Connecting the Dots of COVID-19 Transmissions in India

Roshan Singh [1] and Pranav Kumar Singh[2] *

1- Open Source Intelligence Lab - Indian Institute of Technology
Guwahati - India

2- Dept. of Computer Science & Engineering - Central Institute of Technology
Kokrajhar - India

roshansingh3000@gmail.com, snghpranav@gmail.com

Abstract. Witnessing its first case in late January 2020 India has seen a sharp rise in the number of positive cases of COVID-19. 34 States/UT (s) of the country have been found to be affected by the pandemic to date. We in this work, study the progress of COVID-19 pandemic in India. We aim to create transmission network visualization (s) of COVID-19 in India and perform analysis upon them. Using the transmission networks obtained we attempt to find the possible Super Spreader Individual (s) and Super Spreader Events (SSE) responsible for the outbreak in their respective regions. We discuss the potentials of network analysis in mitigating the further spread of the disease. This is one of the initial studies of the outbreak in India and the first attempt to study the pandemic in the country from a transmission network perspective.

1 Introduction

The initial cases of COVID-19 were reported in Wuhan Province, China in late 2019. COVID-19 is a viral disease in humans with the major symptomps of respiratory difficulties, dry-cough and high fever. Originating from China the virus has spread over 210 countries causing 2,000,065 positive cases of infection and 126,754 causalities worldwide as of 5:12 am GMT of 15th April, 2020 [1]. On 11th February 2020, the World Health Organisation declared COVID-19 as a global pandemic. SARS-CoV-2 [2] is the virus responsible for spread of the disease. Droplet transmission and direct contacts are the most common mode of the SARS-CoV-2 transmission in humans [3]. Precautionary measures such as social-distancing, self isolation and lockdowns are being looked as the only effective strategy for mitigating the spread of the novel virus, as no effective vaccine is available against it yet. Such measures aims to reduce social encounters or contacts to a minimum level, hence decreasing the chances of virus contraction.

1.1 Problem Statement and Motivation

India, the second most populous country in the world has seen a sudden rise in the number of COVID-19 cases. Observing, its first case on 30th January 2020 in a student returned from Wuhan, China the country has recorded a total of 9272 active cases and 353 deaths as of 15th April 2020 (Fig. 1).

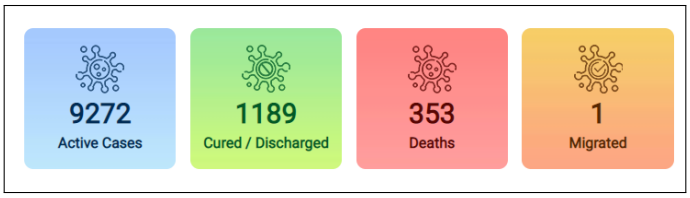


Fig. 1: COVID-19 in India as on : 15 April 2020, 02:32 GMT+5:30 (Source: https://www.mohfw.gov.in/)

A nation wide lockdown is being observed since 22nd March 2020. The lockdown was initially set for 21 days but was further extended to 3rd May 2020 [4]. Public gathering and movement has been restricted to a minimum. The

*.

disease has been reported to be in phase 2 (local transmission) yet with limited or localised community transmissions in some corners of the nation [5] . Local transmission of the disease occurs when a healthy person gets in contact with an infected ones or contaminated surfaces or surroundings. Efforts are being made to check the disease in phase 2 itself. Failing, to check the disease in phase 2 will lead to phase 3 of the disease spread also called the community transmission. Checking, spread in stage 3 is much challenging as the disease spreads in the population in ways that it becomes difficult to trace the point of contraction. In this phase people having no travel history to outbreak effected countries nor having any direct contact with an infected patient are often diagnosed with the disease. Community transmission of the disease may have deadly consequences for the nation with a population of 1.3 billion.

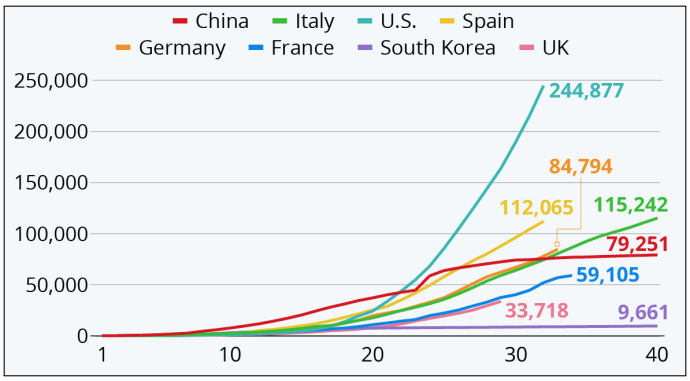


Fig. 2: Growth of confirmed COVID-19 cases in selected countries from the day infection numbers hit 100, As of April 02, 2020 (Source: John Hopkins University)

As shown in Fig. 2, the developed economies such as the United States, Spain, Italy, France and the United Kingdom are now severely affected by the coronavirus and have experienced higher death rates. As illustrated in Fig. 1, the number of COVID-19 cases in India is on a steady rise. However, it will not stand far behind to the above mentioned countries if prompt and proper case finding, contact tracing, analysis not carried out. Although there is still not much evidence of community transmission of coronavirus in India (according to the Indian Council for Medical Research (ICMR)), there is no guarantee that this will not happen. Community transmission, if it begins, can significantly affect the social, cultural, economic, and healthcare infrastructure of different states of the country.

In this paper we study the evolution of COVID-19 in India from the initials. First, we explain how COVID-19 entered into India, then we explain how and why the cases remained to grow. We continue to describe the steps and preventive measures taken to address the pandemic. We generate, visualize and analyse transmission networks of the pandemic across 6 states/UTs. At, last we discuss the observations and the potentials of applying network analysis in mitigating the further spread of the disease.

2 COVID-19 in India

2.1 Ground Zero:

The place where outbreak of pneumonia of unknown etiology was observed for the first time [6]. It was provisionally named as 2019 novel coronavirus or 2019-nCoV, then renamed as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [7] and now as COVID-19. The COVID-19 outbreak first emerged at the end of 2019 (December 2019) in Wuhan City, Hubei Province of China, which is known as an epic centre of the COVID-19.

