Annals of Library and Information Studies
Vol. 69, March 2022, pp. 66-74

How collaborative is Indian academia? A case study of top three ranked institutions

Bhaskar Mukherjee[a] and Ankit Singh

Department of Library & Information Science, Banaras Hindu University, Varanasi, India

[a]Email: mukherjee.bhaskar@gmail.com

Received: 13 December 2021; revised: 14 March 2022; accepted: 14 March 2022

The present study employs bibliometric methods to examine the pattern of existing collaboration in India's top three ranked academic institutes using publications indexed in the Web of Science for the period 2000 to 2020. The results show although the number of collaborations and the degree of collaboration have increased over time, however, the collaboration coefficient remains almost the same in the three institutes. The lesser negative Pearson correlation between authors and articles with a higher positive Pearson correlation between articles and citations for JNU publications suggests that collaboration with a smaller group is more successful than a larger group for gaining citations. Collaborative publications of Banaras Hindu University (36%) and Indian Institute of Science (33%) are more inclined towards authors of the same department, while for Jawaharlal Nehru University, it is with other authors from different universities (41%). The foreign collaboration for all three institutes is almost the same. The network visualization of collaboration in three institutes suggests that the collaborative research in IISc is more diverse than JNU or BHU and in national collaboration, distance between two national organizations also play an important role for strong collaboration. Overall, theoretical aspects of physics lead in collaborative publications followed by chemical sciences. Agricultural biotechnology, clinical medicine, polymer sciences and nanoscience are some emerging disciplines where organizations are increasing their participation through collaborative research.

Keywords: Collaborative research; Collaboration; Bibliometrics

Introduction

Individual scientific research is evolving into collaborative research owing to the many inherent complexities in scientific research. Many scientific problems can be solved by working together with a team of scientists from different countries, institutions, or backgrounds. It is believed that useful and effective sharing of viewpoints, specialized knowledge of scientific disciplines, multi-disciplinary studies, increasing research costs and political factors all have played important role in increasing the level of collaboration between researchers[1].

Collaborations also open opportunities to work with industries, the private sectors as well as governments through effective communication and partnership. The USA had enacted the Bayh-Dole Patent Reform Act in the 1980s for promoting cooperative ventures between and among research communities. (https://www.govinfo.gov/content/pkg/CHRG-110hhrg36592/pdf/CHRG-110hhrg36592.pdf). Many other countries have also introduced various acts based on the Bayh-Dole act. India, however, is yet to have any such act in force.

Indian Institute of Science (IISc), Jawaharlal Nehru University (JNU), and Banaras Hindu University (BHU) are the top three leading universities of India under the University category as per NIRF 2021 (https://www.nirfindia.org/2021/UniversityRanking.html). National Institutional Ranking Framework (NIRF) ranks institutes every year based on five parameters. Of these five, one parameter is 'Research and Professional Practice" (30% weightage) in which publications (PU, total score 35), quality in publication (QP, total score 35), intellectual property rights (IPR, total score 15) and projects & professional practices (FPPP, total score 15) have been considered. In 2021 ranking IISc, Bangalore got 35 in PU and 35 in QP. JNU got 20.15 in PU & 20.56 in QP and BHU, 18.18 in PU and 23.64 in QP.

To promote collaboration with national and international partners, the three institutions have established linkages with universities as well as industries. While IISc has a Centre for Scientific and Industrial Consultancy, JNU has linkages with institutes in 48 countries. The International Centre, BHU was established to promote collaboration with

various nations and has adopted National Innovation & Start-up Policy. All these three centrally funded institutes have more than 50 years of existence. Comparing the research productivity of such reputed institutions is a significant and positive predictor of understanding both fiscal performance and trends in research.

Review of literature

Bibliometric analyses are relevant to the identification and characterization of the scientific profile of institutions and research fields[2] to identify future research priorities, funding sources, and interdisciplinary collaboration[3]. Such analysis enables institutions to judge how their policies translate into reality, to assess their strengths and weaknesses on research fronts[4], and accordingly modify and implement research policies. Bibliometric studies on collaboration have two preferred themes of inquiry viz., explanatory factors of collaboration and effect of collaboration on publications[5].

It is widely believed that collaboration correlates with research productivity[6] and especially international collaboration[7] with impact in research[8], however, Larivière et al[9] asserted that the impact of an article in terms of citation is particularly related to the number of participant authors, number of address and number of countries represented in the byline of an article. Narin et al[10], in addition, also observed that articles are more cited when collaborators are foreign as compared with those that are signed by local and national collaborators. But the number of collaborations is a predictor of publishing productivity in normal count method. It is not so in the fractional count of papers of the collaboration.

