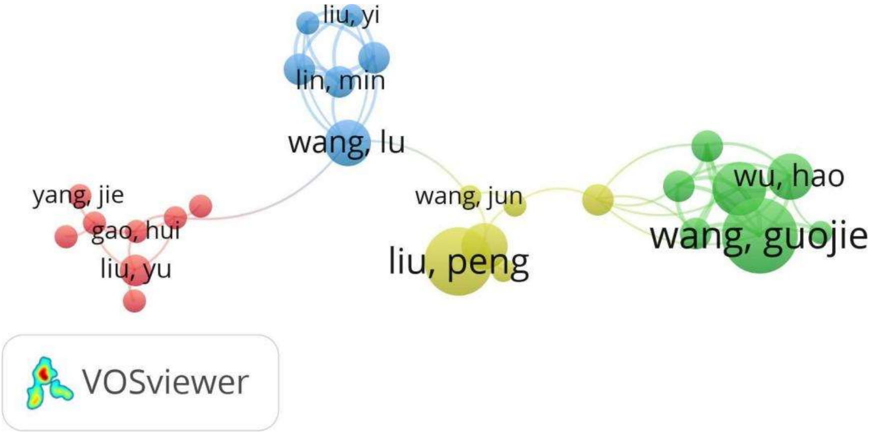


Figure 6 Co- Authorship network Analysis

The mystery of why the largest yellow node Liu, Peng is connected to only one other node is solved by the overlay visualization.

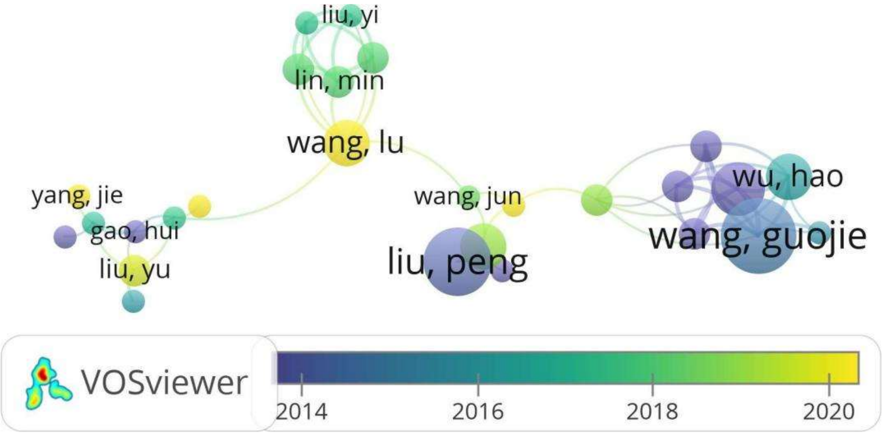


Figure 7 Co- Authorship network Analysis Overlay Visualization

Liu, Peng and Wang, Guojie are colored in blue in **Figure 7**, which suggests that they are legacy pioneers of this field. This points to two more things, one, that they have not published since 2015 and two, their work was so fundamental that it still carries great citation weight today.

Wang, Lu here, seems to be the rising star driving the research in present date in this field.

Table 2 shows the demographic indexation of the field. Part of the reason why all of the leading female authors are from China is due to its huge share in overall publication compared to other countries, as seen earlier in Figure 5.

Table 2 Top 10 female authors in the field and their labs

Author full name	Author code	Labs
Li, Lianzhen	57986500000	MOE (Ministry of Education) Key Laboratory of Macromolecular Synthesis and Functionalization
Liu, Xiaolin	57192926012	Polymeric Biomaterials and Tissue Engineering Laboratory
Li, Meng	56424069600	Key Laboratory of Biomedical Polymers of Shaanxi Province
Zhang, Chujun	57188973711	State Key Laboratory of Polymer Materials Engineering
Liu, Shuwei	57204908989	State Key Laboratory of Chemical Resource Engineering
Wang, Di	57198728902	Research Center for Biomedical Engineering, Xiamen University
Liu, Hui	57216168481	Jiangsu Key Laboratory of Advanced Functional Polymer Design and Application

Sun, Yanan	55737772300	Key Laboratory of Biocompatible Materials, Zhengzhou University.
Yang, Liqun	55733025000	Department of Biomaterials at Xiamen University and the Research Center for Biomedical Materials.
Zhao, Xin	56941042200	Department of Biomedical Engineering, The Hong Kong Polytechnic University (PolyU).