2.2 First Case in India

The first case of COVID-19 in India was reported on January 30, 2020, in the Thrissur district of Kerala. The patient, a 20-year-old female student at Wuhan University, returned to India from Wuhan, China, for vacation. Thus, the first case reported in India is from the imported transmission category. After the test result came positive, she was immediately placed in isolation at the General Hospital of Thrissur District and has now recovered from COVID-19.

2.3 Initial Cases

After the first case reported at the end of January, only two more cases were detected in Kerala at the beginning of February, 2020, and no other case was reported in the rest of the month. All these three imported cases till February 2020 were medical students who traveled from Wuhan, China, to Kerala, India. As per the report [8], all these three have fully recovered from COVID-19.

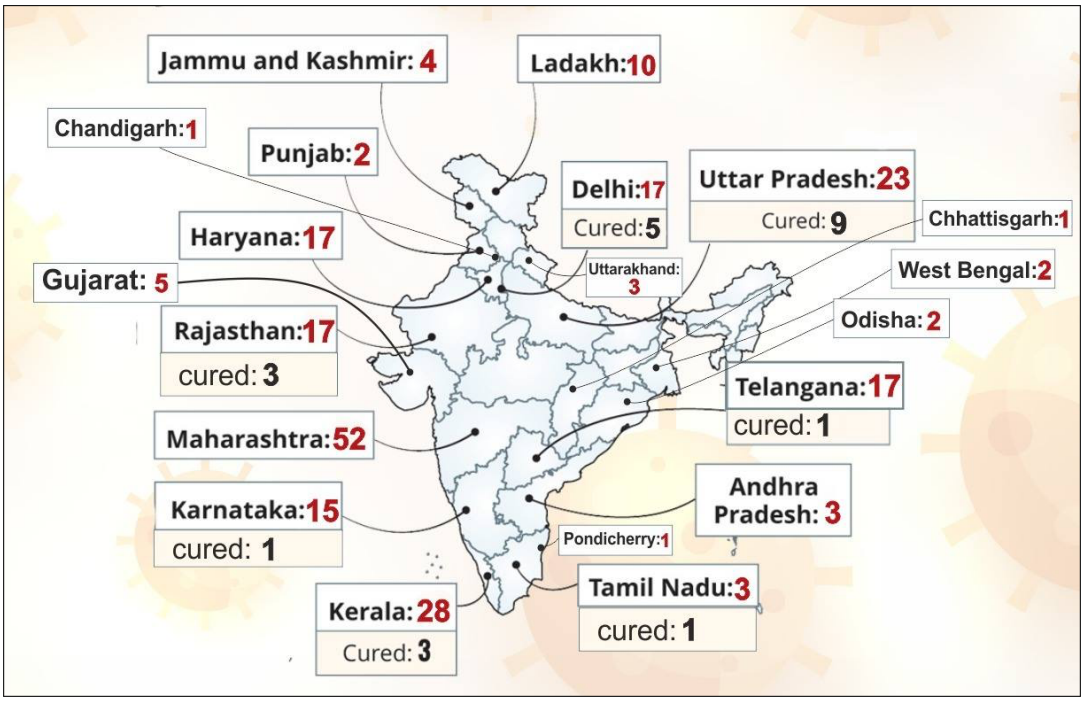


Fig. 3: Number of confirmed COVID-19 cases across India, As on March 20, 2020 at 5:00 PM (Source: Press Information Bureau - PIB, Government of India)

As shown in Fig. 3, in March 2020, the COVID-19 cases escalated in various states and were reported across all over the country. By mid-March, COVID-19 had crossed 100 cases (110 as on March 15), and by the end of the month crossed 1,500 marks (1,619 as on March 31). Most of these cases were of imported transmission category, i.e., linked to a people who had a travel history to affected countries.

2.4 Outbreak

The outbreak of COVID-19 in India was observed in April 2020. The confirmed cases reached to 7600 marks on April 10, 2020, from 1635 confirmed cases on March 31, 2020. In 10 days, a total of 5965 more cases were recorded. As per the report of ICMR on April 10, 2020, 9:00 PM [9], the number of individual tested for COVID-19 were 147034 and

confirmed cases were 6872. As on April 10, 2020, COVID-19 cases have reached to 354 districts out of 727 districts in India.

2.5 Causes of COVID-19 Outbreak in India

Religious gathering, imported transmissions, and local transmissions due to contact with already infected persons are the leading causes of coronavirus spread in India.

2.5.1 Religious Gathering:

Tablighi Jamaat, a religious congregation, held from March 1-15 in Delhi's Nizamuddin area, has emerged as an epicenter for the COVID-19 outbreak in India. It is one of the main causes of the spread of the coronavirus in different parts of the country. Nearly 9,000 missionaries may have attended the congregation [10]. Among those, 1,306 people are foreigners who are Tablighi Jamaat workers and their families that traveled from 40 foreign countries. The rest others are from different states of India [11]. Tablighi Jamaat participants were aggressively pursued following positive test results from six participants who returned from the event to the Andaman and Nicobar Islands. The island administration reported to Delhi administration that several participants are the likely carriers of the COVID-19 disease that they may not be aware of. More detail of the incident is available here [12]. As of 6 April, there were 4,067 confirmed COVID-19 cases out of which 1,445 were linked to Tablighi Jamaat in 17 Indian states and union territories [12]. As of April 11, 2020, 712 cases out of 1,069 COVID-19 cases confirmed in Delhi are linked to this event, which accounts for two-thirds of the total confirmed cases in Delhi [13]. As of April 10, 2020, Assam has 29 COVID-19 positive cases, out of which 28 had a travel history to Tablighi Jamaat in New Delhi, and one patient has linked to this even has died [14]. As of April 10, 2020, Uttar Pradesh has 433 COVID-19 positive cases. In a bulletin later, the state government updated that 245 out of 433 are linked to the Tablighi Jamaat event. As on April 11, 2020, Tamil Nadu has reported 969 COVID-19 positive cases, most of which are linked to the single source of religious gathering.