Frenken et al[11] showed that the diffusion of scientific knowledge as measured by citation is dependent on both intra- and inter-organizational characteristics. Citation impact can be related to the geographical scale of collaboration. Therefore, it is not fair to say that collaboration always leads to citations as there are other factors like number of collaborators, type of institutions involved and country of affiliation which also act as a catalyst for getting more citations.

Researchers who wish to add something new to their field may find that the reward is greater in doing so through remote collaboration than with others of the same laboratory[12]. International collaborations are preferable as they seem to produce higher impact[13]. It has also been believed that trade-off between academic publication and industry-oriented research and collaboration with industry lead to an initial increase in productivity[14].

To understand the diversity of collaborations, social network analysis becomes an important tool to study the partner's position embedded in collaboration network[15]. The configuration of linkage between partners, including the center and periphery in the organizational network, helps in determining the process of creation and flow of knowledge among partners[16]. It also helps to answer the question of how partners should change their interactions to acquire a more desirable and advantageous position within a network[17]. The degree of centralities like closeness and betweenness helps to understand the number of collaborators each node has, and also the distance between nodes and partners, and further the number of times a node lies 'between' other pairs of nodes[18].

Research collaboration is common in research, including natural and medical sciences as well as social sciences[19]. It is also observed that across all disciplines, science in contemporary time has globalized at steady rate and the average collaboration distance per publication has increased from 334km in 1980 to 1553km in 2009. Despite significant difference in globalization rates across nations, a pervasive process in motion has been observed in the context of collaboration in science.

De Sola Price[20]pointed out that collaboration plays a pivotal role, alongside competition in the innovation process of the country and has suggested that most productive researchers are those who collaborate most. The existing literature on collaboration pattern in India mostly discusses the authorship pattern or explains the pattern of collaboration in specific discipline like chemistry[21], biotechnology[22], solar cell research[23], economics[24], psychology[25]. However, irrespective of discipline, how academic authors of a large-scale institutes participate in knowledge-focus collaboration with national and international partners, or property-focused collaboration with industries, or how collaboration effects in getting citation, and overall, how collaboration exhibit holistic knowledge output in different disciplines of an institution is yet to be explained.

This study is an attempt to assess the current situation of collaboration by considering India's top three academic institutes in terms of quantity, citation,

extend of national & foreign participation in collaboration, and prominent areas of collaboration. To handle the data to a manageable extent, the present paper analyse all these parameters by restricting only top three NIRF ranked academic institutes of India.

Objectives of the study

- To identify the scientific activity (publications, collaboration, citations) of top three institutions; and form of collaboration (domestic or international, partnering countries);
- To assess the extent of collaboration between top national and international partners by using social network analysis; and
- To compare the collaborative dimensions (sectors, disciplines, and publication outlets) by establishing a subject framework.

Methodology

We identified top three ranked universities from the National Institutional Ranking Framework (NIRF) 2021. In the mid of June 2021, we retrieved publications of the three institutions from Web of Science for the period 2000 to 2020. We used the following parameters: *Affiliation* [name of each institution as mentioned in A-Z list] and *Year Published* [2000-2020]. Full bibliographic records of 'articles', 'reviews', 'proceedings', were considered from total download for analysis and however, publication types like 'Letters', 'Corrections', 'Editorial materials', and 'News Items' were excluded from the total downloaded data.

MS-Excel software was used for data analysis. Simple descriptive statistics like collaborative index (CI), degree of collaboration (DC), and collaboration coefficient (CC) have been calculated using formula given below. While CI is counted by the formula suggested by the Lawani[26]; the DC is counted by the formula suggested by the Subramanyam[27]; and the CC is counted by the formula suggested by the Ajiferuke et al.[28], which are as follows:

$$C1 = \frac{\sum_j^k j \times f_j}{N}, DC = 1 - \frac{f_1}{N}, CC = 1 - \left\{ \sum_{j=1}^{n} (1/j) f_j / N \right\}$$

Where,

j = the number authors in an article i.e. 1, 2, 3 ……

f_j = the number of j authored articles during the period

f1 = the number of single-authored articles

N = the total number of articles published during the same period, and

k = the number of authors per article

To analyze and visualize the collaborative network of these three institutions, the social network analysis tool VOS viewer and Pejak have been used. VOS viewer is a freely available tool based on Clauset, Newman, and Moore's[29]algorithm developed by Waltman, van Eck, and Noyons[30].

It was required to group subjects from a number of diversified author keywords in a framework from which the country's research performance and emerging research fronts could be properly gauged. For this, we followed two steps. In the first step, all the subfields of the publications were identified; in the second, all these subfields were categorized into a framework of major domains of research.

