

Indo-French cooperation in water sciences: capturing research dynamics through co-authorship analysis

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Water scarcity and quality are among the key challenges of the 21st century. Compelling necessity to address this problem has led to the emergence of various types of international collaboration. India is one of the countries seriously affected by water scarcity and quality. International collaboration has emerged as an important component of India's strategy for mitigating the water-related challenges. One of the key linkages in India's international cooperation in water sciences is observed with France. This cooperation has led to the establishment of two joint laboratories: Indo-French Centre for Groundwater Research and Indo-French Cell for Water Sciences.

The present study examines the structure of this research cooperation through co-authorship analysis. Analysis over a period of time showed that authors from the two laboratories played a key role in developing the network. The importance of this network is also discussed.

Keywords: Co-authorship network, international collaboration, research dynamics, social network analysis, water sciences.

THE challenge of addressing water scarcity and quality has become one of the key global agenda of the 21st century. The recent ranking by the World Resource Institute of 167 countries found that 33 developing as well as developed countries will face extremely high water stress by 2040. OECD¹ estimates that about 1.5 billion people are living in areas seriously affected by water scarcity and this number will increase to almost 4 billion by 2050. It has been estimated that by 2050 the world's population will grow to 9 billion, which will increase the need for water by 50% (ref. 2). Acceleration of hydrologic cycles due to climate change is making wet places wetter and dry places drier. *The Economist*³ in its recent issue, has succinctly flagged the key factors behind this water scarcity: increasing world population, climate change, bad farming practices, industry misutilization and poor water resource management.

Recent debate on sustainable development has shown how much efforts are still required to meet the basic needs for water access and quality globally. Water is a sector where 'return to investment' is not defined strictly in economic terms, but more in terms of addressing developmental challenges. A whole economy has grown around water with private players successfully translating

it as a commodity. Access to safe drinking water has created a new divide between the rich and poor. The Sustainable Development Goals (SDGs)⁴ articulated in 2015 have defined a specific goal for this sector, SDG6 (Clean Water & Sanitation). This goal directs attention to water quality, water efficiency, universal water, natural ecosystem and integrated management. Population expansion, urbanization, deforestation and climate change are focusing on the need for increasing international cooperation in addressing water challenges. This is motivating development of new cooperation models like Global Water Research Coalition⁵ (GWRC), and Water supply and sanitation Technology Platform⁶ (WssTP). South-South cooperation is also developing specific agenda/dialogue forum for addressing challenges in this sector. A case in point is the IBSA (India-Brazil-South Africa) trilateral forum which is providing funds for water desalination plants in the South countries. Bilateral collaborations are also bringing water in their priority of cooperation. India, for example, has developed bilateral cooperation agreement in water with France and the UK.

India has a complex governance structure for addressing water challenges. A separate ministry, the Ministry of Water Resources acts as a central coordinating agency for planning and coordinating various aspects related to water in the country. Other ministries and departments, primarily the Department of Science and Technology (DST), University Grants Commission (UGC), Department of Biotechnology (DBT), Ministry of Environment, Forest and Climate Change, are also involved in this sector. One

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of their activities is funding research and technology development in various research institutions in India in the water sector. The 'National Water Mission' is one of the key missions identified by the National Action Plan on Climate Change (NAPCC). This mission aims to integrate water resource management, i.e. conserve water, minimize wastage and ensure its uniform distribution among different communities. Another major programme the 'Water Technology Initiative' supported by DST to promote R&D activities in water covering three major components, namely technology development, assessment and capacity building. An important component of the above programmes is to develop cooperation with different countries.

One of the key linkages in India's international cooperation in water sciences is observed with France. This cooperation has led to the establishment of two joint laboratories in water sciences: Indo-French Cell for Water Sciences (IFCWS) and Indo-French Centre for Groundwater Research (IFCGR). IFCWS was established in 2001 between the Indian Institute of Science (IISc), India and the Institut de Recherche pour le Développement (IRD), France at the IISc Campus, Bengaluru. The other partners of this laboratory are National Institute of Oceanography (NIO), as well as Indian Institute of Tropical Meteorology (IITM) from India, and National Center for Scientific Research (CNRS), National Center for Space Studies (CNES), and National Institute for Agricultural Research (INRA) from France. From 2010, IFCWS has been recognized as an International Joint Laboratory. This has motivated the Laboratory to further expand its vision by developing collaborations at regional and international levels.