There was another religious gathering on a Sikh festival held in Anandpur Sahib from 10-12 March in Punjab. A preacher who had returned to Punjab from Germany via Italy carried the COVID-19 virus and attended the gathering in Anandpur Sahib. Later on, 27 COVID-19 positive cases were traced back to him [15]. The preacher became the first victim of the coronavirus in Punjab and fourth in the country. There was a report that authorities in Punjab have quarantined over 40,000 residents in 20 villages in the state to contain the COVID-19 spread, which may be linked to the same preacher [16]. State authorities busted many such religious gatherings in different parts of the country during the lockdown such as in Delhi, UP, West Bengal, Assam, Bihar, and many other states.

2.5.2 Imported and Local Transmissions:

Being in the initial stages , India had quite a lot of cases in imported case category. Significant number of nationals abroad such as NRIs, students, pilgrims, working professionals, migrant workers, businessmen and others returned to the country during the COVID-19 epidemic. Many of them have returned from certain high-risk countries.

Punjab, India's land of NRIs working overseas, alone experienced a massive influx in March 2020. The Punjab government rang the alarm on March 23, 2020, by announcing the recent return of 94,000 of these NRIs [17]. Most of them returned from COVID-19 hotspots, including the UK, US, Spain, and Italy. On March 24, 2020, the CM of Punjab informed that the state authorities had sent 30,000 out of 94,000 NRIs into isolation [18]. Fig. 4 shows the number of International Airline Travelers by Indian State, in January 2020.

After the initial outbreak due to imported transmissions, India badly hit by a lot of local transmissions, mainly amongst family members of imported cases and health workers such as doctors and nurses treating the patients, and so on. Tablighi Jamaat has been observed as one of the biggest contributors to local transmissions, and many components remain to be identified. As of April 10, 2020, India has 27% imported cases and 73% cases of local transmissions.

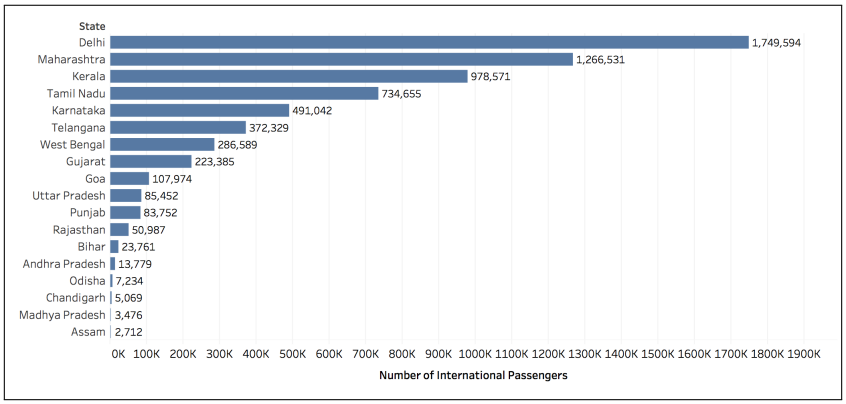


Fig. 4: Number of International Airline Travelers by Indian State, in January 2020. (Source: [19])

2.5.3 Super-Spreaders of COVID-19 in India

The sudden brust of outbreaks of the disease across India is mainly contributed by certain events such as congregation of Nizamuddin Markaz. We call such events as Super Spreader Events(SSEs). Also, there exists a number of individuals who played a key role in transmitting the disease at a large scale. These are the people who contracted the COVID-19 infection either from an affected country or during a visit to the religious gathering and after heading back to home, took part in a meeting, workshop, party at different locations and came in contact with others during their stay and travel instead of visiting to the hospital for check up and undergoing self-quarantine.

2.6 Infographics of COVID-19 related statistics in India

2.6.1 COVID-19 Status of India

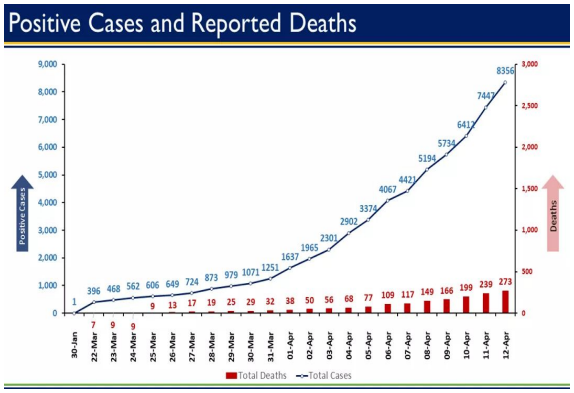
As shown in Fig. 5a, a total of 8356 COVID-19 positive cases and 273 death cases have been reported as on April 12, 2020. As illustrated in Fig. 5b, by the same time, a total of 716 patients recovered for the COVID-19. Daily trend of these cases are visible in those plots. From the curve of positive cases, it is visible that the number of cases is increasing day by day, which is alarming for a densely populated country in India.

2.6.2 Number of Tests Conducted- Date wise

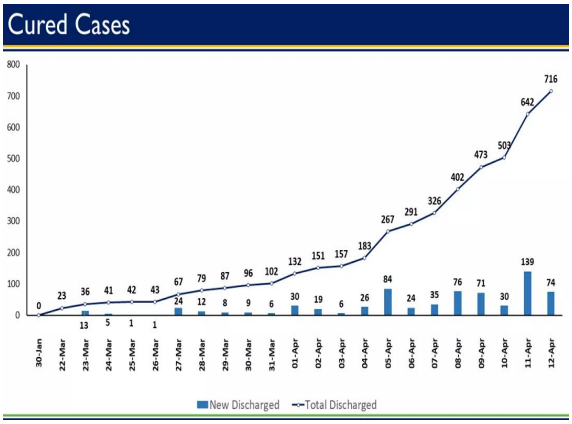
Fig. 6a and Fig. 6b illustrate the date wise test samples and new tests conducted, respectively. From these figures, it is evident that the country is continuously increasing the number of tests per day by upgrading its testing capabilities. This is a good sign and one of the best measures to contain the spread of COVID-19 in the country. Fig. 7a, and Fig. 7b, depicts top 10 states of India by number of COVID-19 tests conducted aas on April 12, 2020.