WoS proves a tag, 'SC' (Research Area). One thousand three hundred and twenty-eight (1328) unique 'SCs' were identified. For effectiveness, we developed a framework and grouped all these subfields into a cluster of broad fields.

To develop the framework, we consulted the Essential Science Indicator (ESI) maintained by Clarivate Analytics and the *Revised Fields of Science & Technology* (FOS) classification in the Frascati Manual of OECD (2007) to understand how the subjects of science can be grouped in the best possible manner. Both the classification schemas organize related subjects under a broad subject category. By consulting both the schemas, we have developed a new schema consisting of 10 broad fields and 25 subfields.

In case the 'SC' field of any publication contained more than one subfield of our scheme, we kept it as multidisciplinary. The reason behind developing a new schema was that the existing two frameworks are not fully compatible to show the emerging and important research areas of Indian science and technology. For grouping subjects, two principals were kept in mind, viz. 1). Specific research fields are preceded by General research fields and 2) if any publication has 'practice' as well as 'theory' emphasis, the publication has been kept in practice sub-fields.

Results

Table 1 summarizes the publication, fractional publications, authors, and authors in contrast with citations for the three academic institutions. IISc authors received more citations than BHU and JNU authors. However, the dataset in our analysis suffers

from dispersion as the standard deviation of publication (56.93, 89.60, & 65.86 for IIS, JNU, and BHU respectively) of all three organizations significantly exceed its means (22.39, 20.82, & 20.52 for IISc, JNU, and BHU respectively). This skewed distribution suggests that a small number of publications received many citations while many publications receive a small number of citations.

The collaboration index shows that on average, each article from BHU was the result of collaboration between more authors than JNU or IISC. This is because there are 51 articles from BHU and 18 articles from JNU where the number of authors per article is more than 500, whereas no article of IISc has such large author group.

Figure 1 shows the number of collaborative publications for BHU has increased steadily as compared to JNU or IISC. Overall, a degree of collaboration of 0.85 to 0.96 showed a relatively similar tendency towards collaborative works. The collaboration coefficient nears to 1 for all three institutions which indicates that the trend of collaboration is more towards the multi-authored paper. However, at the same time, a negative Pearson correlation between author and article means although 'number of collaborative articles per year' has increased from 2000 to 2020, the other variable that is 'number of authors per article' has not increased with the same magnitude, or the two datasets move in a non-linear way.

A higher degree of collaboration is found only because of a limited number of articles where the number of authors is quite high. Negative moderate degree correlation has been observed in IISc whereas a negative weak degree correlation has been observed in BHU and JNU. In contrast, a positive correlation between author and citation indicates that the number of authors in an article is deciding factor in getting more citations.

If we relate the quality of publication with the number of citations received, it may be concluded that quality could generally be dependent on collaboration activities but collaboration with a smaller group is more effective than in a larger group, as the Pearson correlation is much higher for JNU than BHU or IISc.

In Table 1, we have summarized that collaboration has a relation with citation. In the next steps, we try to understand which form of collaboration leads to more citation.

Table 1 — Publication pattern of top three academic institutions

Particulars	IISc	JNU	BHU*
Total Output: Output in collaboration (%)	31946: 29925 (93.67)	7884: 6748 (85.59)	17872: 17235 (96.44)
Average authors/ collaborative articles	3.98	2.76	11.82
Collaborative Index	3.83	7.44	11.43
Degree of Collaboration	0.9500	0.8559	0.9643
Collaboration Coefficient	0.6806	0.6107	0.6842
Cit./Art (Solo): Cit./Art (Collaborative)	12.31: 22.39	3.98: 20.82	10.94: 20.52
Fractional Cit. /Collaborative article	6.90	4.73	5.10
Pearson Correlation [article & author] (r)	-0.46756	-0.23108	-0.20662
Pearson Correlation [author & citation] (r)	0.059493	0.466553	0.288156

