

Science in pre-independent India: a scientometric perspective

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Scientific publications and different types of collaboration pattern in pre-independent India are mapped using scientometrics and social network analysis tools. Publication data of Indian authors published before 1947 are downloaded from the Scopus database of Elsevier science. The study traces the literature growth patterns, core journals, productive authors, authorship collaboration patterns, productive institutions and their collaboration patterns. The result shows that maximum literature was published in the year 1936. The growth of publications during the mid-1930s was evident as many scientific institutions were established by that time. The subject-wise maximum activity was observed in chemistry followed by agricultural and biological science. *Proceedings of the Indian Academy of Sciences* was the most preferred journals. Universities played the prominent role in scientific research. Some private institutions with 'nationalistic' enthusiasm, for example, *Indian Institute of Science* and *Indian Institute for Cultivation of Science* were very productive institutions and also prominent in institutional collaboration. These institutions started in the colonial period continue to be the pillars of modern science in India.

Keywords: Colonial Science; Scientometrics; India, Social Network Analysis; History of Science

Introduction

Over the last couple of decades, there have been growing interests in the history of science in British India. Development and institutionalization of science and technology (S&T) under British imperialism and its establishments in former British colonies are termed as colonial science. The important contributions of Basalla¹, Kumar^{2, 3, 4}, MacLeod⁵, Raina⁶ had enriched and legitimized the concept of colonial science^{7, 8}. "This term colonial science broadly refers to the status of S&T activity under colonialism in the colonies, and its subjugation to the imperial political and economic interests in the metropolis"⁷. Basalla's three stage model for the diffusion of Western science acted as a pillar for colonial science. Basalla proposed that science originated in the Western Europe and diffused in colonies in the three stages. In Phase I, the non-scientific society or nations provided a source for European science. In this initial phase of exploration, colonies provided raw data and materials for scientific analysis in the West. The Phase II was the period of actual consolidation of colonial science and advanced

scientific activities. Finally, the Phase III was the independent scientific tradition or cultures that were gradually evolved in the British colonies¹.

This idea of colonial science has been contested, confronted and refined over the years²⁻¹². According to these historians, science existed even before the establishment of the British colonies. They argued that Basalla had carefully excluded the rich scientific and cultural heritage that already existed in the ancient Indian and Chinese civilizations^{7,13}. Rather colonial science was the science in the colonies that were planned activities that originated from the United Kingdom (UK). The colonies were given the lower level of tasks for example; 'data exploration'. However, the data analysis and synthesis took place in London. These kind of science lacked intellectual essence and the proper scientific practice in the colony^{4,7}.

This paper is an attempt to map the science in pre-independent undivided India (including India and Pakistan) extracting data from the Scopus database of Elsevier Science.

Objectives of the study

- To study the literature growth patterns of Indian researchers during the British period;
- To identify core journals during pre-independent India;
- To examine the prominent subject areas of research;
- To list productive authors and examine the authorship collaboration patterns; and
- To identify productive institutions and institutional collaboration patterns.

Methodology

This paper uses the analytical framework of scientometrics for mapping the growth of literature, subject-wise activity, core journals, authorship and institutional collaboration patterns^{14,15}. The authorship and institutional collaboration patterns are mapped using the Social Network Analysis (SNA) tools. A social network is a set of individuals or groups, each of which has connections of some kind to some or all of the other actors¹⁶. SNA is a multidisciplinary approach based on mathematical Graph theory¹⁷. The authorship and institutional collaboration pattern represented through the graph are examined from a macro- (the whole network) or from a micro- (individual actor) perspective. The macro-structure of a graph shows how the actors are embedded in the network that arises out of the physics of its connections¹⁸. In macro-level analysis shows the overall centrality, density, clustering coefficient, geodesic path etc¹⁹.

Scopus of Elsevier launched in 2004 is the largest abstract and citation database of peer-reviewed literature. It covers more than 21,500 titles from more than 5,000 international publishers in the fields of S&T, social science and humanities. According to Scopus content coverage guide (updated in January 2016), it has over 60 million core records. Over 22 million records of Scopus are pre-1996 publications, which go back as far as 1823. The database continuously updates its collection and approximately 3 million new records are added every year²⁰.

Literature data for this study was searched and downloaded from Scopus putting 'India' or 'Pakistan' in the 'affiliation country' search field. The retrieved set of results was restricted till the year 1947, the year

of India's independence and the creation of two separate nations India and Pakistan. The retrieved sets of records were downloaded and taken for further analysis.

The network maps of authorship and institutional collaboration patterns were drawn using social network analysis software UCINET. The software is developed by Borgatti, et.al and distributed by Analytic Technologies. The integrated freeware program with UCINET called NETDRAW is used to visualize and draw network maps^{21, 22}. Social network analysis software Gephi was also used to get the whole network level statistics. Gephi, is an open-source software for the visual representation and the analysis of complex social network²³.