IFCGR was established in 1999 between the National Geophysical Research Institute (CSIR-NGRI), India and Bureau of Geological and Mining Research (BRGM), France at the NGRI campus, Hyderabad. The other major partners of this laboratory are French Embassy in India, Indo-French Centre for Promotion of Advanced Research (CEFIPRA), Andhra Pradesh Ground Water Department, UNESCO, University of Paris, University of Grenoble, Central Water Commission, Central Ground Water Board, and French Institute of Pondicherry. Scientific research cooperation to solve critical local, regional as well as global issues using complementary expertise of the two nations is the key objective of the two laboratories.

Scientific cooperation has become an unprecedented choice of doing research the world over to solve global problems. The issues associated with water are much more complex and call for interdisciplinary approach. The growth of science across the world and the increasing interdependence of different regions, and the need for complementary expertise underscore the need for strengthening international cooperation. In the last two decades or so, one has observed increasing number of agreements on international R&D collaboration the world

over. One can say that international collaboration has emerged as an inherent feature of contemporary global science. From a policy perspective, the critical issue is to measure the nature and extent of cross-border science and technological linkages.

Various studies have explored the international cooperation with different objectives. Adams *et al.*⁷, for example, pointed to the increasing levels of cooperation between leading research economies. Leydesdorff and Wagner⁸ examined the global research network of 14 countries that form the core of this network. They argued that peripheral countries could be disadvantaged by increased strength at the core. King⁹ argued that major facilities (for example, CERN) and cooperative programmes (for example, WHO, IPCC) play an important role in facilitating networks in the global system. Bhattacharya and Shilpa¹⁰ studied the growth and changing dynamics of science globally. Influential reports (see for example, ref. 11) have given a comprehensive account of the changing global research agenda and drivers that are key agents of change. One interesting aspect of the above studies is their increasing reliance of using research papers as a proxy for capturing the structure and dynamics of research cooperation.

Majority of the contemporary studies highlight the macro trends and draw indications for policy corrections at the national/global level. This has been contested as challenges are not uniform across sectors¹². Keeping this as an argument, we underscore the need for examining international collaboration at the sectoral level for more informed policy intervention. From this perspective, the present study examines the Indo-French research network in water sciences. It explores the patterns of collaboration, relation among individual actors and their role in shaping the network structure. This is done by applying the method of social network analysis (SNA) to co-authorship networks. We have taken the case study of Indo-French cooperation as these two countries have come into formal agreement by establishing two joint laboratories in the sector of water sciences. The bilateral cooperation model developed by India and France has led to establishment of CEFIPRA. This is now cited among the most influential models for bilateral collaboration¹³. Six laboratories, including the two in water sciences have emerged through the Indo-French cooperation. Sectoral level cooperation between the two countries has been established in different areas over a period of time and thus is a good motivation to capture the research network developed by these two countries in an important sector¹⁴.

Methodology

Indo-French cooperation in water sciences was captured through research publications from the Web of Science (WoS) covering the period 1991–2015. Delineation of journals for data extraction was based on journal

categorization of this database. The study applies co-authorship analysis to capture the structure of Indo-French cooperation in water sciences. For this purpose authors associated with Indo-French laboratories were identified through primary survey conducted by the present authors, analysis of secondary documents (websites, annual reports, etc.) and author affiliation provided in the papers.