Art. = Article, Cit.=Citation, * =Excluding IIT-BHU

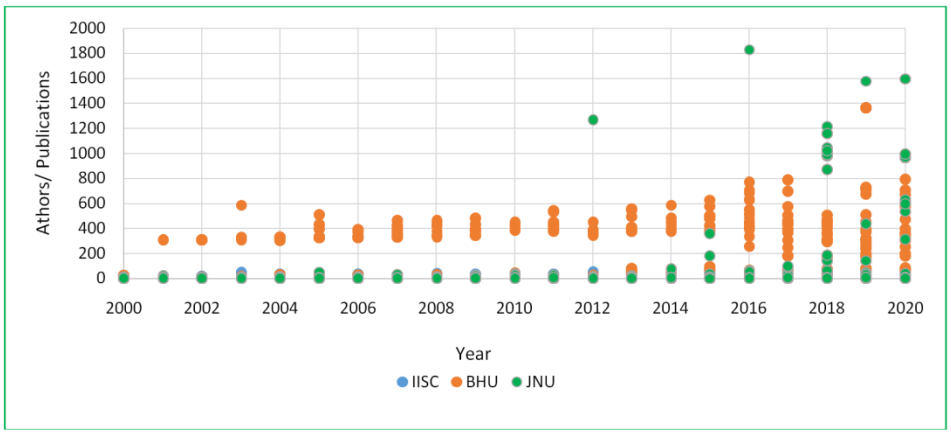

Fig. 1 — Collaborative research trends

While collaborative publications of BHU (36%) and IISc (33%) are more inclined towards authors of the same department (ID), authors of JNU collaborate more with other authors from different universities (41%) Table 2. The foreign collaboration publications for all three institutes are almost equal, which never exceed 20%. However, authors of almost 160 countries out of 195 countries of the world have participated in collaborative activities. Articles published in collaboration with foreign authors received 37% of the total citations for JNU, 33% for BHU but only 22% for IISc.

Collaboration as visualized in network analysis

Table 3 indicates the number of links, closeness centrality, and betweenness centrality of the top 5 national and international institutions of each of these organizations based on total collaborative publications. The disparity in total publications and total links indicates that real social connections are difficult to establish. The larger number of clusters for IISc suggests that the dimension of collaborative research in IISc is more diverse than JNU or BHU. JNU and BHU have more generic characteristics and thus yield fewer clusters. In national collaboration,

Table 2 — Extent of collaboration in academic institutes

Collaborative Publications & Citations	IISc	JNU	BHU
% Global:% Citations	20.77:22.95	20.04:37.02	19.52:33.70
% Local: % Citations			
University-Industry (UI)	6.51 :7.25	7.34 :7.07	8.89 :7.63
University-University (UU)	29.47 :29.71	41.06 :33.24	25.02 :19.65
Intra-Department (ID)	33.52:31.46	26.90:13.93	36.34:30.24
Intra-University (IU)	9.29:8.62	3.42:2.43	9.90:8.78
Active MoUs (# Countries)	110 (27)	91 (36)	57 (22)

Table 3 — Major National & International Collaborators (collaborate in 10 or more articles)

Top Indian Collaborators	NIRF Rank	IISC (13 clusters)				JNU (5 clusters)				BHU (3 clusters)			
		TP	TL	CC	BW	TP	TL	CC	BW	TP	TL	CC	BW
Indian Institute of Technol(s)	1, 2-8	1041	228	0.703390	0.145330	220	179	0.689362	0.046602	378	267	0.683128	0.000990
University of Delhi	19	115	98	0.550885	0.011162	365	203	0.498462	0.090938	279	382	0.811075	0.003085
Bhabha Atomic Res Cent	-	205	65	0.526984	0.007880	40	28	0.514286	0.002028	369	134	0.577726	0.000513
CSIR	-	257	118	0.566553	0.028274	82	152	0.641584	0.014176	208	334	0.752266	0.000537
AIIMS	M-1	50	40	0.501511	0.001798	156	172	0.675000	0.017914	81	345	0.764977	0.000451
Tata Inst Fundamental Res	R-10	365	126	0.614815	0.052990	43	26	0.513471	0.000985	-	-	-	-
BHU	U-3	112	44	0.510246	0.002669	110	269	0.723214	0.024317	17141	-	-	-
JNU	U-2	61	38	0.506612	0.002244	6523	-	-	-	110	269	0.685007	0.001593
IISc	U-1	29061	-	-	-	63	52	0.536424	0.003686	-	-	-	-
JNCASR	R-19	1064	181	0.609547	0.056503	23	11	0.491654	0.000146	-	-	-	-
Bangalore University	U-69	256	59	0.520376	0.017472	-	-	-	-	-	-	-	-
Jamia Millia Islamia	30	17	14	0.463687	0.000259	193	52	0.538206	0.010442	-	-	-	-
ICGEB	-	43	18	0.457721	0.000199	179	58	0.540902	0.011902	-	-	-	-
Top Foreign Collaborators	QS Rank												
University Tokyo	24	77	92	0.543075	0.010502	34	184	0.690832	0.003104	246	430	0.879859	0.009308
Columbia University	19	52	87	0.538378	0.008369	17	196	0.702820	0.003411	242	465	0.937853	0.012013
University Colorado	230	40	36	0.499498	0.001532	51	180	0.677824	0.003888	190	429	0.878307	0.010257
Lund University	97	26	36	0.488714	0.001108	10	183	0.689362	0.001485	237	432	0.882979	0.009349
University of Cambridge	7	127	119	0.569794	0.016595	24	169	0.624277	0.001956	65	387	0.817734	0.003243
University of Oxford	5	64	85	0.538961	0.006178	38	223	0.755245	0.006158	71	431	0.881416	0.004341
Nat. University Singapore	11	135	76	0.543668	0.010248	13	182	0.689362	0.007314	24	311	0.727007	0.000131
French National Centre for Scientific Research (CNRS)	-	119	100	0.554566	0.014369	22	131	0.612476	0.001733	27	220	0.641753	0.002194
Harvard University	3	60	75	0.530351	0.005055	35	221	0.751740	0.004288	68	433	0.884547	0.004473
Nanyang Technol University	13	95	48	0.522013	0.004116	18	181	0.689362	0.012577	25	330	0.747748	0.000307
Hiroshima University	321	10	25	0.477927	0.000290	-	-	-	-	237	242	0.660477	0.003576
University Tennessee	432	-	-	-	-	-	-	-	-	240	312	0.728070	0.005751
Tohoku University	79	119	43	0.514463	0.002586	-	-	-	-	-	-	-	-