The study has the following limitations. Firstly, it is based only on the scholarly publication data from Scopus. Although the Scopus has extensive coverage of global literature, it has English language bias. Secondly, many of the Indian publications of pre-independent India may not be covered in the Scopus considering that the citation database is a relatively new database and no citation or bibliographic database exhaustively covers all the Indian S&T publications. For example, Bhattacharya et al. (1989) found about 2,124 science publications in Indian languages between 1875 and 1896. The Calcutta Book Society, formed in 1817, contained 333 journals, book and other forms of publications in various fields of S&T^{24, 7}. Despite the known limitations of Scopus, it was used to examine the trends as revealed through this data set.

Analysis

For the period 1807 to 1947, 6,008 records were retrieved from the database. The records were downloaded and further analyzed. The categorization of the whole set of 6,008 records, based on the document types are as follows; Articles 4,899; Letters 880; Notes 125; Errata 48; Reviews 43; Conference Papers 7 and Short Surveys 6. There were 5,505 records (92 percent) in English followed by 498 records (8 percent) in German, 4 records in French and 1 in Italian.

Literature growth patterns

The literature growth pattern from India during pre-independent period is shown in Figure 1. From

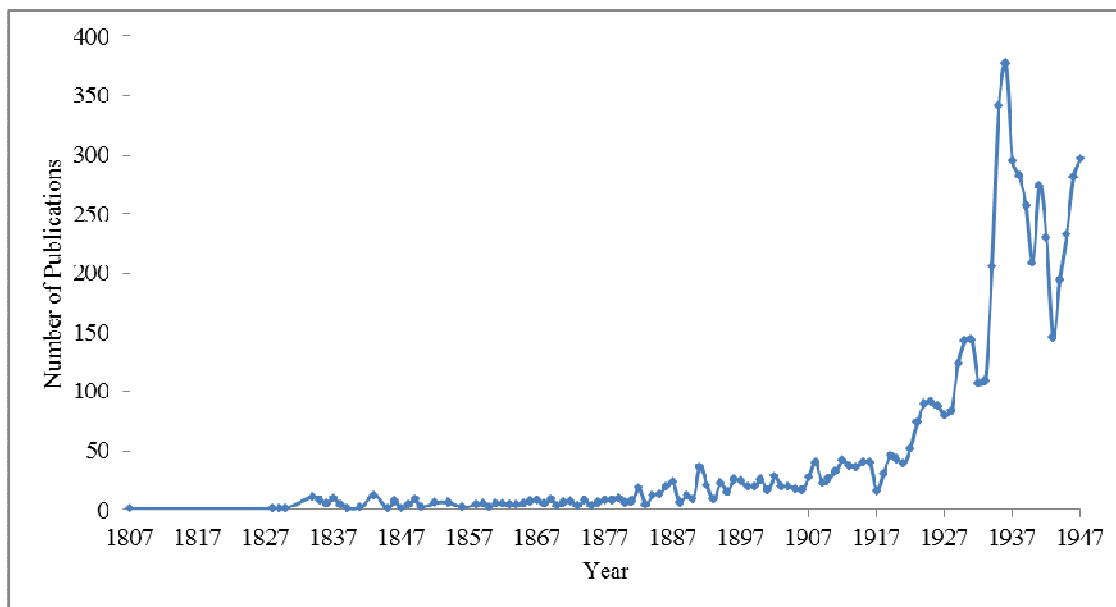


Fig. 1—Growth of scientific publications from India during 1807-1947

the earliest publication in 1807 till 1858, the publication history from India was very sporadic. With a span of 51 years only about 99 articles had been published. A three digit growth is seen from 1929 onwards with 123 articles published in that year. The highest number of publications was in the year 1936 with 377 articles published from India. Perhaps the growth of publication in 1930s was due to the consolidation of institutional building process.

Subject areas

Scopus widely covers peer-reviewed literature and web sources in all branches of knowledge. It classifies the universe of knowledge into four broad subject clusters (life sciences, physical sciences, health sciences and social sciences & humanities). These subjects are further divided into 27 major subject areas and more than 300 minor subject areas²⁰. The subject-wise distributions of articles shows (Figure 2) that publications in chemistry were more in number.

Preferred journals

Ranking of journals is one of the most commonly used analytical tools in bibliometric research^{15, 25, 26}. The 6,008 Indian scholarly publications appeared in 244 journals. The maximum number of publications were published in *Proceedings of the Indian Academy of Sciences Section A* (1432 papers, ~24 percent) followed by *Proceedings of the Indian Academy of Sciences Section B* (621 papers, ~10 percent), *British*

Medical Journal (555 articles, ~9.24 percent), *Nature* (420 ~7 percent) and so on. These three journals altogether published about 50 percent of total articles. The other 50 percent articles are scattered in 240 journals. The top journals with more than 50 articles are shown in Table 1.

Authorship pattern

If two or more individuals are recorded as co-authors of the same publication, it is assumed that those people must have collaborated in research. Also, it is quite possible that researchers who collaborate in any scholarly publication become co-authors^{27,28}. There are altogether 3,443 authors for the total 6,008 articles. Table 2 shows the most productive authors with more than 20 publications as available from the Scopus database. The most productive author was T.R Seshadri from Andhra University with 175 articles in the area of chemistry followed by N. R. Dhar with 143 articles from University of Allahabad and C. V. Raman with 74 articles from Indian Association for the Cultivation of Science and Indian Institute of Science.