Co-authorship network, an important form of social network, has been intensively studied in the literature (see for example, refs 15, 16). SNA is an innovative method to explore the collaborative behaviour of different actors which opens new perspectives for S&T collaboration studies. Ucinet¹⁷ and Netdraw¹⁸ are two preferred software used for SNA. Ucinet allows computational analysis of various measures of linkages in a network. Netdraw is a visualization software that allows graphic representation of networks^{19,20}. 'Centrality' is an important concept in SNA, as it reveals the structure of a network by measuring linkages among actors in the network²¹. There are different kinds of centrality measures to capture the network structure. Here three centrality measures, i.e. degree centrality, closeness centrality and betweenness centrality have been used to map the actors in co-authorship network. Degree centrality equals the number of ties that a vertex has with other vertices. Generally, vertices with higher degree or more connections are more central and tend to have a greater capacity to influence others. Closeness centrality emphasizes the distance of a vertex to all other vertices in the network by focusing on the geodesic distance from each vertex to all others²². Betweenness centrality is based on the number of shortest paths passing through a vertex. Vertices with a high betweenness play the role of connecting different groups²³.

Results

The field of water sciences has become an intensive area of research globally with a large number of research institutions and multilateral bodies visible in this area. One indication of the intense research activity is observed through research publications. During 1991–2015, 1,749,531 research articles were published in WoS-covered journals in this area. Table 1 highlights research activity of countries prolific in water sciences.

One can observe that research activity is distributed between developed and developing economies, highlighting the research priority given to this area globally. Also, it can be observed that a large proportion of these papers includes internationally collaborative papers (Table 1).

Closer examination of papers from India and France highlights a large number of countries involved as collaborative partners in their research publications. Indian authors had partnership with 161 countries in their re-

search papers in water sciences, whereas France had 192 partners. During 1991–2015, 824 papers were jointly published by the two countries. (This is part of an extensive study of the two Indo-French laboratories in India. We have observed that the key results are jointly published from India and France in high-impact journals. While many other publications emerge from these cooperative partners individually. This cannot be strictly quantified, but in general we found this in the ratio of 1 : 3. It reveals that joint partnership is much more influential in real statistics. This may be true for other joint co-operations in water sciences. It may also be true for other international research co-operations.) Thematic areas primarily addressed by the joint publications are: geological mapping, hydraulic tests, geochemistry, oceanography, groundwater sampling and quality modelling, geostatistics, groundwater flow and solute transport modelling, influence of monsoons and on water resources, biogeochemical dynamics in the Indian Ocean, bioremediation, and modelling of urban water systems. This cooperation has been a key determinant in developing a niche in various sub-domains globally as well as building capacity for the two countries.

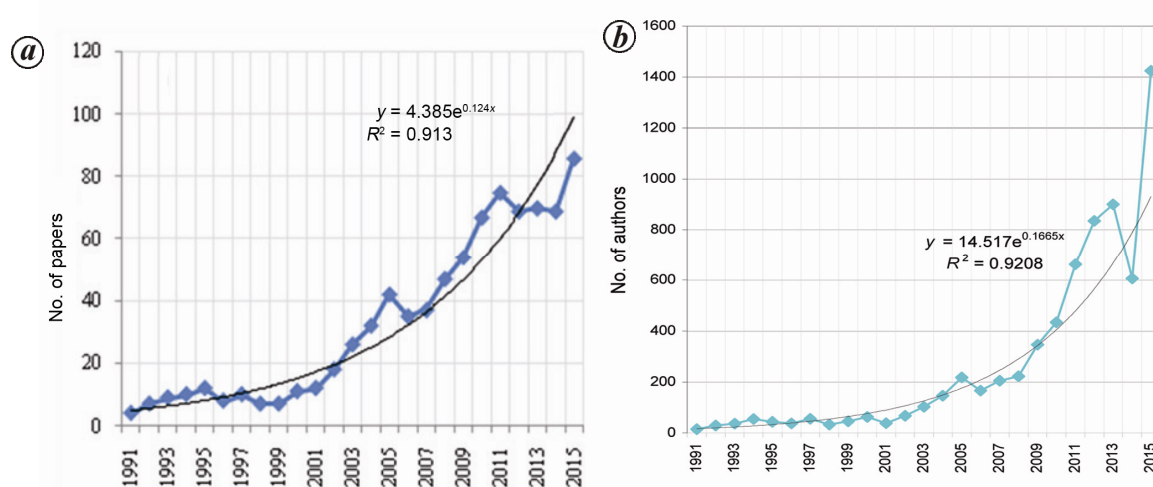
Figure 1 exhibits distribution of research papers jointly published by the two countries and authors associated with these papers during 1991–2015. The two curves show an exponential growth with research papers trend captured by the equation $y = 4.385e^{0.124x}$, and authors trend by $y = 14.51e^{0.166x}$. High value of fit can be observed in both the cases with R^2 values of 0.913 and 0.920 respectively. The exponential curves indicate that the increase will be a function of the volume of papers or authors at a given time. Thus we can conclude that over a period of time there will be significant increase in the number of papers and authors visible in the Indo-French water sciences network. A sharp drop is observed in 2013 and the reason for the same is not clear. Increasing trend is visible again from 2014, which is difficult to explain. However, one can discern an important reason behind this trend to be the high priority given to water sciences in Indo-French cooperation. This is observed from the formal agreements between the two countries over a period of time in water sciences²⁴.