TP-Total Publications, TL-Total Links, CC-Closeness centrality, BW-Betweenness centrality, QS Ranking 2021, NIRF Ranking 2021 (M-Medical, U-University, R-Research), JNCAR- Jawaharlal Nehru Centre for Advanced Scientific Research, ICGEB- International Centre for Genetic Engineering & Biotechnology, Technol- Technology, Cent-Centre, Res-Research, Nat. –National, CSIR-Council of Scientific & Industrial Research, AIIMS-All India Institute of Medical Science

location also play an important role as two nearby institutions collaborate more than institutions located at distance.

In organization co-authorship network of IISc, institutions like BHU, BARC, University of Hyderabad, IITs, University Tokyo, National University of Singapore are more likely to collaborate on similar subjects. Therefore, they are in the same cluster (Cluster 1). Foreign organizations like Stanford University, MIT, Columbia University, Lund University are in another cluster (Cluster 2); CNRS, TIFR, CSIR in yet another cluster (Cluster 6).

In case of JNU, University of Delhi, BHU, ICMR, University of Illinois, IITs, AIIMS, International Centre for Genetic Engineering and Biotechnology constitute a cluster as they collaborate on the same subjects while University of Colorado, University of Cambridge, University of Hyderabad are in other clusters but have very weak relation between them. In the third cluster, University of Washington, University of Tokyo, Karolinska Institute have a greater role in collaboration. University of Oxford and Harvard University play an important role in connecting Clusters 2 and 3. For BHU, there are three clear clusters visible whereas University of Tokyo, University of Tennessee, BARC, etc. constitute a strong cluster while IITs, University Delhi, CSIR, etc. constitute another cluster. University of Cambridge, Punjab University, etc., are in the third cluster but have no relation between these organizations.

The co-authorship network of organizations shows that group of organizations with more closer relationships and greater productivity are in the centre, while the organizations which have relatively less connectivity, are situated on the periphery. Closeness centrality (CC) considers how close the node is to any other node in the network. The CC (measured through Pejak) of a node is calculated considering the total distance between one node and all other related nodes, where a larger distance yields a lower closeness centrality score.

As it is inverse to the mean distance, a smaller index value indicates a higher distance between the nodes and a higher closeness score demonstrates a shorter distance between the nodes. On the other hand, the betweenness indicates, how important a node is in terms of connection with other nodes and how it serves as a gatekeeper. An institution with higher betweenness means the institutions has more control over the flow of information and has more capacity to keep groups of co-authors separate.

In this study, we observed that only a small group of organizations exercised minimal control over the knowledge flow. The mean of these indices is close to zero and even organizations those appeared highlighted have low scores. The shortage of nodes that serve the function of gatekeeper could be considered as a determining factor for the low connectivity of the network and for contributing to narrowing of the knowledge into small communities.

The collaboration network maps of IISc, BHU and JNU with institutions that they have each collaborated or 10 or more article is shown in Figures 2, 3 and 4.