Authorship collaboration network

Among the retrieved set of 6,008 articles 1,948 (33 percent) articles are collaborative articles. Among the 1,948 collaborative articles, 1,395 are two authored, 346 are three authored, 56 are four authored, 17 are five authored and rest have more than five authors.

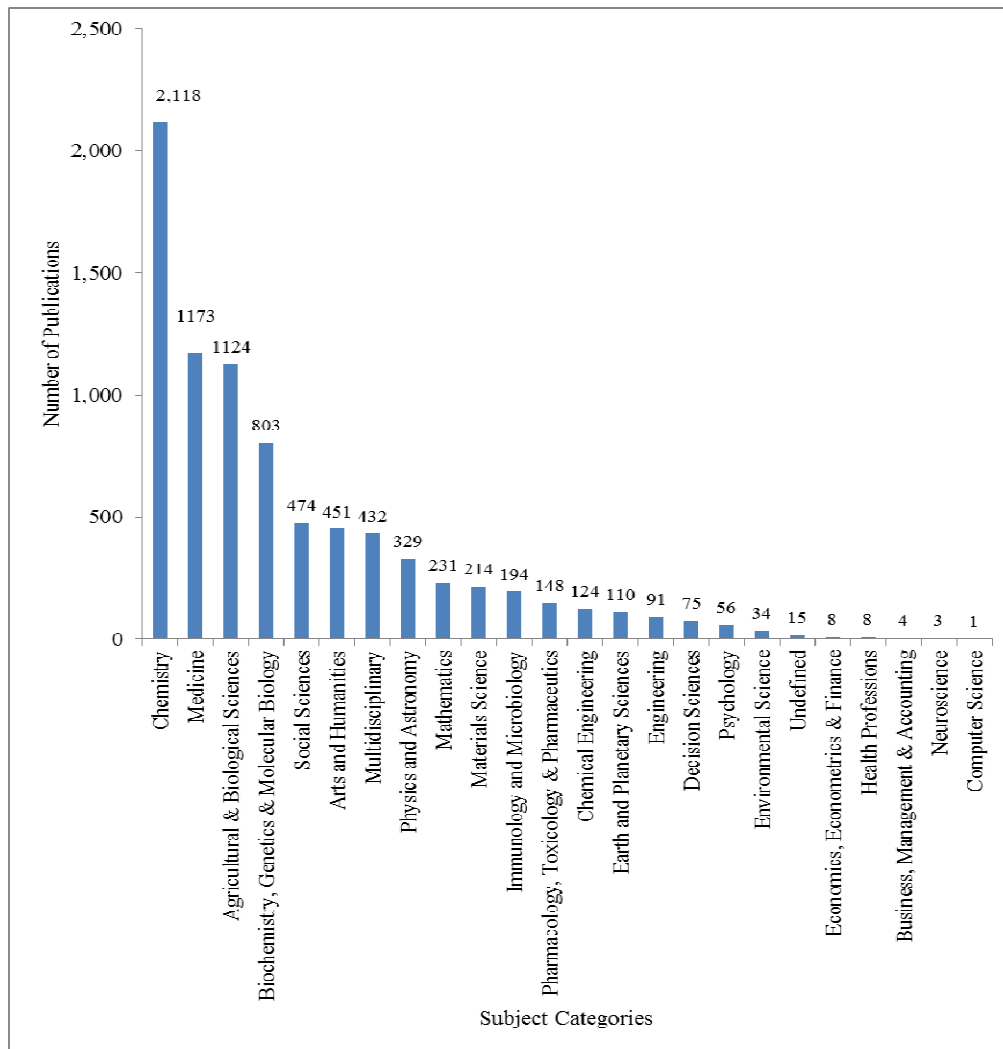


Fig. 2—Subject wise distributions of articles

A network or graph in social sciences are the collections of vertices joined by edges. Vertices and edges are also called and actors and ties in sociology^{29,30}. The collaborative authorship network in the present study has 1,892 nodes and 1,644 ties. The network average degree is 1.738 and average weighted degree is 1.932. This is far below of the average observed statistics for a number of networks. For example, Newman has found that network average degree of mathematics is 3.92, physics is 9.27 and biology is 15.53^{30,31}.

Diameter of an ego network is the length of the longest path between connected actors. The network diameter is the span or extensiveness of the network. This measurement shows the distance between the two furthest actors situated in a network. In this network, the actors are not very far apart in the ego

networks of most actors¹⁹. Network diameter of the authors' collaboration network is 24. It means from one author to reach another author located at the furthest point it requires 24 nodes to cross.

One important characteristics of social network is the small average distance between a pair of nodes. It is general measured by the shortest path length (*Average geodesic distance*) between two nodes. The concept was drawn from the famous "six degrees of separation". Scientific collaboration networks also exhibit the similar phenomenon. The average path length in this authorship collaboration network is 10.005. This long path length shows that authors were not quite close to each other. Newman shows that the average distances in co-authorship network are different branches of knowledge are follows; 4.92 in Biology, 6.19 in Physics and 7.57 in Mathematics^{31,32}.

