Indo-French Cooperation in Water Sciences: Capturing Research Dynamics through Co-Authorship Analysis

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Abstract

Water scarcity and quality has become one of 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 Center for Groundwater Research and Indo-French Cell for Water Sciences.

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

Keywords: Indo-French Cooperation, Water Sciences, Social-Network-Analysis, Co-authorship Network

Introduction

The challenges for addressing water scarcity and quality has become one of the key global agenda of the 21st century. The recent ranking by World Resource Institute of 167 countries found that 33 developing as well as developed countries will face extremely high water stress by 2040. OECD[1] (2012) 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 percent (FAO, UN[2]). Acceleration of hydrologic cycles due to climate change is making wet places wetter and dry places drier. The Economist in its recent issue has succinctly flagged the key factors behind this water scarcity: increasing world population, climate change, bad farming practices, industry misutilisation and poor water resource management[3].

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 it is defined more in terms of addressing developmental challenges. A whole economy has grown around water with private players successfully translating water as a commodity. Access to safe drinking water has created new divide between rich and poor. The Sustainable Development Goals (SDGs)[4] articulated in 2015 has 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 Coalition[5] (GWRC), and Water supply and sanitation Technology Platform[6] (WssTP). South-South

cooperation are 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 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 UK.

India has complex governance structure for addressing water challenges. A separate ministry, '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 Department of Science and Technology (DST), University Grant Commission (UGC), Department of Biotechnology (DBT), Ministry of Forest & Environment (MOEF) are also involved in this sector. One of their activity is funding research and technology development in various research institutions in India in water sector. 'National Water Mission' is one of the key mission 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 uniform distribution of water among different communities. Another major program is 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. One important component of the above programs 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 Center for Ground Water 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, Bangalore. The other partners of this laboratory are National Institute of Oceanography (NIO), 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 Center 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 two nations is the key objective of the two laboratories.

Scientific cooperation has become an unprecedented choice of doing research world over to solve global problems. The issues associated to 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 underscores 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 world over. One can say that international collaboration has emerged as an inherent feature of contemporary global science. From 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] (2007), for example, pointed to the increasing levels of cooperation between leading research economies. Leydesdorff and Wagner[8] (2008) examined the global research network of 14 countries that form the core of the global research network. They argued that peripheral countries could be disadvantaged by increased strength at the core. King[9] (2012) argued that major facilities (for example CERN) and cooperative programs (for example WHO, IPCC) play an important role in facilitating networks in the global system. Bhattacharya and Shilpa[10] (2016) studied the growth and changing dynamics of science globally. Influential reports (see for example Royal Society, 2011[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 sectors[12]. Keeping this as an argument, we underscore the need for examining international collaboration at the sectoral level for more informed policy intervention. Keeping this perspective, the paper examines the Indo-French research network in water sciences. Study 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 case study of Indo-French cooperation as these two countries have came 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

collaboration[13]. Six laboratories including the two laboratories in water sciences have emerged through the Indo-French cooperation. Sectoral level cooperation between the two countries have 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 sector[14].

Methodology

Indo-French cooperation in water sciences was captured through research publications from 'web of science' covering the period 1991-2015. Delineation of journals for data extraction was based on journal categorization of this database. The paper 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 authors, analysis of secondary documents (website, 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, Liu *et al.* 2005[15]; Vidgen *et al.* 2007[16]). Social Network Analysis (SNA) is an innovative method to explore the collaborative behavior of different actors which opens new perspectives for S&T collaboration studies. Ucinet[17] and Netdraw[18] are two prefeered softwares used for SNA. Ucinet allows computational analysis of various measures of linkages in a network. Netdraw is visualisation 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 network[21]. There are different kinds of centrality measures to capture the network structure. In this paper three centrality measures were used: degree centrality, closeness centrality and betweenness centrality. These were 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 others[22]. 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 groups[23].

Results

Water sciences have become an intensive area of research globally with a large number of research institutes and multilateral bodies visible in this area. One indication of this intense research activity is observed through research publications. During 1991-2015, 1,749,531 research articles were published in water in WoS covered journals in this area. Research activity of countries prolific in water sciences is highlighted in Table 1.