2.7 Preventive Measures taken till date

The Government of India (GOI) has taken many proactive, preventive, and mitigating steps since the early beginning with the gradual tightening of international travel, the issuance of public advisories, the establishment of quarantine facilities, contact tracing of people contracted with the virus and various social distancing initiatives. Government has temporarily suspended all metro, rail and domestic air traffic services. Central and state governents has proactively imposed and extended lockdowns till May 3, 2020. GOI has urged NGOs, academic institutions, industries, PSUs, research institutes and other organizations to manufacture and supply PPEs, masks, testing kits, ventilators and other specific equipment for emergency deployment, both for patient care and safety of health workers. Government

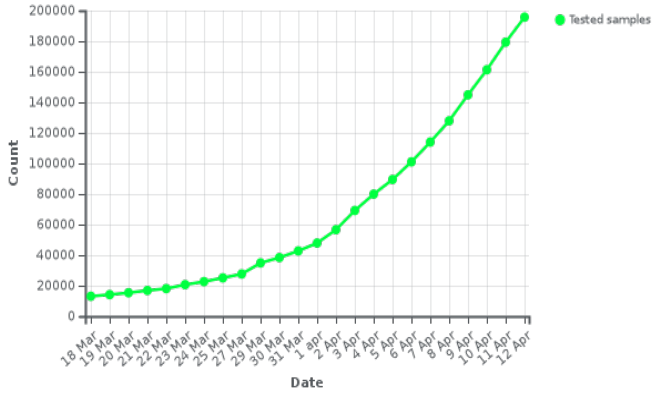


(a) COVID-19 in India: Positive Cases and Reported Deaths

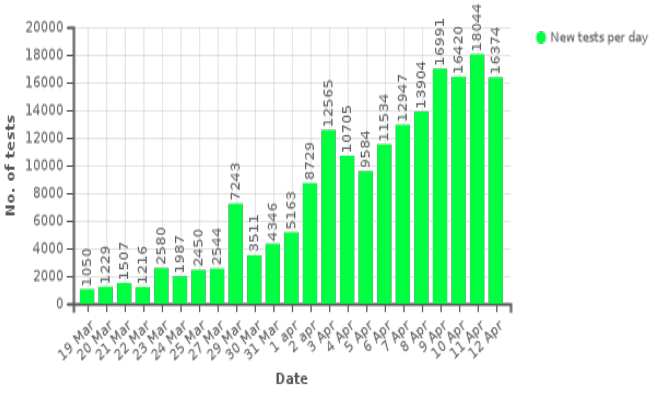


(b) COVID-19 in India : Cured Cases

Fig. 5: COVID-19 in India, Timeline January 30, 2020 to April 12, 2020. (Source: PIB, GOI)

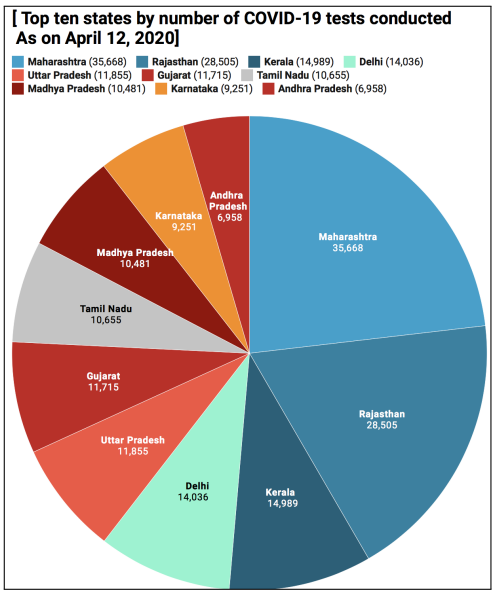


(a) COVID-19 India: Tested Samples

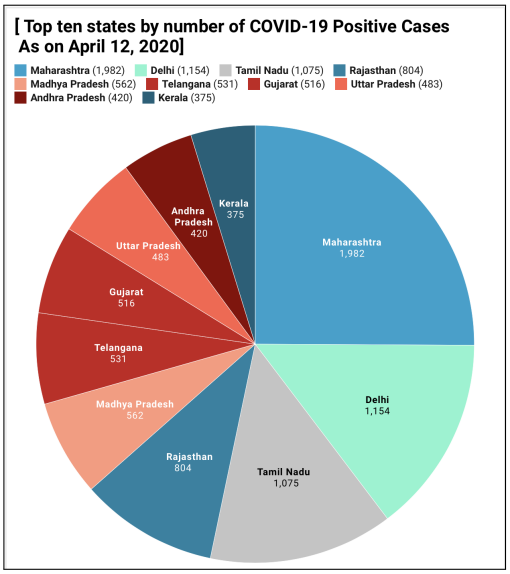


(b) COVID-19 India: New Test Per Day

Fig. 6: COVID-19 Tests in India: Timeline March 18, 2020 to April 12, 2020. (Source: Data from ICMR)



(a) COVID-19: Top ten states by number of COVID-19 tests conducted



(b) COVID-19: Top ten states by number of COVID-19 Positive Cases

Fig. 7: COVID-19: Top ten states by Test and Positive Cases (As on April 12, 2020.) (Source: Data from covid19india.org)

has also expedite the procurement process of these special equipment. Government has launched Aarogya Setu App to connect the health services with its citizen to fight COVID-19.

All state governments are strictly following the guidelines and working hard for contact tracing, extensive testing, identification of COVID-19 hotspots, sanitizing affected zones, implementing social distancing norms, sealing of districts and state boundaries to contain the spread, quarantining patients, designating hospitals and isolation wards for COVID-19 patients, mobilizing acute and ICU surge capacity, training to ensure availability of sufficient numbers of skilled and supervised health workers, daily review of stocks of essential medicines and equipment, developing IT solutions to connect people for health services, and live tracking, etc.

As shown in Fig. 13, GOI swift and strict measures to curb the coronavirus has been reflected in the stringency index on Oxford COVID-19 Government Response Tracker (OxCGRT) [20], where country scores 100 as on April 1, 2020. The tracker aims to compare the government responses to the coronavirus epidemic worldwide, rigorously, and consistently. The OxCGRT collects information on various common policy responses by the government, calculate the scores in terms of stringency of such measures, and aggregates them into a common Stringency Index. It collects publicly available information on 13 indicators of government response, which includes policies such as closures of the schools, workspaces, public transports, cancellation of public events, border closure, travel bans, and other financial indicators.