Table 1—Top 20 journals with more than 50 publications

| Rank | Journal | Number | Cumulative | Percent |
|------|--|--------|------------|---------|
| 1. | <i>Proceedings of the Indian Academy of Sciences - Section A</i> | 1432 | 1432 | 23.83 |
| 2. | <i>Proceedings of the Indian Academy of Sciences - Section B</i> | 621 | 2053 | 10.34 |
| 3. | <i>British Medical Journal</i> | 555 | 2608 | 9.24 |
| 4. | <i>Nature</i> | 420 | 3028 | 6.99 |
| 5. | <i>Journal of the Royal Asiatic Society of Great Britain & Ireland</i> | 130 | 3158 | 2.16 |
| 6. | <i>Zeitschrift für Physik</i> | 128 | 3286 | 2.13 |
| 7. | <i>Zeitschrift für anorganische und allgemeine Chemie</i> | 121 | 3407 | 2.01 |
| 8. | <i>Notes and Queries</i> | 112 | 3519 | 1.86 |
| 9. | <i>Kolloid-Zeitschrift</i> | 110 | 3629 | 1.83 |
| 10. | <i>The Muslim World</i> | 97 | 3726 | 1.61 |
| 11. | <i>BJOG: An International Journal of Obstetrics & Gynaecology</i> | 89 | 3815 | 1.48 |
| 12. | <i>Physical Review</i> | 81 | 3896 | 1.35 |
| 13. | <i>Soil Science</i> | 79 | 3975 | 1.31 |
| 14. | <i>Journal of Physical Chemistry</i> | 79 | 4054 | 1.31 |
| 15. | <i>Transactions of the Indian Ceramic Society</i> | 77 | 4131 | 1.28 |
| 16. | <i>Journal of the Chemical Society, Transactions</i> | 74 | 4205 | 1.23 |
| 17. | <i>Journal of the Chemical Society (Resumed)</i> | 69 | 4274 | 1.15 |
| 18. | <i>Transactions of the Royal Society of Tropical Medicine and Hygiene</i> | 66 | 4340 | 1.10 |
| 19. | <i>Parasitology</i> | 61 | 4401 | 1.02 |
| 20. | <i>Proceedings of the Zoological Society of London</i> | 52 | 4453 | 0.87 |

Table 2—Top 10 productive authors

| Rank | Author | Number | Major Affiliations |
|------|----------------|--------|--|
| 1. | T. R. Seshadri | 175 | Andhra University |
| 2. | N. R. Dhar | 143 | University of Allahabad |
| 3. | C. V. Raman | 74 | Indian Association for the Cultivation of Science / Indian Institute of Science |
| 4. | R. D. Desai | 64 | Muslim University, Aligarh/ St. Xavier's College, Bombay/ Department of Chemical Technology, Bombay University |
| 5. | A. N. Puri | 53 | University Chemical Laboratory, Lahore, India/ Irrigation Research Laboratory, Lahore, India |
| 6. | S. Bhagavantam | 51 | Indian Institute of Science and the Andhra University/ Indian Association for the Cultivation of Science |
| 7. | R. S. Krishnan | 50 | Indian Institute of Science, Bangalore |
| 8. | B. K. Singh | 43 | University of Allahabad/ Science College, Patna/ Government College, Lahore |
| 9. | S. Chowla | 39 | Andhra University/ Government College, Lahore |
| 10. | B. N. Singh | 38 | Benares Hindu University |

Graph density is the measurement of the closeness of a network. In an ideal condition, the graph density will be equal to 1 if it is a complete graph with all possible ties are present. In this co-authorship collaboration network the graph density is 0.001. It means that only 0.01 percent of possible ties are present¹⁹.

A weak component is the largest number of actors who are somehow connected. It ignores the direction of the ties in undirected data¹⁹. Number of weakly

connected component in this co-authorship network is 376. The largest component has 641 nodes with authors like N.R. Dhar, T.R. Seshadri, R. D. Desai, S.S. Bhatnagar and so on. The second largest component consists of 36 authors. The prominent among them are B. N. Desai, J. N. Mukherjee, P. M. Barve, A. M. Patel, K. Prosad and so on. The third largest component consists of 26 collaborative actors with B. S. Rao, K. S. Rao, K. S. G. Doss, T. Krishnappa and so on are among the prominent authors.

Among the large components with more than 10 author collaborations, the component number 96 (size 17), 89 (size 12), 93 (size 16), 158 (size 16), 128 (size 13) are formed solely by the interaction among the British authors. It is also important to note here that there are very limited collaborations happened between Indian and British scientists at that time.

The clustering coefficient measures the average probability that two neighbors of a vertex are themselves neighbors. In effect it measures the density of triangles in the networks. It is of interest because in many cases it is found to have values sharply different from what one would expect on the basis of chance³⁰. Average clustering coefficient 0.176 is quite low in this case. It can be seen from the Figure 3 that a few actors are surrounded by local neighborhoods that are fairly dense. It is mentioned earlier that the overall density of the entire graph in this population is also low (.001). However, the density of local neighborhoods is higher than the density of the whole graph because of the presence of some prominent actors.