Table 1: Publication and International Collaborative Papers in Water Sciences of Prolific Countries

Rank	Country	Total papers	Internationally Collaborative papers	% of Internationally Collaborative Papers	Rank	Country	Total papers	Internationally Collaborative papers	% of International Collaborative Papers
1	USA	454217	130823	29	6	England	94765	49798	53
2	China	197948	45724	23	7	Canada	87422	35524	41
3	Japan	122146	28371	23	8	India	73256	12939	18
4	Germany	114351	55223	48	9	Spain	68085	28003	41
5	France	94851	47040	50	10	Australia	62267	27390	44

Source – Web of Science

One can observe that research activity is distributed among 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 are internationally collaborative papers (Refer Table 1).

Closer examination of papers from India and France highlight large number of countries involved as collaborative partners in their research publications. Indian authors had partnership with 161 countries in their research papers in water sciences whereas France had 192 partners. During 1991-2015[1], 824 papers were jointly published by the two countries. Thematic areas primarily addressed by the joint publications are: geological mapping, hydraulic tests, geochemistry, oceanography, groundwater sampling and quality modeling, geostatistics, groundwater flow and solute transport modeling, influences of monsoons and on water resources, biogeochemical dynamics in the Indian Ocean, bioremediation, and modeling of urban water systems. This cooperation has been a key determinant in developing 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 associatied 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 author 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 indicates that the increase will be 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 number of papers, and authors visible in the Indo-French water sciences network. A sharp drop is observed in 2013 and causality behind this dip is not clear. Increasing trend is visible again from 2014. It is difficult to ascribe a causality behind this exponential trend. However, one can discarn an important reason behind this trend would be the

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[1] This study is part of extensive study of two Indo-French laboratories in India. Through our primary survey, it is observed that the key results are jointly published by scholars from India and France targeting high impact journals. While many other publications emerge which are published by these cooperative partners individually. This cannot be strictly quantified but in general we found this in the ratio of 1:3. This reveals that joint partnership is much more influential then visible in real statistics. This may be true for other joint cooperations in water sciences. This may also be true for other international research cooperations.

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 sciences[24].

Figure 1: Yearly Distribution of Indo-French a) Papers and b) Authors in Water Sciences
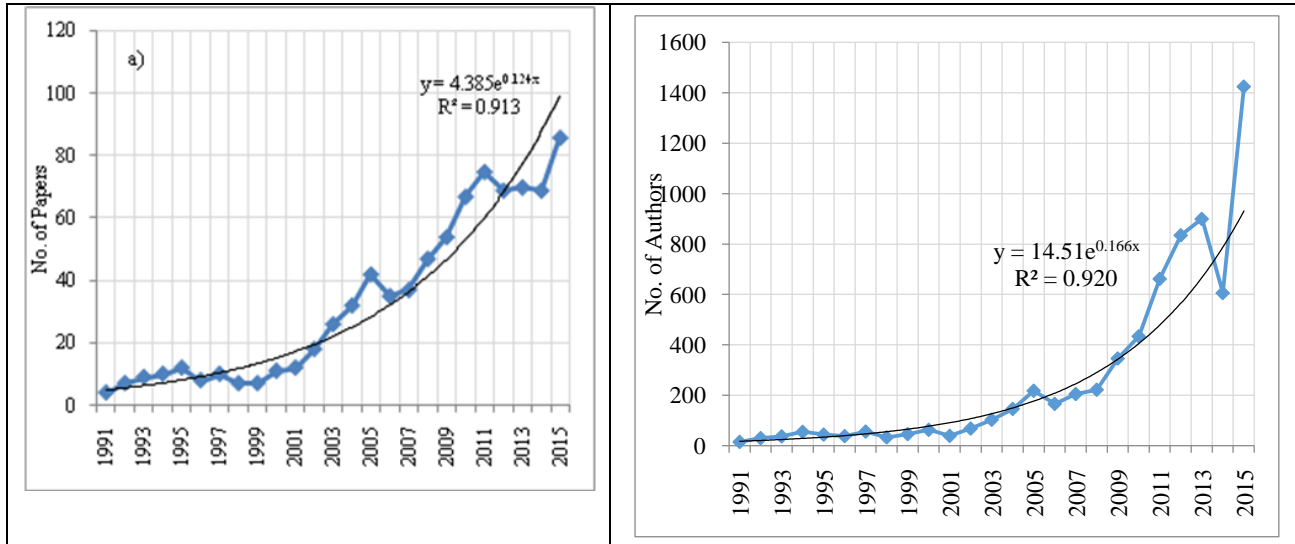
The authors affiliation of Indo-French papers in water sciences from 2000 onwards were further analysed. A positive trend is visible in number of papers from the authors associated with the two Indo-French laboratories in water sciences. In year 2001, 10% papers were from the authors of these two laboratories 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 papers in water sciences. The establishment of Indo-French laboratories have not only increased the quantity of research output but has also positively influenced the quality of research.