4.6 Bibliographic Coupling of Countries

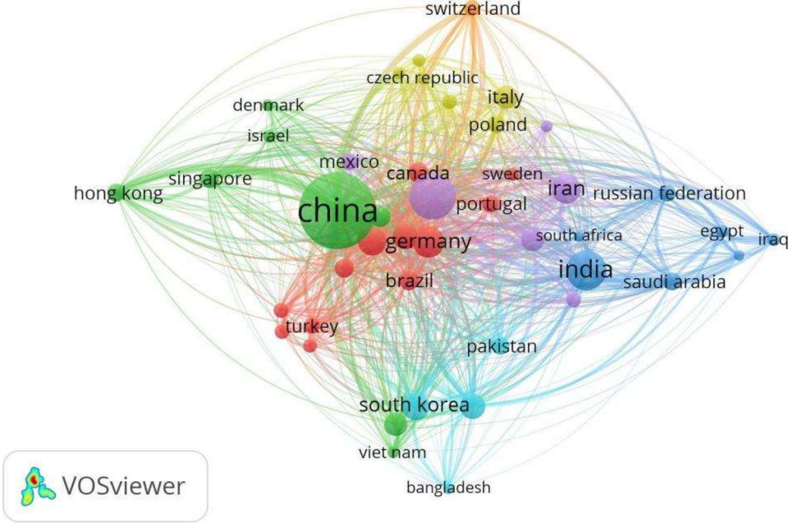


Figure 8 Bibliographic coupling of countries

In this bibliographic coupling of countries map, the baseline of understanding is: size of node represents the country's total document publishing volume or citation weight. If two countries are close together and linked, it implies that these nations are citing the same foundational literature. According to these baselines, the first and most prominent insight is that China is the main anchor of this field, and is closely followed by India, Germany and United States. China thus serves as the foundational base for the entire ecosystem.

A key takeaway form this visualization is how countries like Bangladesh, Vietnam, Egypt and Iraq sit on the edges of this network. This means that they are publishing in this domain but they are academically isolated which is shown by their tiny circles and long and thin lines. Thus, there is a critical need for global knowledge sharing initiatives to integrate the research spaces of the developing nations into the mainstream global network.

This world map has been split into very distinct geographic and socioeconomic clusters based on their common literature choices.

The first is the Green, east Asian/Pacific Cluster: The key nodes are China, Singapore, Hongkong, South Korea and Vietnam. The proximity of Hongkong and Singapore to China suggests that even though they may be sharing the same literature, they may not be heavily collaborating. Proof of this ishow in section, Top Countries in the field, both Hong Kong and China published seminal papers, but not in collaboration. Theycame one after the other showingthat they do share the same literature, but are not necessarilycollaborating. Both Singapore and Hongkong are global research hubs that publish heavily in English, have diverse international faculties and collaborate extensively with the western nations.

While China and India alike, are big independent research hubs with huge publishing volumes.

This brings us to discuss the blue cluster on the right with India being the main player. In this cluster as well, KSA, Russian federation, Egypt and Iraq, despite sharing the same foundational literature are pushed to the edges. Part of the reason is the same as Hongkong and Singapore's, diverse international faculties, and part of it is also that they share the same color because they all rely on traditional, open-source or broadly accessible foundational literature rather than being deep into highly specialized niches and dominating them like China or Germany.

Thus, India is acting as the primary intellectual bridge for the developing research corridors in South Asia and Middle East[28], [29], [30]. It is observed from **Table 4** that the southern part of Inda is more active. The top Universities that are contributing to this research are shown in **Table 3**.