The Ministry of Home Affairs (MHA), GOI, in its recent lockdown extension order till May 3, 2020, has mentioned that following activities will remain prohibited: all domestic and international air travel, movement by trains, (with few exceptions for security and other crucial services), buses for public transport, metro rail services, inter-district, and inter-state movement (except for medical reasons), all educational, training and coaching institutions, all industrial and commercial activities, hospitality services (except permitted by guidelines of the order), taxis and cab services, all cinema halls, malls, shopping complex, bars, assembly halls, and similar such places, any gathering such as social, political, sports, entertainment, academic, cultural, religious, and others. The religious congregations are

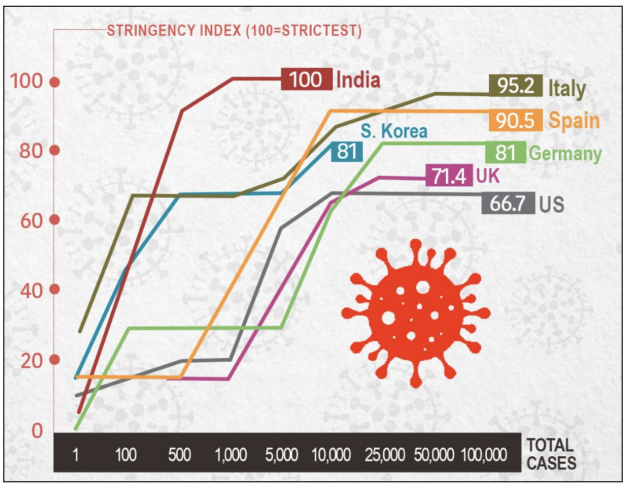


Fig. 8: COVID-19: Government Responses Stringency Index. (Source: Data from [20])

strictly prohibited, and religious places must be closed. The MHA has issued additional guidelines for hotspots and containment zones.

3 Transmission Networks of COVID-19 in India:

Transmission networks have been useful for understanding disease outbreaks and pathogen transmissions in a population. Such networks are widely considered for studying Sexually Transmitted Infections(STIs) such as HIV[21], viral diseases like MERS [22] and Foot-and-Mouth disease in livestock. Transmission network analysis helps to identify potential hotspots, super-spreader individuals or events of the disease. A study [23] from 1997 finds out that the 20% of individuals in a population are responsible for 80% of the infections.

In this section, we investigate COVID-19 transmission in India using the connection structure among them. Open-source data made publicly available by *covid19india.org* [24] till 12:40 am IST of 11th April, 2020 was considered for the study. Data were collected using the provided API and were processed to derive the relational information. Transmission networks for each of the 6 states/UT taken for the study were generated. The symbolic notations followed in our transmission networks are defined in Fig. 9 We use the notation of C1, C2 so on to refer to different group of nodes or components in the network wherever required. We analyze the derived COVID-19 transmission networks in India based upon two centrality measures.

1. **Degree Centrality** - In an undirected network, a node's degree is the number of edges incident on the node. Degree Centrality is used to reveal the most prominent nodes in the network. In our context, the value for the degree of a node specifies the number of individuals to which one individual of the network is directly associated. More an individual having direct relationships with other individuals more are its chances of spreading the disease if she is already infected. Also, the vice versa - more the connections, more the chances of acquiring the infection.

2. **Betweeness Centrality** - Is being used to find out the pairs of nodes that can be connected through the shortest path. Betweeness value of a node specifies the number of nodes in the network that require a node as a junction to reach the other nodes. In our context this is the number of infections that would have not happened if an infected individual was not there in the pathway to the newly infected ones in the network.

Note: All the nodes present in both types of centrality networks for each state/UT in our study are homogeneous, representing the patients along with their numerical IDs to refer.

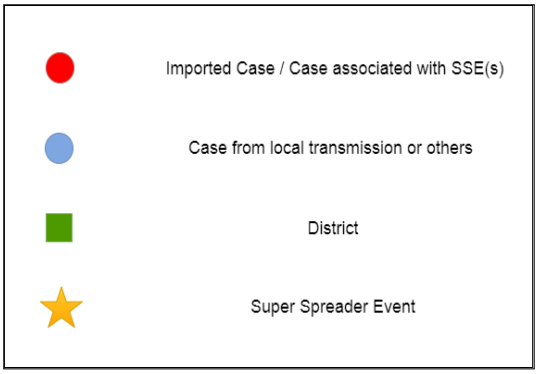


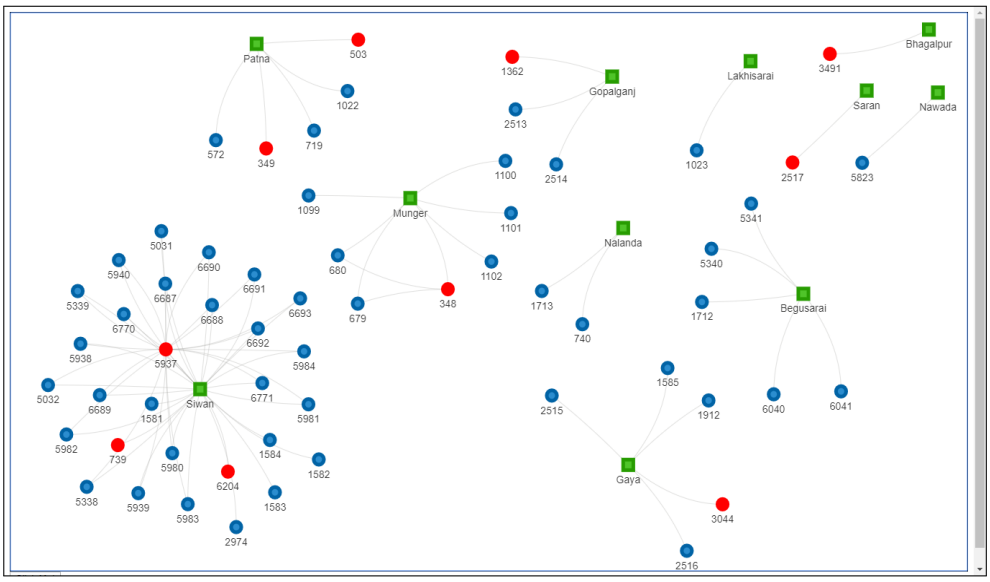
Fig. 9: Notations in our Transmission Networks of COVID-19.