Subject distribution

The collaboration pattern in different research areas and its effect on citations are indicated in Table 4. It is seen that the overall, theoretical aspects of physics lead to collaborative publications followed by chemical sciences. However, an increasing collaboration is observed in the fields like biochemistry and

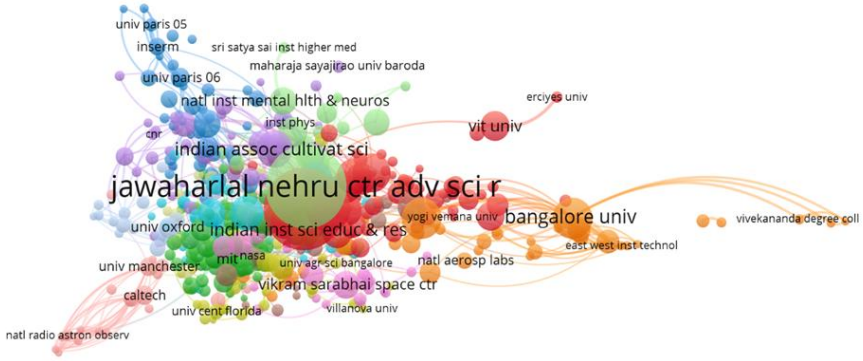

Fig. 2 — Collaboration network of IISc

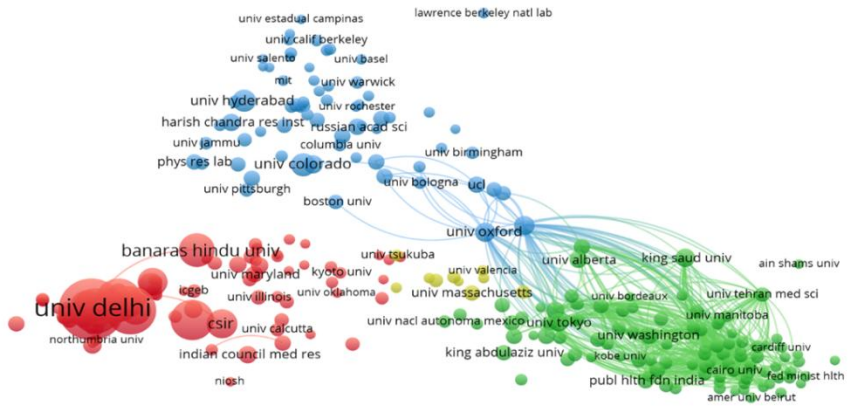

Fig. 3 — Collaboration network of JNU

Fig. 4 — Collaboration network of BHU

Table 4 — Subject pattern in collaborative articles

Main Division	Subdivisions	BHU		JNU		IISc	
		Art	CTA	Art	CTA	Art	CTA
Agricultural Sciences & Applications (AG)	Agricultural Sciences including Dairy and Veterinary sciences (AG-A)	479	12.76	74	16.97	105	15.6
	Agricultural Biotechnology (AG-B)	296	33.86	81	53.2	63	25.92
Biological Sciences & Applications (BS)	Animal Sciences (BS-A)	256	19.41	47	20.02	313	16.13
	Biochemistry & Molecular Biology (BS-B)	856	17.32	970	22.31	2350	20.51
	Plant Sciences (BS-C)	623	22.37	226	24.65	115	24.11
	Other Biological Sciences (BS-D)	389	13.8	213	14.15	300	17.81
Chemical Sciences (CH)	Electrochemistry (cell, energy, and fuels etc.) (CH-A)	449	25.64	16	18.56	494	29.89
	Polymer Science including Material science (CH-B)	1114	16.16	169	11.68	2789	20.83
	Other Chemical Sciences (CH-C)	1839	18.84	384	18.29	4406	29.63
Earth sciences (ES)	Geosciences, Meteorology & Atmospheric Sciences (ES-G)	1088	16.6	543	31.7	1036	24.39
	Oceanography, Hydrology, Water Resources (ES-W)	75	14.79	107	24.78	197	24.49
Engineering and Technology (ET)	Civil, Mechanical & Electrical Engineering (ET-A)	857	16.24	394	12.06	3913	18.96
	Chemical, Material & Environmental Engineering (ET-B)	1060	26.78	201	21.2	2728	26.27
	Biotechnology & nanotechnology (ET-C)	796	23.58	455	20.38	606	21.37
Medical & Health Sciences (MH)	Basic Medicine (MH-B)	1334	23.4	510	21.88	731	21.55
	Clinical Medicine (MH-C)	1558	25.14	480	37.79	577	19.07
	Health science & medical Biotechnology (MH-H)	432	24.37	189	14.55	82	15.63
Physical Sciences (PS)	Physics - Theoretical Aspects (PS-A)	1742	23.18	647	13.57	4375	20.92
	Physics - Experimental Aspects (PS-B)	307	14.98	33	7.03	428	13.76
	Space Physics (PS-C)	322	17.72	19	12	621	19.3

(*Contd.*)

Table 4 — Subject pattern in collaborative articles (*Contd*.)