**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 two laboratories, 1999 for IFCGR and 2001 for IFCWS and the recognition given to IFCWS as

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 water network within and between the two countries. Role of authors of these two laboratories in developing the overall research network in water sciences between the two countries 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 atleast 3 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 author's collaboration network in these three 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 the authors from India, circle represents the authors from France and triangle represents the authors from other countries. The thickness of the line represents the number of papers in cooperation and size of vertex represents the relative frequency of papers.

Figure 2: Co-authorship Map in Three Different Time-period
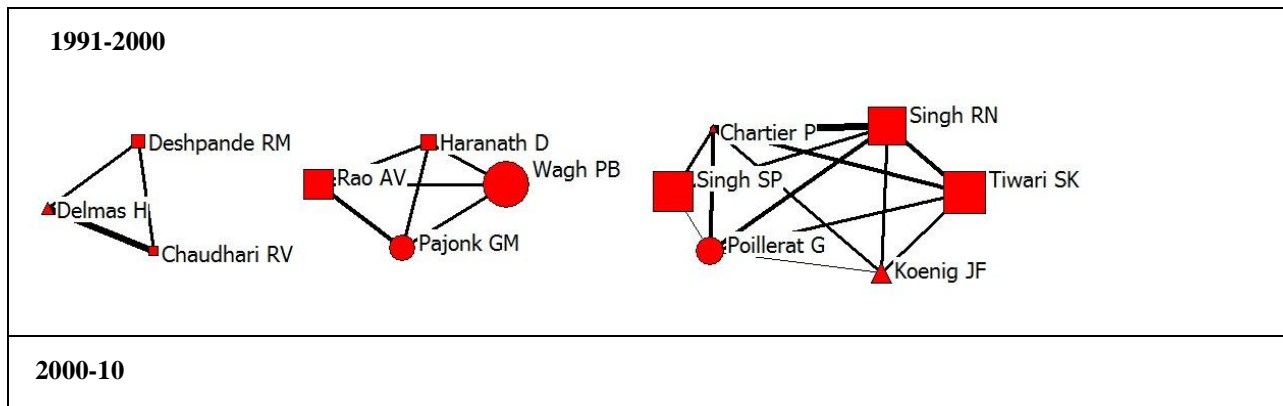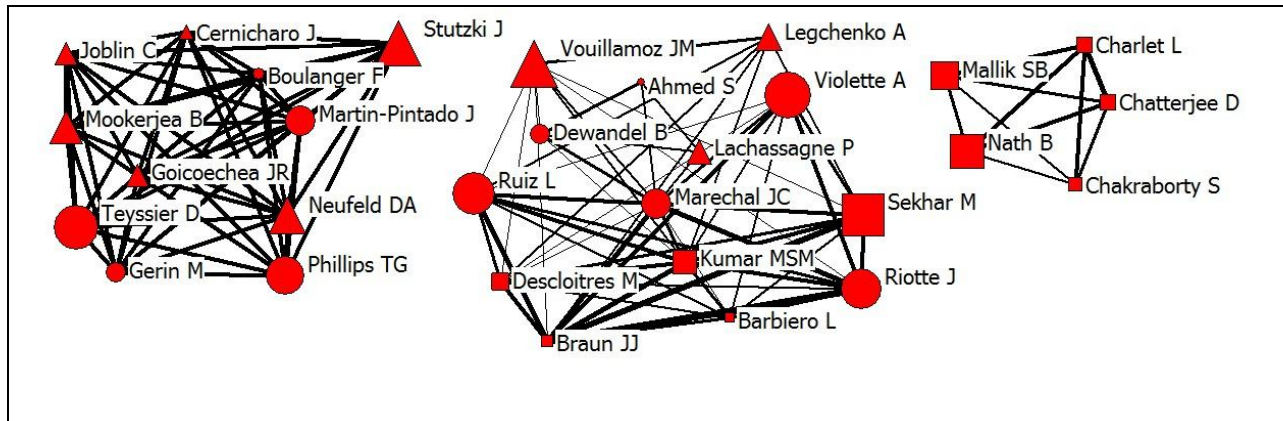
2011-15
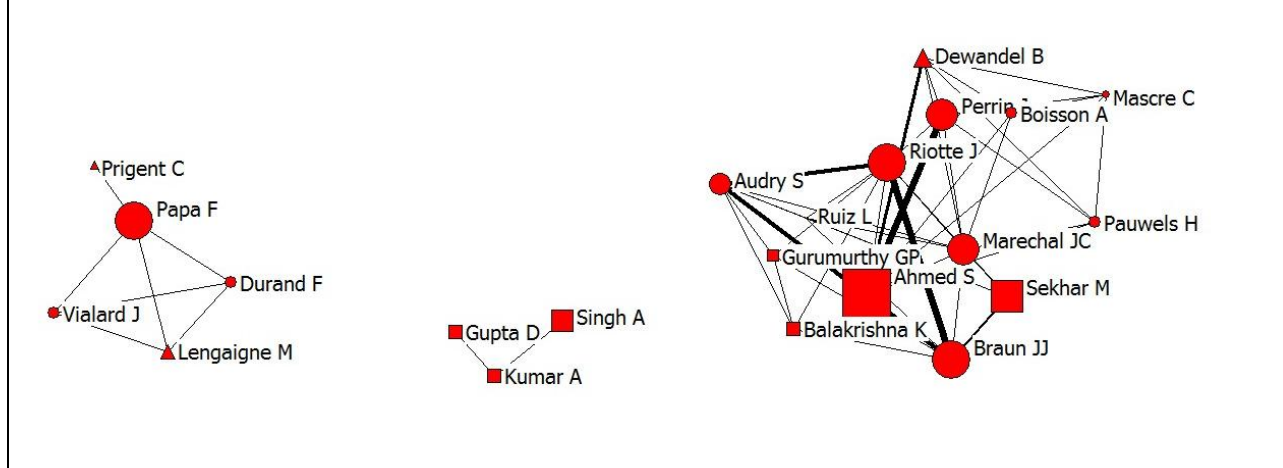
We observe different structures of the networks in three time periods. In 1991-2000 there are distinct group of authors. In 2000-2010, the network is getting denser and some level of interconnectivity is visible in different groups. The network is however again scattered in 2011-2015. However, unlike 1991-2000 the group size has increased and also there are linkages emerging atleast in two important groups through a common node. Marechal JC has emerged as a common node in later time periods, playing an important role in connecting two groups working in two different Indo-French laboratories i.e. IFCWS and IFCGR.

Table 2 further shows the top 10 authors based on closeness, betweenness and degree centrality calculated with the co-authorship network 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)		
	1991-00	2001-10	2011-15	1991-00	2001-10	2011-15	1991-00	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

The authors visible in 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[2]. It is interesting to see these scholars as 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 (present in 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 JJ Braun. In SNA framework it indicates his control over the network. JJ Braun was deputed in India and was directly associated with IFCWS as co-chairman from 2001 to 2014. Marechal JC has 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 JC was chairman of IFCGR from 2000 to 2003 and was also involved as a lead in many research projects. Marechal JC has the lowest closeness centrality. High betweenness centrality and low closeness centrality indicates his ubiquitous presence in the network.