3.1 Transmission Network of COVID-19 in Bihar

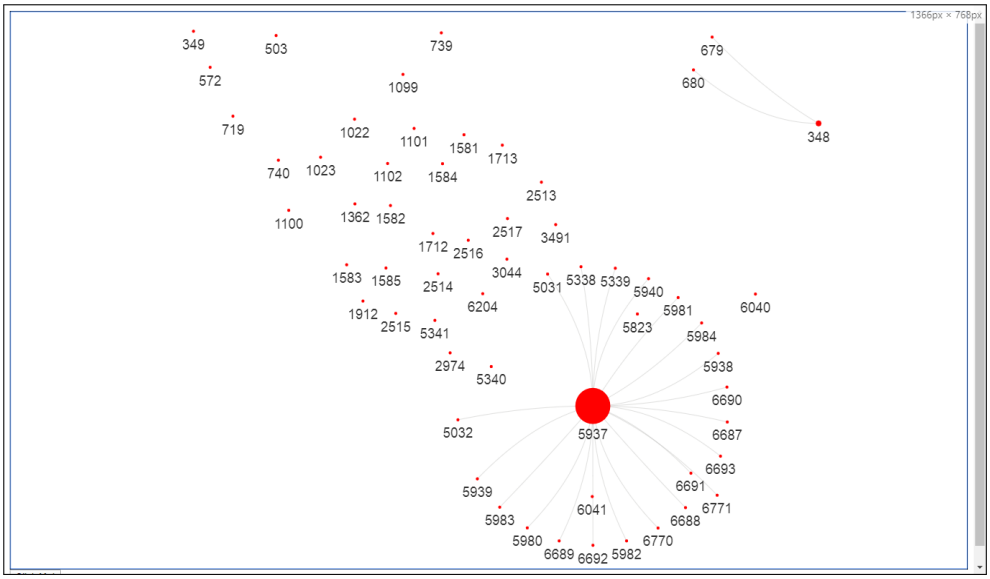
Bihar is the third populous Indian state in the eastern part of the country. The first case of COVID-19 was detected on the 22nd of March 2020, in Munger district of the state. The patient was 38 years male who did return from Qatar. Later he succumbed to death while undergoing treatment at All India Institute of Medical Sciences(A.I.I.M.S) Patna. However, the epicenter of the outbreak in the state turned out to be in Siwan district. A person having recent travel history to Oman did infect a total of 21 others, a majority of infected being his family members. Like Siwan, many other districts in the state facing the crisis has the roots of someone having travel history to COVID-19 affected foreign nations. Table 1 provides the details of the imported cases district wise for Bihar. The COVID-19 transmission network in the state is shown in Fig. 10a, Fig. 10b and Fig. 10c show the degree centrality and betweeness centrality network of COVID-19 in Bihar. There were a total of 60 nodes with 23 connections in the centrality networks. 41.7% of the nodes in the network were having connections to some other nodes in the network. 51.3% of the nodes remained isolated. The node with id 5937 can be seen to be highly central in both the networks, this is the same person responsible for the outbreak in Siwan.

Table 1: Imported cases in Bihar

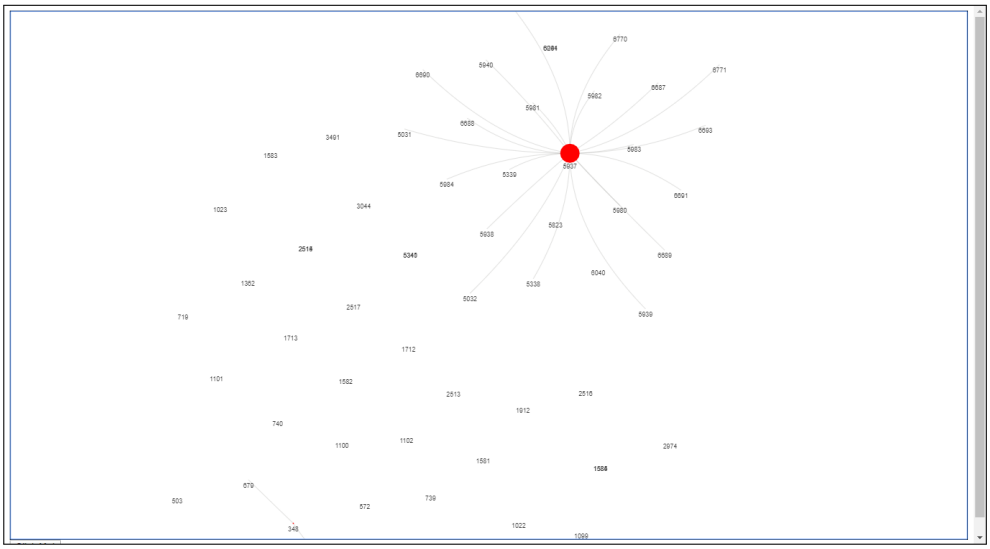
District	**No. of Foreign Cases**	**Foreign Nations**
Siwan	3	Oman,Dubai,Middle East
Munger	1	Qatar
Gaya	1	Dubai
Patna	2	UK, Scotland
Gopalganj	1	Saudi Arabia
Saran	1	UK
Bhagalpur	1	UK



(a) Transmission Network of COVID-19 in Bihar As of April 11, 2020



(b) Degree Centrality Network of COVID-19 in Bihar, As of April 11, 2020



(c) Betweeness Centrality Network of COVID-19 in Bihar, As of April 11, 2020

Fig. 10: Networks of Bihar state, India

3.2 Transmission Network of COVID-19 in Assam

Assam is one of the 8 North-Eastern states of India and plays a crucial role in the economics of the other 7 states. A total of 12 districts have been affected by the pandemic. Out of which cases from 11 districts has direct association with the SSE (Nizamuddin Markaz congregation). The transmission network for the state can be seen in Fig. 11a, Fig 11b describes the normalized centrality network of COVID-19 in Assam, followed by the betweeness centrality network shown in Fig 11c. All the nodes in the network are having uniform centrality values for both the measures as no interconnection among them exists.