In almost all social network analyses, the micro level or individual actor level centrality stress on four centrality measures. These centrality measures are Degree, Betweenness, Closeness and Eigenvector (Table 3). Degree centrality of a node is the number of edges that are adjacent to that

node^{21,33,34}. Betweenness centrality is the measure of how often a node appears on shortest paths between nodes in the network^{16,35,36}. Closeness centrality is the average distance from a given node to all other nodes in the network¹⁹. It measures how close a node is to all the other nodes³⁷. According to Opsahal et.al, the distance between nodes in disconnected components of a network is infinite. So, this is the limitation of closeness centrality measure because it cannot be applied to networks with disconnected components^{34,37}. Eigenvector centrality shows the importance of an actor in a network depend on its connection with other important node. A node is considered important if it is relatively close to all other nodes. A node is central to the extent that the node is connected to others who are central³⁸.

Productive institutions

During the British period, research was conducted both in government as well as private research institutions³⁹. The top institutions in their decreasing order of publications are shown in Table 4. Indian Institute of Science (IISc), Bangalore is the top institute with 600 publications. IISc was established in 1909, with monetary grant from Sir J.N. Tata and the Maharaja of Mysore. The institute conducted basic and applied research in many fields of science and technology. The second most prominent institute established with private initiative was Indian