The authors affiliation of Indo-French papers in water sciences from 2000 onwards was further analysed. A positive trend is visible in the number of papers from the authors associated with the two Indo-French laboratories. In 2001, 10% of papers were from the authors of these two laboratories, which increased to almost 20% in 2005, 35% in 2011 and more than 50% in 2015. It is also observed that most of the papers emerging from these two laboratories are among highly cited papers of Indo-French publications. The establishment of Indo-French laboratories has not only increased the quantity of research output but has also positively influenced the quality of research.

Table 1. Publication and international collaborative papers in water sciences of prolific countries

Rank	Country	Total papers	Internationally collaborative papers	Percentage of internationally collaborative papers
1	USA	454,217	130,823	29
2	China	197,948	45,724	23
3	Japan	122,146	28,371	23
4	Germany	114,351	55,223	48
5	France	94,851	47,040	50
6	England	94,765	49,798	53
7	Canada	87,422	35,524	41
8	India	73,256	12,939	18
9	Spain	68,085	28,003	41
10	Australia	62,267	27,390	44

Source: Web of Science.

**Figure 1.** Yearly distribution of Indo-French (a) papers and (b) authors in water sciences.

Analysis of Indo-French co-authorship network in water sciences

To capture the evolution of this network, analysis of co-authorship was undertaken for three time-periods, i.e. 1991–2000, 2001–2010 and 2011–2015. The year of establishment of the two laboratories – 1999 for IFCGR and 2001 for IFCWS, and the recognition given to the latter as an International Joint Laboratory in 2011 was the rationale behind choosing differential time-periods. We posit that these events played an important role in strengthening intellectual and innovative linkages in the water network within and between the two countries. Role of authors of these two laboratories in developing the overall research network strengthens our argument. Research papers, however, provide only a partial indication of this. In the discussion later, we have highlighted the wider impact of these two laboratories based on our primary study.

In order to show the main co-authorship structure of the network, we selected prolific authors with at least

three papers in each time-period. This threshold resulted in 21, 42 and 30 authors respectively, in these three periods. Figure 2 is a co-authorship map of these authors exhibiting the structure of the collaboration network in these time-periods. The map is composed of core sub-networks which are not connected with each other. The shape of nodes represents the affiliation of the authors, square represents authors from India, circle represents authors from France and triangle represents authors from other countries. The thickness of the line represents the number of papers in cooperation and size of the vertex represents the relative frequency of papers.