The frequency distributions for authors in two time periods (i.e. 2001-2010 and 2011-2015) are shown in figure 3.

Figure 3: Frequency Distribution of Closeness, Betweenness and Degree Centrality in Co-authorship Network

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2001-2010	2011-2015
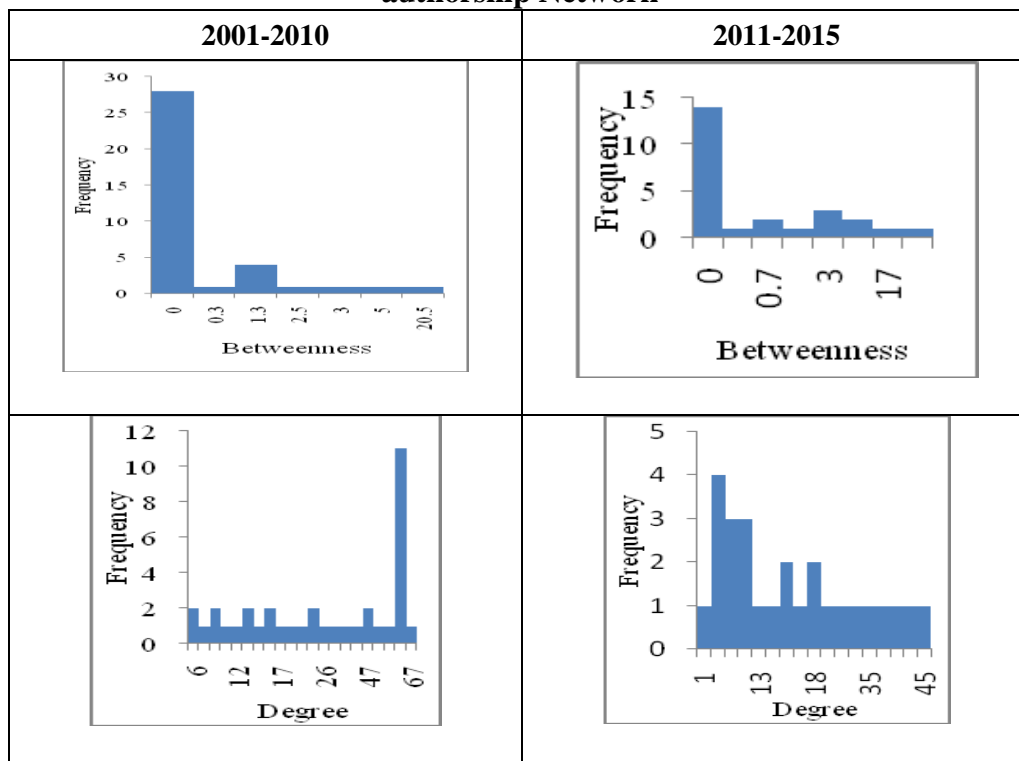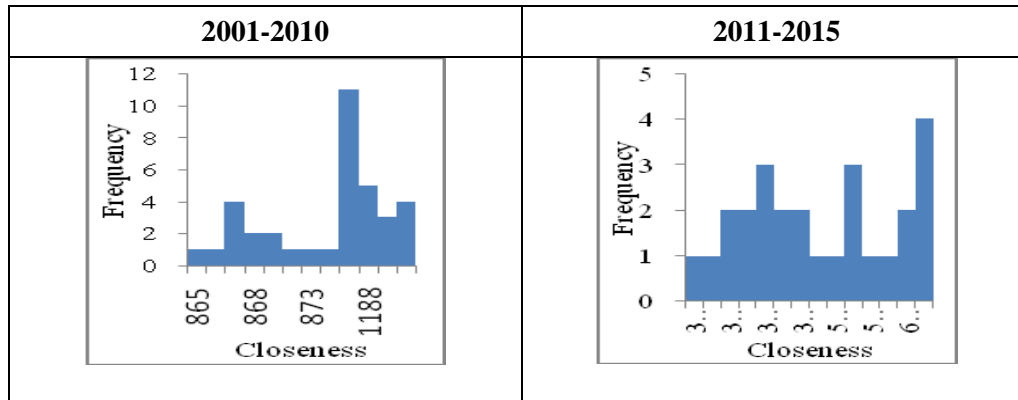
The frequency of betweenness centrality, and degree centrality, follows power-law distribution and closeness centrality distribution follows the normal curve except in the last phase i.e. 2011-2015. Very few authors have high betweenness centrality values which mean that few authors are playing important 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 possess high closeness centrality which shows that these are the authors well connected to the other authors in the network. In time period 2011-2015, closeness centrality is well distributed among authors.