Main Division	Subdivisions	BHU		JNU		IISc	
		Art	CTA	Art	CTA	Art	CTA
Mathematics & Computer sciences (MC)	Mathematics (MM)	247	8.01	44	4.27	682	7.49
	Computer Science & Information Sciences (CS)	149	11.62	176	10.97	673	13.25
Arts & Social Sciences (AS)	Arts & Humanities (History, Archaeology, Languages, Philosophy, etc. (AS-A)	5	7.6	16	2.62	4	9.75
	Sociology, Psychology, Political Science, Educational sciences, media, and communications, etc. (AS-B)	83	6.54	119	7.62	31	9.96
	Economics & Management Sciences (AS-C)	38	8.74	118	13.58	105	14.92
Multidisciplinary (MDS)	Many disciplines all from different subject fields	840	21.38	515	20.06	2201	27.21

Only Collaborative Articles Considered here. CTA= Average Citation per Title, Art-Articles

molecular biology, polymer sciences, environmental sciences. But subjects under arts and humanities, social science received little attention for collaboration. On the other hand, articles in agricultural science tend to have more citations on average when in collaboration followed by clinical medicine. Subjects like space physics, nanotechnology, and molecular biology also received more citations while collaborating. Very less citations have been noted for collaborative articles in mathematics.

Discussion

Analysis of institutional collaboration by employing bibliometric methods unveils collaborative trends in the top three Indian academic institutes for the last two decades. This study shows that the frequency of collaboration in top Indian universities is growing and articles in collaboration receive more citations. Collaboration with a group consisting of a few members is more effective than collaboration with many authors and institutions. Such small-group collaboration is more predominant in IISc than BHU or JNU. Communication between universities, even foreign institutes is also noticed in this study but collaboration between industries is quite less. For improving the innovative environment that better meet the need of society, the collaboration between university and industries are expected.

The network analysis of collaboration between institutions suggests that the distance between institutions is a deciding factor of national collaboration, as we have observed that JNU remains more collaborative with Delhi University; IISc with Jawaharlal Nehru Centre for Advanced Science & research, Bangalore, and BHU with IIT, Kanpur. However, for international collaboration, these three institutions collaborate more with institutes located in advantageous countries like the USA, UK, Germany, Singapore, etc. These findings are in accordance with the findings of Sooryamoorthy[31].

Conclusion

The domains where most collaborations have been made indicate that collaboration is still more predominant in traditional fields like physics, chemistry, or its allied application-oriented disciplines. However, the citation behavior of articles in fields like agricultural biotechnology, clinical medicine, polymer science, nanotechnology suggests that there may be a wide scope to increase participation with such subjects which have industrial emphasis. Further analysis of how each existing collaboration group is formed is desirable to imply such practices in other disciplines too. As India is yet to have any act like Bayh-Dole Patent Reform Act, a holistic framework seems to be effective to address many positive aspects of university-industry collaboration.

Acknowledgment

This research is an outcome of IoE, BHU funded grants under the Faculty Incentive Scheme. Thanks to Prof. Archana Kumar, Department of English, BHU for copyediting in the final draft.

References

1. Newman ME, Co-authorship networks and patterns of scientific collaboration. *Proceedings of National Academy of Science*, 101 (2004) 5200–4.
2. Miguel S, Moya-Anegon F and Herrero-Solana V, Aproximaciónmetodológica para la identifcación del perfil y patrones de colaboración de dominio scientíficosuniversitarios. *Revista Española de Documentación*, 28(1) (2006) 34-53.
3. Zyoud S H, Global toxocariasis research trends from 1932 to 2015: a bibliometric analysis. *Heal Research Policy System*, 15(14) (2017). https://doi.org/10.1186/s12961-017-0178-8.