3.3 Transmission Network of COVID-19 in Punjab

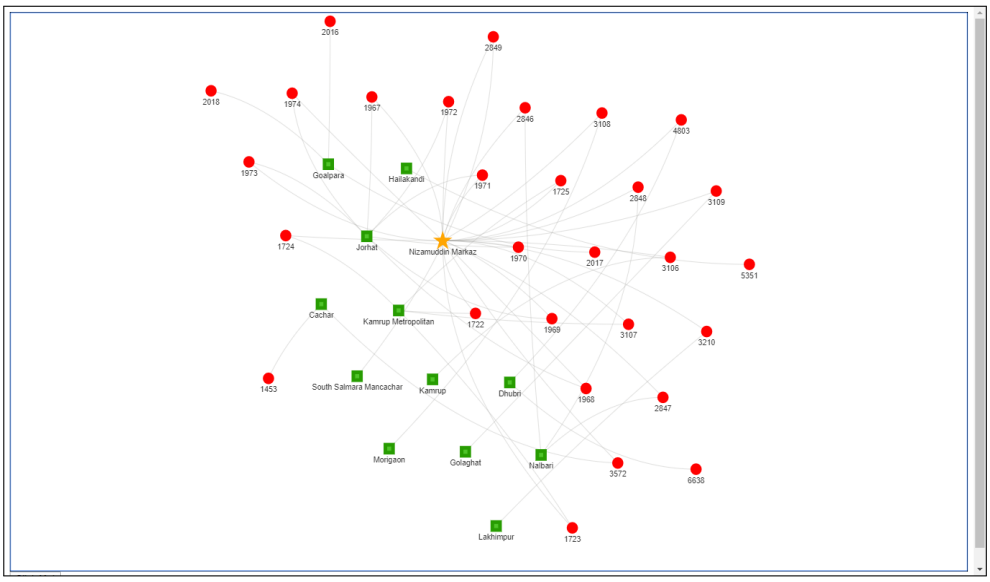
Punjab witnessed its first case of COVID-19 on 9th March 2020. The patient was a 48 years old male from Amritsar having recent travel history to Italy. Till the 11th of April 2020, a total of 17 districts were found to be affected in the state. However, out of 151 cases in the state 11 had direct associations with the SSE(Nizamuddin Markaz congregation). Table 2 provides the details of the imported cases district wise for the state. A total of 5 major components can be observed in the transmission network diagram of the state. A majority of the cases from Shahid Bhagat Singh Nagar in C2 of Fig. 12a is because of the local transmission from one of the foreign cases. The second case of local transmission was observed in S.A.S Nagar where 7 persons working in the same bakery tested positive for COVID-19, they are suspected to have acquired the virus from the owner of the bakery who did earlier tested positive for the virus. Fig. 12b and Fig. 12c shows the degree and betweeness centrality network of Punjab. There were a total of 154 nodes with 43 connections in both the centrality networks. 34.4% of the nodes in the network were having connections to some other nodes in the network. 65.6% of the nodes remained isolated with no connection to others. Node 182 is found to be the most central nodes in both the networks. 182 is responsible for the local transmission in C2.

Table 2: Imported cases in Punjab

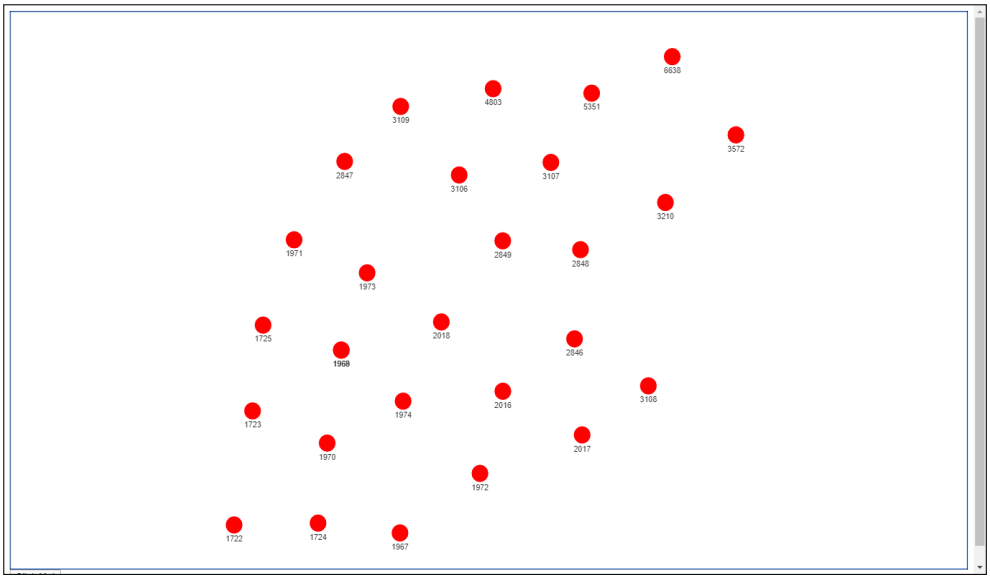
District	**No. of Foreign Cases**	**Foreign Nations**
Amritsar	2	Italy, UK
Shahid Bhagat Singh Nagar	3	Germany, Italy
S.A.S. Nagar	2	UK
Jalandhar	1	Italy