The red cluster, consists of Germany, Canada, Brazil, Turkey, Mexico, Netherlands, Romania, Hungary, Portugal, Sweden and Thailand. An interesting cluster. Thailand is obviously a geographic outlier here. This phenomenon highlights the impact of the historic academic exchange networks such has Franco- Thai cooperation programs and the long - standing alliance between Chulalongkorn University, one of Thailand's top research universities and the Max Planck Institute for Polymer research in Mainz, Germany, which is one of the world's top-tier authorities on smart materials. Because of Thailand's deep European ties, Thai researchers are being trained in European methodologies and are thus heavily citing the same classic European frameworks as Germany, France or Romania.

The red and purple cluster together form the trans-Atlantic academic bloc (apart from the few geographical outliers mentioned). The Latin core is drawn towards the western academic and research systems, likely due to deep rooted collaborative funding pipelines or common historic literature references between the western Europe and North America.

Table 3 Top 5 publishing universities in India

Row Labels	Sum of Count of papers
CSIR-NIIST Trivandrum	6
BR Ambedkar National Institute of Technology, Jalandhar	4
IIT-Roorkee	3
University of Kerala	3
IIT-Hyderabad	3
Grand Total	19

Table 4 Top 5 publishing states in the India:

Row Labels	Count of State
Tamil Nadu	16
Delhi	8
Maharashtra	7
Gujarat	5
Karnataka	5
Grand Total	41

The **Table 4** and **Table 3** show that the domestic landscape is heavily dominated by the Southern states (e.g., Tamil Nadu, Karnataka) and Western technical corridors (e.g., Maharashtra)

4.7 Co-Occurrence of Keywords Analysis - The Overlay Visualization

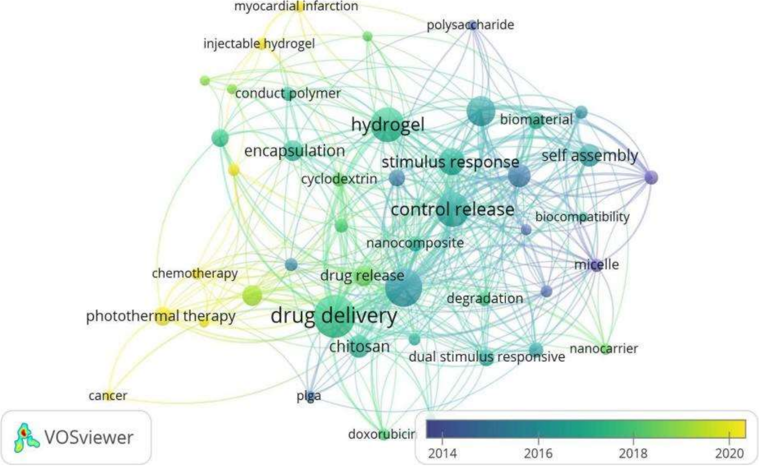


Figure 9 Co-Occurrence of Keywords Analysis - The Overlay Visualization

This field's roots originate in classic nanotechnology and chemistry. Early researchers were focused on understanding how amphiphilic (compounds that have both hydrophilic (water-loving)parts and hydrophobic(water-hating)parts) block copolymers organize themselves unprompted through selective solvent thermodynamics to become nanoscale, core-shell structures[3]. These principles were then systematically used to build and engineer standard carriers like micelles or PLGA-PEG nanospheres[31], [32] which served primarily to encapsulate and carry highly toxic chemotherapy payloads such has doxorubicin to alter their baseline release kinetics as discussed in [33], [34].

As the timeline transitions into the middle of our network which is represented by teal and green nodes, the vocabulary shows a significant perspective shift from self-assembly structure formation to engineering controls in them that are dynamic. During this transformative stage, the research domain extended beyond just encapsulation that degrades passively to heavily focusing on achieving precise controlled release kinetics by developing advanced stimulus response systems[35] that can be tailored to react actively with localized biological environments[36]. This era is also characterized by a pivot in architecture towards complex, cross-linked structures such has hydrogels[37], with a clear inclination towards natural, biocompatible and easily functionalized biopolymers like chitosan[38].