We observed different structures of the network in three time periods. In 1991–2000 there is a distinct group of authors. In 2000–2010, the network is getting denser and some level of interconnectivity is visible in different groups. The network is, however, again scattered in 2011–2015. However, unlike 1991–2000, the group size has increased and also there are linkages emerging at least in two important groups through a common node. J. C. Marechal has emerged as a common node in later

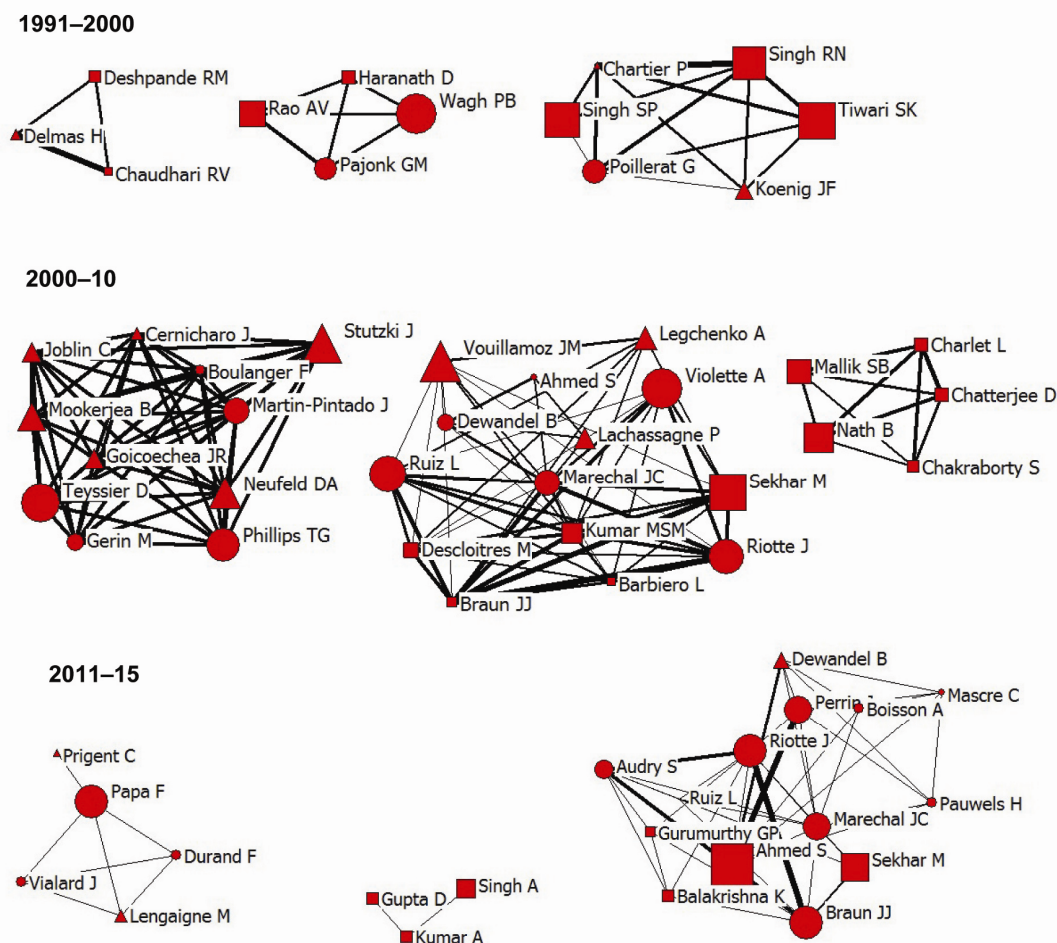


Figure 2. Co-authorship map in three different time-periods.