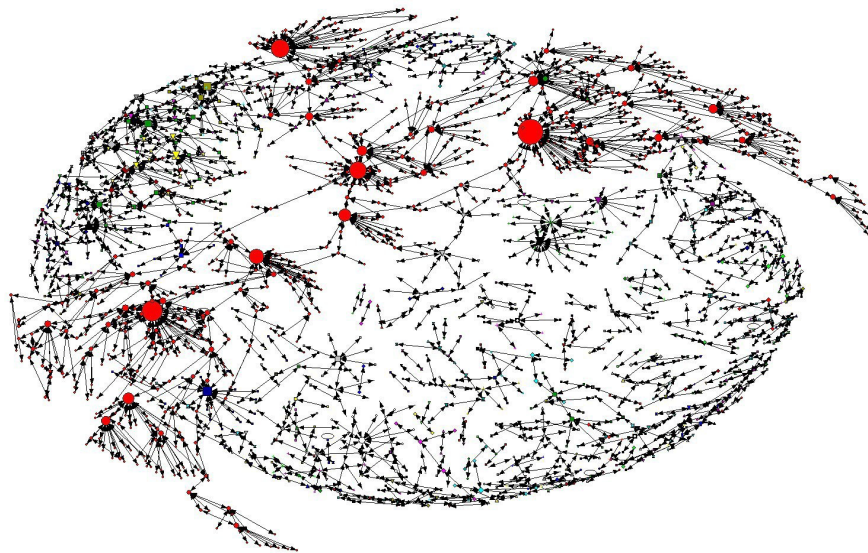


Fig. 3—Authorship collaboration network

Table 3—Centrality measures of productive authors

| Author | Degree centrality | Author | Betweenness centrality | Author | Closeness centrality | Author | Eigenvector centrality |
|---------------------|-------------------|---------------------|------------------------|----------------------|----------------------|--------------------|------------------------|
| N. R. Dhar | 49 | B. K. Singh | 113097.49 | A. K. Chattopadhyaya | 2378792 | N. R. Dhar | 0.674 |
| T.R. Seshadri | 38 | S. S. Bhatnagar | 100040.30 | N. K. Dutt | 2378792 | S. Ghosh | 0.213 |
| R. D. Desai | 34 | B. N. Singh | 85437.16 | B. K. Goswami | 2378792 | S. Prakash | 0.159 |
| S. S. Bhatnagar | 31 | S. Prasad | 75433.19 | A. K. Majumdar | 2378792 | D. N. Chakravarti | 0.12 |
| B. N. Singh | 28 | S. Rajagopalan | 74525.16 | S. N. Maulik | 2378792 | M. N. Chakravarti | 0.12 |
| B. K. Singh | 21 | N. R. Dhar | 73529.49 | P. B. Sharkar | 2378792 | S. N. Banerji | 0.12 |
| C.V. Raman | 20 | K. Ganapathi | 67530.20 | P. Chandra Mukherjee | 2378295 | L. S. Bhatia | 0.12 |
| M. Prasad | 17 | M. Singh | 66927.89 | S. Chandra Sen Gupta | 2378295 | K. C. Sen | 0.116 |
| A. N. Puri | 16 | A.B. Lal | 63496.40 | N. Nath Ghosh | 2378295 | H. L. Dube | 0.113 |
| T. Fowler | 16 | R. C. Ray | 63338.90 | R. De | 2378287 | L. N. Bhargava | 0.113 |
| K. Venkataraman | 15 | P. B. Ganguly | 61764.40 | M. L. Dey | 2378287 | P. B. Ganguly | 0.11 |
| K. C. Pandya | 15 | B. B. Dey | 44673.00 | A. C. Ghosh | 2378287 | A. K. Bhattacharya | 0.109 |
| E. B. Ford | 15 | C.V. Raman | 38587.00 | S. C. S. Gupta | 2378287 | M. R. Mehrotra | 0.109 |
| T. H. D. La Touche | 15 | R. Samuel | 38251.00 | J. N. Rakshit | 2378287 | W. V. Bhagwat | 0.107 |
| S. Bhagavaniam | 14 | H. Lessheim | 37884.00 | K. C. B. Ray | 2378287 | K. N. Malaviya | 0.106 |
| S. Ghosh | 13 | P. Krishnamurti | 37375.00 | J. N. Sen | 2378287 | S. Gosh | 0.106 |
| B. S. Rao | 13 | B. Singh | 32162.49 | K. N. Choudhury | 2378171 | B. C. Banerji | 0.106 |
| R. Samuel | 12 | M. Sreenivasaya | 30708.83 | K. Choudhuri | 2378171 | S. N. Chakravarti | 0.098 |
| R. N. Chopra | 12 | V. I. Vaidhianathan | 30007.99 | K. N. Choudhuri | 2378171 | G. G. Rao | 0.098 |
| G. N. R. Ayyangar | 12 | S. Rangaswami | 28729.74 | K. Nath Choudhuri | 2378171 | N. G. Chatterji | 0.095 |
| K. Neelakantam | 11 | R. F. Hunter | 28584.00 | P. Ray | 2378153 | C. C. Palit | 0.095 |
| V. Subrahmanyam | 11 | D.L. Shrivastava | 26525.74 | P. Chandra Ray | 2377656 | A. C. Chatterji | 0.095 |
| S. Rangaswami | 10 | S. Ghosh | 25768.00 | P. C. Ray | 2377648 | P. N. Bhargava | 0.095 |
| V. I. Vaidhianathan | 10 | A. N. Puri | 25213.99 | P. N. Das Gupta | 2377540 | B. K. Mukerji | 0.093 |
| R. F. Hunter | 10 | M. Srinivasan | 23394.82 | T. C. Sarkar | 2377540 | S. K. Mukerji | 0.093 |
| H. B. Dunicliff | 10 | T. R. Seshadri | 23274.96 | H. Saha | 2377532 | P. B. Ganguli | 0.093 |
| R. L. Datta | 10 | E. M. Taylor | 23116.98 | M. K. Bose | 2377526 | A. Ram | 0.091 |
| B. N. Desai | 10 | R. W. Linton | 22021.82 | S. R. Seth | 2377381 | N. N. Biswas | 0.091 |
| J. K. Thornton | 10 | B. N. Mitra | 21390.82 | P. R. Mehta | 2377377 | J. K. Verma | 0.091 |

Table 4—Productive institutions with more than 20 publications

| Rank | Institute | Publications | First publication year | Year of establishment |
|------|--|--------------|------------------------|-----------------------|
| 1. | Indian Institute of Science | 617 | 1914 | 1909 |
| 2. | Andhra University | 387 | 1932 | 1926 |
| 3. | Allahabad University | 280 | 1896 | 1887 |
| 4. | Banaras Hindu University | 191 | 1920 | 1916 |
| 5. | Calcutta University | 163 | 1913 | 1857 |
| 6. | Central College, Bangalore | 158 | 1887 | 1858 |
| 7. | Mysore University | 136 | 1925 | 1916 |
| 8. | University of Madras | 120 | 1885 | 1857 |
| 9. | Muslim University, Aligarh | 116 | 1936 | 1875 |
| 10. | University of Lucknow | 107 | 1923 | 1867 |
| 11. | University College of Science, Calcutta | 107 | 1918 | 1914 |
| 12. | Medical College Calcutta | 103 | 1859 | 1835 |
| 13. | Royal Institute of Science, Bombay | 96 | 1924 | 1920 |
| 14. | Presidency College, Calcutta | 93 | 1882 | 1817 |
| 15. | Government College University Lahore | 91 | 1885 | 1864 |
| 16. | Agricultural Research Institute, Coimbatore / Pusa | 82 | 1911 | 1905 |
| 17. | Annamalai University | 79 | 1929 | 1929 |
| 18. | Indian Association for the Cultivation of Science | 66 | 1914 | 1876 |
| 19. | University of the Punjab Lahore | 66 | 1920 | 1882 |
| 20. | Calcutta School of Tropical Medicine | 54 | 1921 | 1914 |
| 21. | St. John's College Agra | 49 | 1898 | 1850 |
| 22. | University of Bombay | 46 | 1866 | 1857 |

Association for the Cultivation of Science, in Calcutta. This institute ranked 18th with 66 publications. The institute was established in 1876 by Dr. Mahendra Lal Sircar, initially aimed to popularizing science and scientific subjects. Gradually it started fundamental research in physics and chemistry, 'Raman Effect' was discovered by Sir C. V. Raman when he was in this institute.