By utilizing the protonation dynamics of chitosan's primary amino groups in varying pathological cues such as different than normal pH in and around tumor cells[39], these smart macromolecular systems basically bridge the gap between basic biopolymer chemistry and targeted on-demand drug release.

At the absolute edges of the network denoted by bright yellow nodes the research domain shows a important transition from foundational macromolecular chemistry to targeted medical treatments, therapies and clinical applications[40].

Within this emerging area, the academia is heavily marked by oncological applications where experimental study has moved ahead from single agent drug-delivery toward highly complex combination drug delivery systems[41].

Specifically, the network highlights a dense, overlapping trend that combines chemotherapy and photothermal therapy for localized synergistic cancer eradication[25], [42]. In these systems, stimuli-responsive polymer vesicles are functionally engineered to undergo sharp, laser-triggered phase transitions or structural collapse when irradiated with near-infrared radiation(NIR). This photothermal precisely destroys localized tumor cells while simultaneously quickly releasing stored cancer-fighting drugs like doxorubicin or modern taxanes on demand[25], [43], [44]

Another major concurrent shift in the non-oncological domain is seen at the upper boundaries of the network that targets cardiovascular regeneration, more specifically myocardial infarction[45]. Researchers are increasingly employing environmentally triggered injectable hydrogels that dynamically respond to key disease-related changes following infarction (such as localized oxidative stress or disturbed matrix metalloproteinase(MMP) levels)[46], [47], [48] to synthesize shape-conforming, bioactive scaffolds that, apart from drugs also deliver cardiac stem cells or therapeutic microRNAs directly to the ischemic tissues [49], [50].

Last point to be noted here is that this shift is reinforced by integration of conducting polymers (like PEDOT:PSS or polyaniline) into these responsive soft matrices[51], [52]. The inclusion of conductive elements introduces active bio-electronic interfaces and electrical sensitivity or electrically responsive behavior. This allows the vesicle hydrogel networks to move and respond in coordination with the electrical activity of the heart[51] and nerve tissue[53].

5. Discussion

Longitudinal analysis shows a multi-stage production profile where publication volumes rose from 2008 and reached its peak at 107 yearly publications in 2021. This finding is supported by pioneering citation spike in 2013 (7,545 citations).

Analysis on Journal publication volume for this research domain identified Journal of Applied Polymer Science, ACS Applied Materials & Interfaces, and the International Journal of Biological Macromolecules as primary publishing houses. Bibliographic coupling of countries reveals distinct knowledge corridors: The East-Asian academic bloc anchored by China, a trans-Atlantic network anchored by United States and Germany that incorporates emerging nodes like Thailand and Turkey through state-sponsored pipelines and an independent South Asian-Middle Eastern cluster anchored by India. Further co-occurrence keyword analysis revealed a chronological transition starting from core-shell micelle physics and PLGA self-assembly in early 2010s. This further moved towards smart, environment-intelligent chitosan hydrogel structures for controlled release in the late 2010s. The research in the 2010s thus resulted in methodologies and materials that became applications in cancer therapies and led to creating injectable hydrogels for myocardial infarction.

In the end, the integration of conducting polymers indicates a rise in the bioelectronic frontier. While our data was deliberately restricted to biocompatible drug delivery frameworks, which helped us establish a clean boundary and get coherent and conclusive trends from VOS Viewer and BiblioShiny, looking at the wider landscape, it is clear that soft robotics, biomimetic grippers and adaptive automation is currently booming. This creates a clear future scope for cross disciplinary research between material sciences and smart mechanical and industrial engineering applications. The smart, bioresorbable and conductive polymer matrices that have been optimized through almost two decades, are non-toxic possess the exact electromechanical coupling and stimuli-responsive properties that are required by soft robotics domain. Thus, the next rationale for material researchers would be to utilize this cross-disciplinary potential. Future research should focus on taking these highly refined bio-electronic delivery hydrogels and deploying them into robotic actuators, pick-and-place automation systems and biomimetic robot-human interfaces.

6. References

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