Table 2. Top 10 authors based on centrality measures in co-authorship network

Rank	Degree centrality (high to low)			Betweenness centrality (high to low)			Closeness centrality (low to high)		
	1991-2000	2001-10	2011-15	1991-00	2001-10	2011-15	1991-2000	2001-10	2011-15
1	IER P	Braun JJ	Braun JJ	Chartier P	Marechal JC	Marechal JC	Chartier P	Marechal JC	Marechal JC
2	Singh RN	Riotte J	Riotte J	Singh RN	Kumar MSM	Riotte J	Singh RN	Kumar M	Riotte J
3	Poillerat G	Sekhar M	Ahmed S	Poillerat G	Vouillamoz JM	Perrin J	Poillerat G	Braun JJ	Perrin J
4	Tiwari SK	Pajonk GM	Perrin J	Delmas H	Dewandel B	Ahmed S	Tiwari SK	Descloitres M	Ahmed S
5	Koenig JF	Rao AV	Audry S	Chaudhari RV	Descloitres M	Braun JJ	Koenig JF	Sekhar M	Braun JJ
6	Pajonk GM	Kumar MSM	Dewandel B	Pajonk GM	Ruiz L	Audry S	Singh SP	Ruiz L	Audry S
7	Rao AV	Marechal JC	Sekhar M	Rao AV	Braun JJ	Papa F	Haranath D	Vouillamoz JM	Dewandel B
8	Chaudhari RV	Charlet L	Marechal JC	Tiwari SK	Sekhar M	Kumar A	Wagh PB	Riotte J	Sekhar M
9	Delmas H	Chatterjee D	Lengaigne M	Lamboy M	Riotte J	Dewandel B	Pajonk GM	Violette A	Ruiz L
10	Wagh PB	Ruiz L	Vialard J	Rao VP	Pajonk GM	Pauwels H	Rao AV	Barbiero L	Pauwels H

time-periods, playing an important role in connecting two groups working in two different Indo-French laboratories, i.e. IFCWS and IFCGR.

Table 2 shows the top 10 authors based on closeness, betweenness and degree centrality calculated with the co-authorship network in three different time-periods.

The authors visible in the initial years, i.e. 1991-2000 are not present in the later time periods. The reason could

be the initiation of formal cooperation by establishment of joint laboratories in 1999 and 2001. After the initiation of this formal cooperation some scholars working in the area of water sciences from both the countries became associated with these two laboratories (based on findings from a field study). It is interesting to note these scholars are prolific authors in the Indo-French water network. This also indicates their key role in establishing the water

sciences network. Few of the authors with high centrality values are indirectly associated with these laboratories. These authors (Table 2) form the core (degree centrality), have direct connections (closeness centrality) and connect different groups (betweenness centrality).

In the later time-periods, the highest degree centrality is of J. J. Braun. In SNA framework, it indicates his control over the network. He was deputed in India and was directly associated with IFCWS as co-chairman from 2001 to 2014. Marechal has the highest betweenness centrality which plausibly indicates his role in influencing different strands of research groups. In collaborative network, betweenness centrality reflects the author's role in bridging different sub-groups. Marechal was chairman of IFCGR from 2000 to 2003, and was also involved as a lead in many research projects. He has the lowest closeness centrality. High betweenness centrality and low closeness centrality indicate his ubiquitous presence in the network.

Figure 3 shows the frequency distribution for authors in two time-periods, i.e. 2001–2010 and 2011–2015).

The frequency of betweenness centrality and degree centrality follows power-law distribution and closeness centrality distribution follows the normal curve, except in

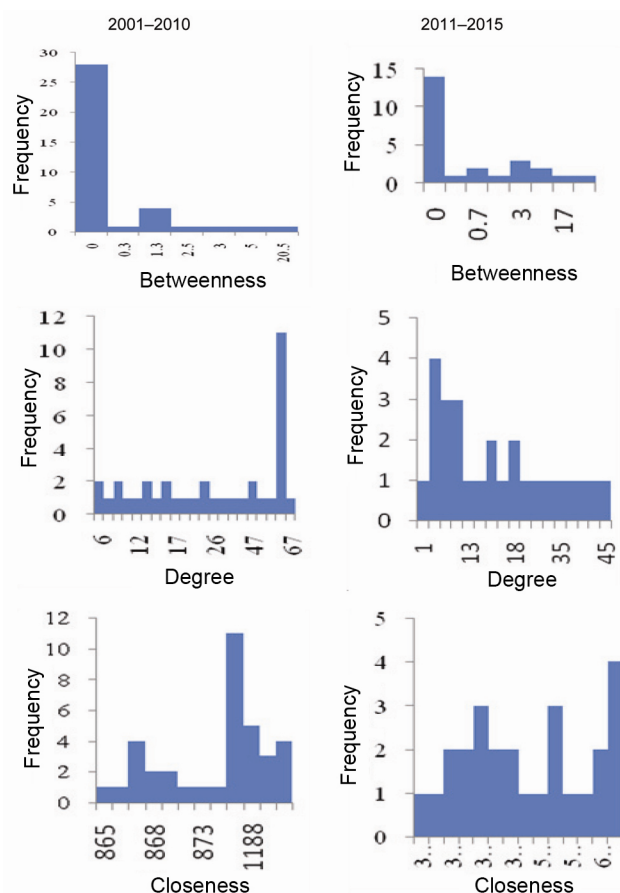


Figure 3. Frequency distribution of closeness, betweenness and degree centrality in co-authorship network.