Discussion and Conclusion

The paper captures the structure and dynamics of Indo-French cooperation in water sciences by applying co-authorship analysis. Applying centrality measures through social network analysis, various patterns of the network structure were revealed. Influence of the two Indo-French laboratories (i.e. IFCWS and IFCGR) on this network is also visible.

The Indo-French network is getting denser over the time period. 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 bridge between the subgroups. In network

terminology these authors have high betweeness centrality. Thus the network possess the charactersitics of a dynamic network.

The implications of the betweenness centrality is that there are good cross-fertilisation of ideas between sub-groups. Strong ties within a group implies the strong integration for solving common problems. Primary field study validates these results. From results of different measures of centrality, Marechal JC has emerged as a key scholar in bridging the different sub-groups. Marechal JC worked as chair of IFCGR, Hyderabad from year 2000 to 2003 and was on deputation from IRD to IFCWS, Bangalore from year 2006 to 2009. His association with both the laboratories for long duration makes him a key actor in Indo-French network even after his formal separation from the laboratories. Both the laboratories had undertaken some challenging projects with researchers from both the countries involved in them. Strong ties is exhibited among a project which is reflected through the research papers. On the other hand authors, Marcechal JC being prominent among them playing a key role in the different projects. This is refelected in his high betweeness 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 and these authors are either directly associated with the Indo-French laboratories or having indirect association. These central authors of the whole network indicates that they are the most influential scholars in the field of water sciences in the Indo-French network. These scholars also had a prominent role in establishing this network as had high positions as chairs or co-chairs of the two bilateral laboratories at some point of time.

The collaboration is not only leading to the increasing number of joint papers but is also expanding the breadth and depth of research of both the countries visible through other type of

outcomes. The increasing number of Memorandum of Understanding and establishment of two joint laboratories have led to increasing involvement of diverse set of actors from the two countries. Projects have been undertaken in key areas such as building models for monsoon prediction, providing flood maps for 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 term association between two countries.

Social network analysis contributes in innovative ways to the evaluation of the collaborative behavior of different actors like researchers, organizations and countries. There are large numbers of applications that can be recovered with this method and opens new perspectives in the S&T collaboration studies. It allows understanding of the research structure in a area, evolution of research networks and the actors embeddness 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 it with different dimensions of collaborations. This has been implemented in a case study presented in a conference and is also dealt in thesis from which this paper is derived[25]. 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 their strength in improving the current impact evaluation.

Acknowledgement

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We thank the referees' for their useful comments/observations. Keeping the comments in perspective, we have made extensive changes in the manuscript. We hope that the revised version will be accepted in your esteemed journal. The revision in the paper as per the comments is enclosed below.

Reviewer Comments

1.   First, why is this analysis important? Did the increase in output of research justify the effort (and cost) involved in setting up the co-operation agreement? The main point is that the paper only looks at the outputs of two labs, and doesn't address the counter-factual situation. That is, is Indo-French collaboration in water research significantly improved compared with what might have happened in the absence of this agreement? For example, is the trajectory of IN-FR co-authorship different from those of, say, IN-UK and IN-DE co-authorship? Has the creation of these two labs led to less co-authorship from other labs? And how many of the papers from these two labs involve both one or more Indians and one or more French researchers? It should be possible to determine this from the names of the authors.