Institutional collaboration network

Out of the total of 6,008 publications, about 339 publications are an outcome of institutional collaborations. The institutional collaboration network has 380 nodes and 628 edges. Average degree is 1.653 and average weighted degree is 1.916. The network diameter is 14 and average path lengths are 5.66. With these overall statistics, it can be observed that the network is not very dense and populated by many locally and isolated institutional actors collaborating with each other.

The collaboration network has the graph density of 0.004 which means that only about 0.4 percent of possible collaboration. The graph has an average clustering coefficient of 0.142. There are total 95

weakly connected components and total 12 triangles present in the network. The largest component is the size of 123 actors. The important actors in this component are Indian Institute of Science, Allahabad University, Calcutta Medical College & Hospitals, Benares Hindu University, J. J. Hospital; Bombay, Government College; Lahore, Haffkine Institute; Bombay, Central College; Bangalore, University of Lucknow, Punjab University; Lahore and University of Madras. Almost all productive institutions were somehow connected at that time and had active collaborations. The second largest component size is of 9 actors and Samaritan Free Hospital; United Kingdom (UK) is the most prominent actor in this component. The institutional collaboration network is shown in Figure 4.

The actor level institutional centrality measures show that Indian Institute of Science had the highest degree of centrality (14). Indian Institute of Science also played a prominent role in collaboration. The actors with high centrality scores are: Allahabad University (10), Calcutta Medical College & Hospitals (9), Samaritan Free Hospital; United Kingdom (8), Benares Hindu University (7),

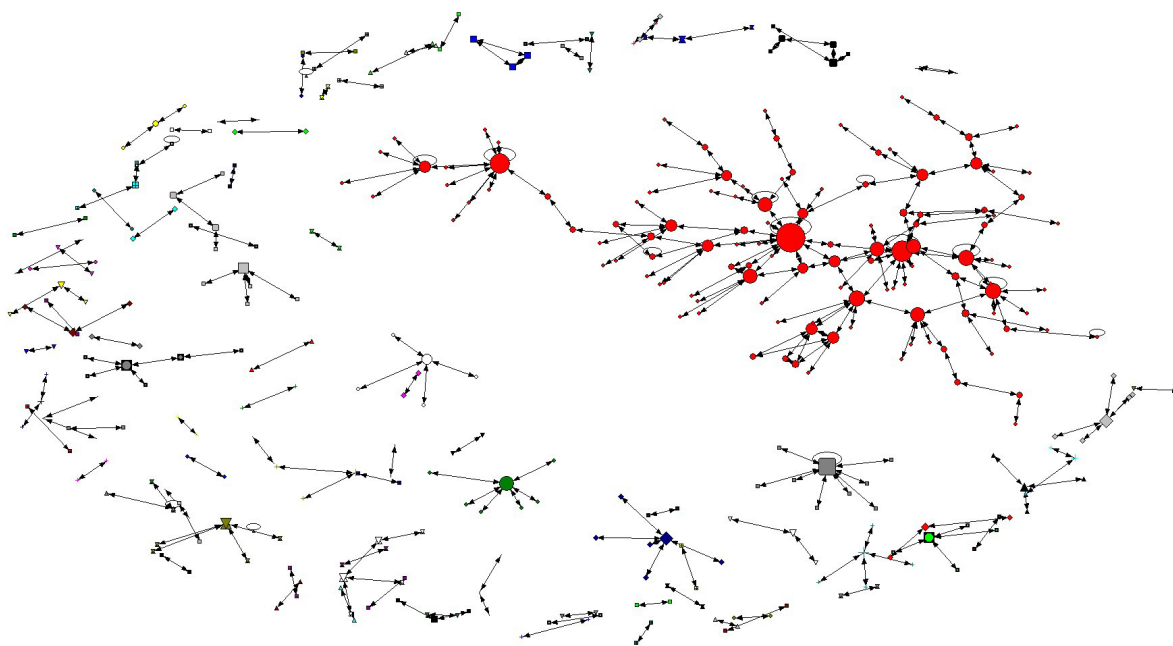


Fig. 4—Institutional collaboration network

J. J. Hospital; Bombay (7) and Government College; Lahore (7). The higher betweenness centrality score of IISc Bangalore shows that it was the centre of collaboration. It was also the most prominent actor in the largest component that consists of 123 actors. The institutions with higher betweenness are: University College; London, Andhra University, Presidency College; Madras and J. J. Hospital, Bombay. This collaboration network is not connected as a whole, so the distance between nodes in disconnected components of a network is infinite. It has been mentioned earlier that the closeness measure cannot be applied to networks with disconnected components^{34,37}. The institutions with high eigenvector centrality are as follows Indian Institute of Science, University College; London, Central College; Bangalore, University of Mysore, Allahabad University and Punjab University; Lahore (Table 5).

Conclusion

Pre-independent Indian science saw the contribution of many seminal works by renowned scientists. Beside the state initiatives, there were many private initiatives both from the individual and political leaders of that time that had a 'nationalistic' zeal. The institutions like Indian Institute of Science, Indian Institute for Cultivation of Science, Bose Institute and so on were formed. These institutions

were very productive in terms of scientific productivity and also prominent in scientific collaboration. These establishments of colonial period still hold the pillars of modern science in India^{8,40,41}.