the last phase, i.e. 2011–2015. Very few authors have high betweenness centrality values, which indicates that few authors are playing an important role in connecting different groups working in this area. In 2001–2010 most of the authors have higher degree centrality, whereas in 2011–2015 most of the authors have low degree centrality. In 2001–2010, most of the authors have high closeness centrality which shows that they are well connected to the other authors in the network. In 2011–2015, closeness centrality is well distributed among the authors.

Discussion and conclusion

This study captures the structure and dynamics of Indo-French cooperation in water sciences by applying co-authorship analysis. Using centrality measures through SNA, various patterns of the network structure have been revealed. Influence of the two Indo-French laboratories on this network is also visible.

The Indo-French network is getting denser over time-periods. Subgroups are emerging with members within each group having strong ties, i.e. high degree and closeness centrality. The subgroups are connected by a few authors acting as a bridge between them. In network terminology these authors have high betweenness centrality. Thus the network possesses the characteristics of a dynamic network.

The implications of the betweenness centrality are that there is good cross-fertilization of ideas between subgroups. Strong ties within a group imply the strong integration for solving common problems. Primary field study validates these results. From the results of different measures of centrality, Marechal has emerged as a key scholar in bridging the different subgroups. He worked as the chair of IFCGR from 2000 to 2003 and was on deputation from IRD to IFCWS from 2006 to 2009. His association with both the laboratories for long durations makes him a key actor in the Indo-French network, even after his formal separation from the laboratories. Both the laboratories had undertaken some challenging projects with researchers from both countries involved in them. Strong ties are exhibited in a project which is reflected through the research papers. On the other hand, Marechal is the prominent author playing a key role in the different projects. This is reflected in his high betweenness centrality as he is present as author in papers emerging from different projects.

We also find that some authors are relatively highly ranked in later time periods, i.e. 2001–2010 and 2011–2015; these authors are either directly associated with the Indo-French laboratories or have indirect association. These central authors of the whole network are most influential. They have also played a prominent role in establishing this network and held high positions (chairs or co-chairs) at some point of time.

The collaboration is not only leading to an increasing number of joint papers, but is also expanding the breadth and depth of research. The increasing number of Memoranda of Understanding and establishment of two joint laboratories have led to increasing involvement of a diverse set of actors from the two countries. Projects have been undertaken in key areas such as building models for monsoon prediction, and providing flood maps for the Bengal Delta. A unique feature of these laboratories is the long-term stay of French scientists in India, which has further helped in building trust and a long association between the two countries.

SNA contributes in innovative ways to the evaluation of the collaborative behaviour of different actors like researchers, organizations and countries. Numerous applications can be recovered with this method and it opens new perspectives in S&T collaboration studies. It also allows understanding of the research structure in an area, evolution of research networks and the actors embeddedness in a network. The co-authorship data represent only one of the possible indicators of scientific collaboration. Not all collaborative efforts result in publications, and not all co-authored papers necessarily imply collaboration in the form of knowledge-sharing among authors. Still, it is assumed that, in most cases, co-authorship forms an active cooperation between partners beyond the simple exchange of material or information.

It will be interesting to complement this analysis with primary surveys of researchers. We need different kinds of data to link them with different dimensions of collaboration. This has been implemented in a case study presented in a conference and is also part of the thesis from which this communication is derived²⁵. It is also possible and necessary to apply centrality measures to other network analysis measures. In future studies, it will be important to improve the algorithm of centrality measure, and utilize its strength in improving the current impact evaluation.

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