4. Leydesdorft L, Caveats for the use of citation indicators in research and journal evaluations. *Journal of the American Society for Information Science and Technology*, 59 (2) (2008) 278-287.
5. Landry R, Traore N and Godin B, An econometric analysis of the effect of collaboration on academic research productivity, *Higher Education*, 32 (1996) 283–301.
6. Glänzel W, Modelling and measuring multilateral co-authorship in international scientific collaboration. Part I: Development of a new model using a series expansion approach, *Scientometrics*, 40(3) (1997) 593-604.
7. Lee S and Bozeman B, The impact of research collaboration on scientific productivity. *Social Studies of Science*, 35 (2005) 673–702.
8. He Z L, Geng X S, Campbell-Hunt C, Research collaboration and research output: a longitudinal study of 65 biomedical scientists in a New Zealand university, *Research Policy*, 38(2) (2009) 306–317.
9. Larivière V, Gingras Y, Sugimoto C R and Tsou A, Team size matters: collaboration and scientific impact since 1900. *Journal of the Association for Information Science and Technology*, 66(7) (2015) 1323-1332. doi: 10.1002/asi.23266.
10. Narin F, Stevens K and Whitlow E, Scientific cooperation in Europe and the citation of multinationally authored papers, *Scientometrics*, 21 (3) (1991) 313–323.
11. Frenken K, Hölzl W and Vor F de, The citation impact of research collaborations: the case of European biotechnology and applied microbiology (1988–2002)', *Journal of Engineering and Technology Management*, 22(1) (2005) 9–30. doi:10.1016/j.jengtecman.2004.11.002.
12. Wagner C S, Six case studies of international collaboration in science, *Scientometrics*, 62 (1) (2005) 3-26.
13. Wagner C S, Whetsell T, Baas J and Jonkers K, Openness and impact of leading scientific countries, *Frontiers in Research Metrics and Analytics*, 3 (10) (2018) 1–10.
14. Bonaccorsi A, Daraio C and Simar L, Advanced indicators of productivity of universities: An application of robust nonparametric methods to Italian data, *Scientometrics*, 66 (2006) 389–410.
15. Abbasi A, Hossain L and Leydesdorff L, Betweenness centrality as a driver of preferential attachment in the evolution of research collaboration networks, *Journal of Informetrics*, 6 (2012) 403–412. https://doi.org/10.1016/j.joi.2012.01.002
16. McFadyen M A, Semadeni M and Cannella AA, Value of strong ties to disconnected others: Examining knowledge creation in biomedicine, *Organization Science*, 20(3) (2009) 552–564. https://doi.org/10.1287/orsc.1080.0388
17. Li E Y, Liao C H and Yen H R, Co-authorship networks and research impact: A social capital perspective, *Research Policy*, 42(9) (2013) 1515–1530. https://doi.org/10.1016/j.respol.2013.06.012
18. Abbasi A, Altmann J and Hossain L, Identifying the effects of co-authorship networks on the performance of scholars: A correlation and regression analysis of performance measures and social network analysis measures, *Journal of Informetrics*, 5(4) (2011) 594–607. https://doi.org/10.1016/j.joi.2011.05.007
19. Waltman L, Tijssen RJW, Eck NJ van. Globalisation of science in kilometres. *Journal of Informetrics*, 5(4) (2011) 574–82.
20. de Solla Price D J and Beaver D, Collaboration in an invisible college, *American Psychologist*, 21(11) (1966) 1011–1018.
21. Pradhan P, Panda S and Chandrakar R, Authorship pattern and degree of collaboration in Indian chemistry literature, In: *Proceedings of the 8th International CALIBER 2011*. doi:10.13140/RG.2.1.3910.3524.
22. Singh M, Authorship pattern and collaboration coefficient of India in biotechnology research during 2001-2016: based on Scopus database, *Library Philosophy and Practice* (2017). Available at: https://digitalcommons.unl.edu/libphilprac/1549.
23. Dutt B and Nikam K, Scientometrics of collaboration pattern in solar cell research in India, *Annals of Library and Information Studies*, 61(1) (2014). Available at: http://nopr.niscair.res.in/handle/123456789/27765
24. Baradar N and Tadasad P G, Authorship pattern and collaborative research in economics, *Journal of the Indian Library Association*, 51(4) (2015) 21-29.
25. Zafrunnisha N and Pullareddy V, Authorship pattern and degree of collaboration in psychology, *Annals of Library and Information Studies*, 56(4)(2009) http://nopr.niscair.res.in/handle/123456789/7264
26. Lawani S, Quality, collaboration and citations in cancer research: a bibliometric study, Ph.D. dissertation, Florida State University, 1980,
27. Subramanyam K, Bibliometric studies of research collaboration: a review,*Journal of Information Science*, 6 (1983) 33-38.
28. Ajiferuke I, Burell Q and Tague J, Collaborative coefficient: a single measure of the degree of collaboration in research,*Scientometrics*, 14(5–6), (1988) 421–433. https://doi.org/10.1007/BF02017100.
29. Clauset A, Newman M E J, and Moore C, Finding community structure in very large network,*Physical Review E*, 70(6), (2004) 066111.
30. Waltman L, Van Eck N J, Noyons E C M, A unified approach to mapping and clustering of bibliometric networks, *Journal of Informetrics*, 4(4) (2010) 629–635.
31. Sooryamoorthy R, Do types of collaboration change citation? collaboration and citation patterns of South African science publications, *Scientometrics*, 81(1) (2009) 177. doi:10.1007/s11192-009-2126-z.