The result of the present study shows that S&T publication activities in undivided India thrived during the mid-1930s. This period is associated with the creation of a series of support structures in S&T and can be considered as consolidation and institutionalization of colonial science. Parallel to colonial science, there emerged a stream of early science policy efforts in nation-building through a number of private initiatives which placed Indian science in the international scientific domain^{7,8}.

The maximum research activity was observed in the area of chemistry followed by agricultural and biological science. Indian scientists preferred to publish their research output in Indian journals. The *Proceedings of the Indian Academy of Sciences* published by the Indian Academy of Science since 1934 were the most preferred journals of publication. Also, prominent Indian scientists of the time preferred Indian journals as their medium of publication of their research outputs.

The authorship collaborations were mainly restricted among the Indian authors with very little or

Table 5—Centrality measures of institutional actors

| Institute | Degree | Institute | Betweenness | Institute | Closeness | Institute | Eigenvector |
|---------------------------------------|--------|--------------------------------------|-------------|---|-----------|--|-------------|
| Indian Institute of Science | 14 | Indian Institute of Science | 4717.216 | Hislop College, Nagpur, C.P. | 98775 | Indian Institute of Science | 0.541 |
| Allahabad University | 10 | University College London | 2797.239 | Hope Tea Estate, North Bengal | 98775 | University College London | 0.288 |
| Calcutta Medical College & Hospitals | 9 | Andhra University | 2094 | Malaria Survey of India, United States | 98775 | Central College, Bangalore | 0.263 |
| Samaritan Free Hospital, UK | 8 | Presidency College, Madras | 1711 | D. J. Sind College, Karachi | 98709 | University of Mysore | 0.26 |
| Benares Hindu University | 7 | J. J. Hospital, Bombay | 1674.691 | Lahore Maternity Hospital, Lahore | 98705 | Allahabad University | 0.235 |
| J. J. Hospital, Bombay | 7 | University of London | 1512 | Brahmachari Research Institute, Calcutta | 98662 | Punjab University, Lahore | 0.201 |
| Government College, Lahore | 7 | Punjab University, Lahore | 1501.714 | Eden Hospital for Women, Calcutta | 98662 | Imperial Institute of Sugar Technology, Cawnpore | 0.182 |
| Hafkine Institute, Bombay | 6 | University of Calcutta | 1417 | London School of Tropical Medicine, UK | 98662 | Science College, Patna | 0.175 |
| Central College, Bangalore | 6 | Calcutta Medical College & Hospitals | 1376 | Chittaranjan Hospital, Calcutta | 98662 | University of Madras | 0.167 |
| University of Lucknow | 6 | University of Madras | 1263 | Bacteriologist to the Government of Bengal | 98662 | Andhra University | 0.155 |
| Punjab University, Lahore | 6 | Allahabad University | 1154.095 | Chemical Examiner to the Government, Bengal | 98662 | University of Lucknow | 0.149 |
| University of Madras | 6 | Government College, Lahore | 1054.452 | Government of Bengal | 98662 | Government College, Lahore | 0.146 |
| University of Bath, UK | 6 | University of Bombay | 1019.667 | School of Tropical Medicine, Calcutta | 98654 | Muslim University, Aligarh | 0.146 |
| University of Bombay | 5 | Hafkine Institute, Bombay | 1019.357 | Karnatak College, Dharwar | 98590 | University of Edinburgh | 0.14 |
| Royal Institute of Science, Bombay | 5 | Muslim University, Aligarh | 928.834 | Elphinstone College, Bombay | 98588 | Bose Institute, Calcutta | 0.129 |
| King Edward Memorial Hospital, Bombay | 5 | Benares Hindu University | 900.667 | Mayo Hospital, Lahore | 98584 | University of Mysore | 0.122 |
| School of Tropical Medicine, Calcutta | 5 | Royal Institute of Science, Bombay | 739 | Institute of Science, Bangalore | 98542 | D.A.V. College, Cawnpore | 0.122 |
| Grant Medical College | 5 | University of Edinburgh | 698 | Calcutta Medical College & Hospitals | 98541 | Fergusson College, Poona | 0.122 |
| Andhra University | 5 | Science College, Patna | 650.595 | King Institute | 98538 | Christi College, Oxford, UK | 0.122 |
| Middlesex Hospital, London | 5 | St. Xavier's College, Bombay | 650.333 | Madras Christian College | 98509 | J.J. Hospital, Bombay | 0.122 |
| University College London | 5 | Christian College, Lahore | 638.333 | Bombay University, Medical School, Poona | 98507 | Punjab University Institute of Chemistry, Lahore | 0.098 |
| Department of Public Health, Cairo | 5 | University of Lucknow | 637.167 | Ismail College, Bombay | 98475 | Benares Hindu University | 0.077 |
| Botany School, Cambridge | 5 | University of Cambridge | 498.691 | Plymouth Laboratory, United States | 98475 | University of Cambridge | 0.067 |

most no collaborations with the scientists from the Great Britain. The similar trends have also been seen in the institutional collaboration patterns. It shows the strength of Indian scientists and institutes in doing independent research at that time.

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