Authors Response

The paper captures the structure of the Indo-French network in water sciences through co-authorship analysis. International collaboration has emerged as an important determinant in addressing water challenges. In this context, capturing research partnership between a developed and an emerging economy in this area has important implications. Social network analysis approach used for this analysis provides novel insights such as the authors that control the network, the key authors that play role in bridging the sub-groups. Structure of an important network also provides a useful demonstration of exploiting SNA for capturing network characteristics.

The paper has been further enriched by undertaking analysis of author's affiliation. This analysis provides evidence of the impact of the two laboratories in strengthening the Indo-French water network. Thus it provides counterfactual argument of the role the two laboratories play in developing the water network between the two countries. The results shows that the authors from the bilateral laboratories are the most influential people in the area while few other scholars indirectly associated with this laboratory also form the core of the network. The detailed analysis has been included at appropriate places in the paper. Publication analysis is only one indicator to show the increasing output of an organisation. The two laboratories have influenced the diversity

of stakeholders involved in cooperation. Earlier this cooperation was primarily dominated by government research institutions while establishment of these two joint laboratories have led to the inclusion of other type of agencies like universities, few industries, CEFIPRA, another type of bilateral organisation and funding organisations like IRD, ANR, CNRS, CSIR, DST. Important projects are also taken up in this joint formal cooperation in the area of addressing the problems for sustainable development through S&T. This has also strengthened the capabilities of the institutions and scholars in the area. The case study of these two laboratories has been undertaken extensively to examine these issues in the PhD thesis of first author in AcSIR, CSIR-NISTADS. However in the conclusion part of the revised paper some important actions that emerged due to establishment of these bilateral laboratories are discussed.

The comparison of the Indo-French trajectories of publication output with other cooperations of India is beyond scope of the objective of this paper. India's only formal cooperation in the area of water sciences is with France. However recently, a virtual India-UK Water Centre has been created in 2016. It will be too early to show a comparison on these joint cooperations and influences of formal cooperation agreements.

2.   Second, what have been the practical effects of this partnership, either for India or for France? Have there been any major projects either started (or perhaps cancelled) as a result of the joint research activity?

Authors Response

The establishment of these two laboratories has lead to tangible outcomes. These are briefly discussed in the conclusion part of the revised paper. The increasing number of Memorandum of Understanding and establishment of two joint laboratories have led to increased involvement of diverse set of actors from two countries. Earlier government research universities formed the core of the network but later in the effect of these two laboratories many other type of organisations came into prominence like CEFIPRA, a bilateral funding organization, universities, and few industries like IBM. Apart from this, the Indian government has realized the potential of the complementary expertise of this cooperation and has provided funds for some mega projects like building models for monsoon prediction, providing flood maps for Bengal Delta. These laboratories have also helped in building capacity of human resource and laboratories in the different sub-domains of water sciences by organizing workshops and

seminars, and by engaging young scholars. 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 term association between two countries.

3. Third, the "time snapshots" should be of approximately equal duration. It appears from Fig. 2 that collaboration diminished in the last period, but as this was only five years, compared with 10 years for the other two periods, this may be an artefact.

<u>Authors Response</u>

The time period has been taken on the basis of the year of establishment of two laboratories i.e. 1999 for IFCGR and 2001 for IFCWS and the recognition given to IFCWS as International Joint Laboratory. We posit that these events played an important role in strengthening intellectual and innovative linkages in water network within and between the two countries. The revised paper clarifies the rationale behind taking different time snapshots.

4. Fourth, in the diagrams the Indian and French researchers should be distinguished by means of different symbols. How many of each was there in each period?

<u>Authors Response</u>

Editing suggested by reviewer has been done in the figures.

5. Finally, the English needs a lot of improvement, and the paper should be edited by someone whose mother tongue is English.

<u>Authors Response</u>

We have consulted copy editor and done suitable changes as per suggestion.