3.4 Transmission Network of COVID-19 in Kerala

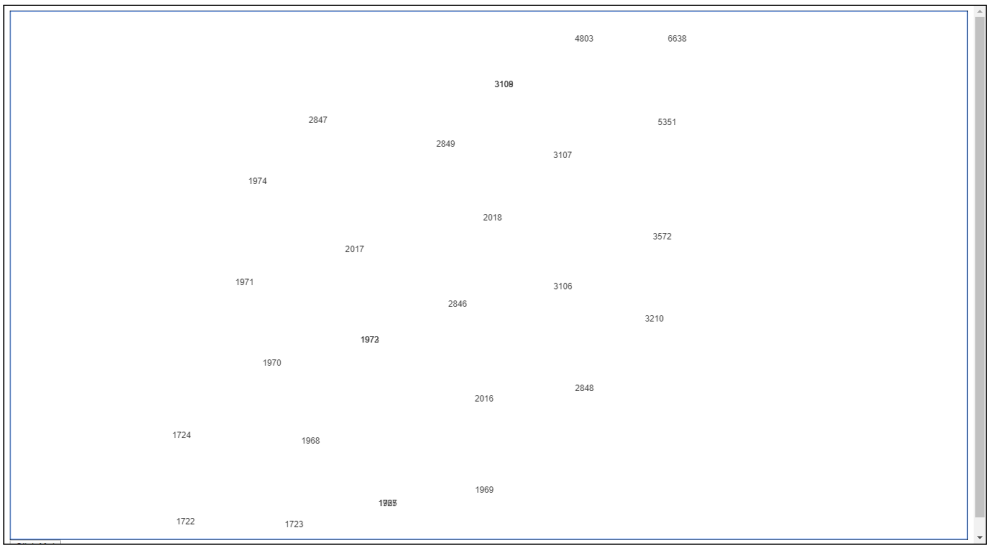
11 out of 14 districts of the states have witnessed COVID-19 cases till 11th April 2020. Kerala was the state where the first case in the country was identified in the Thrissur district. Out of 379 detected cases, 11 cases had a direct associations with SSE(Nizamuddin Markaz congregation). A series of local transmission from the Pathanamthitta district which also expanded further to Kottayam district is observed in C6 of Fig. 13a. An imported case from Italy did infect its relatives and friends and they, in turn, infected their friends. Fig. 13b shows the degree centrality network whereas Fig. 13c shows the betweeness centrality in the state. There were a total of 364 nodes with 57 connections in the centrality networks. 15.3% of the nodes in the network were having connections to some other nodes in the network. 84.7% of the nodes remained isolated. Nodes in the C6 can be seen to have dominated in terms of betweeness centrality. Details of imported cases in the state can be obtained from Table 3.



(a) Transmission Network of COVID-19 in Assam As of April 11, 2020

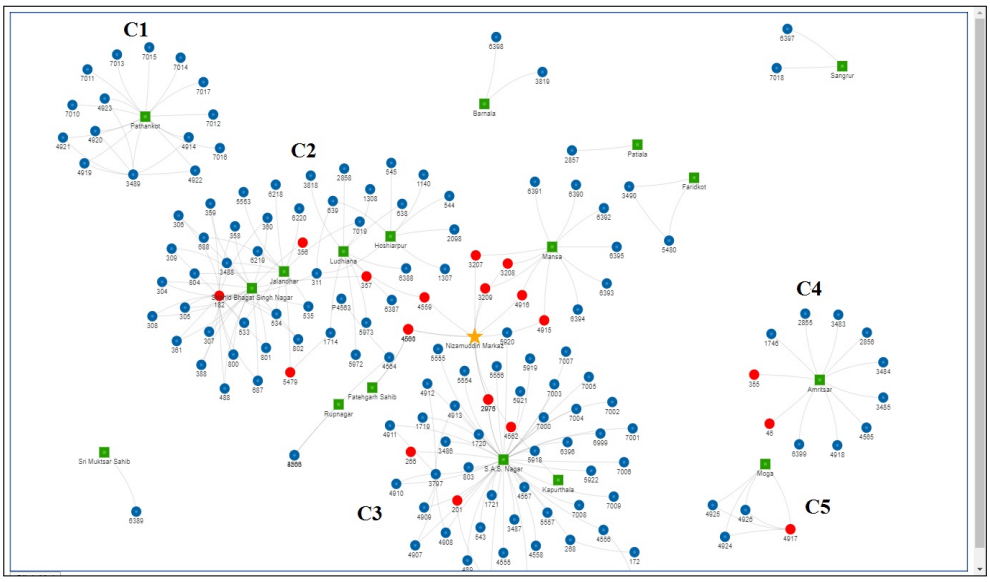


(b) Degree Centrality Network of COVID-19 in Assam, As of April 11, 2020

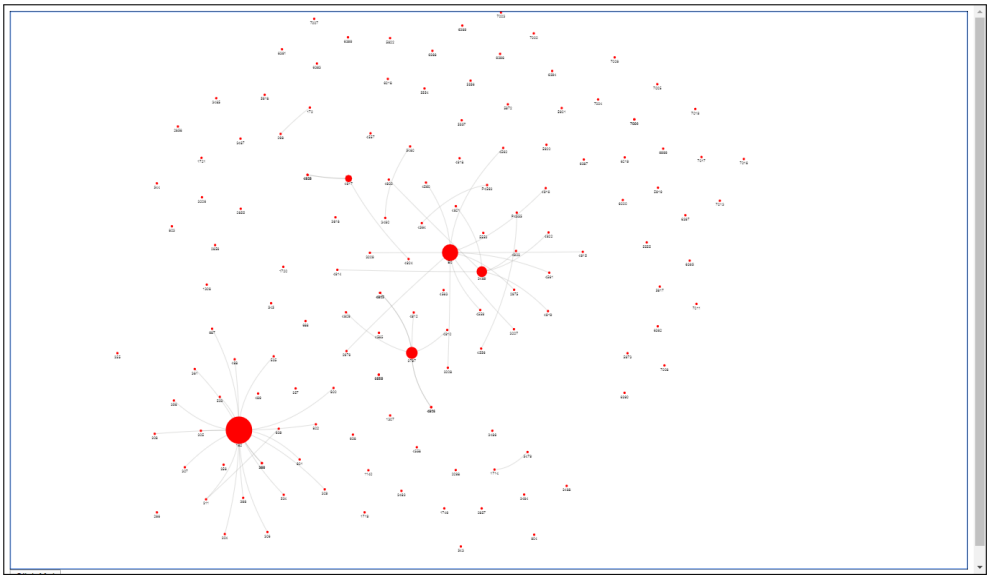


(c) Betweeness Centrality Network of COVID-19 in Assam, As of April 11, 2020

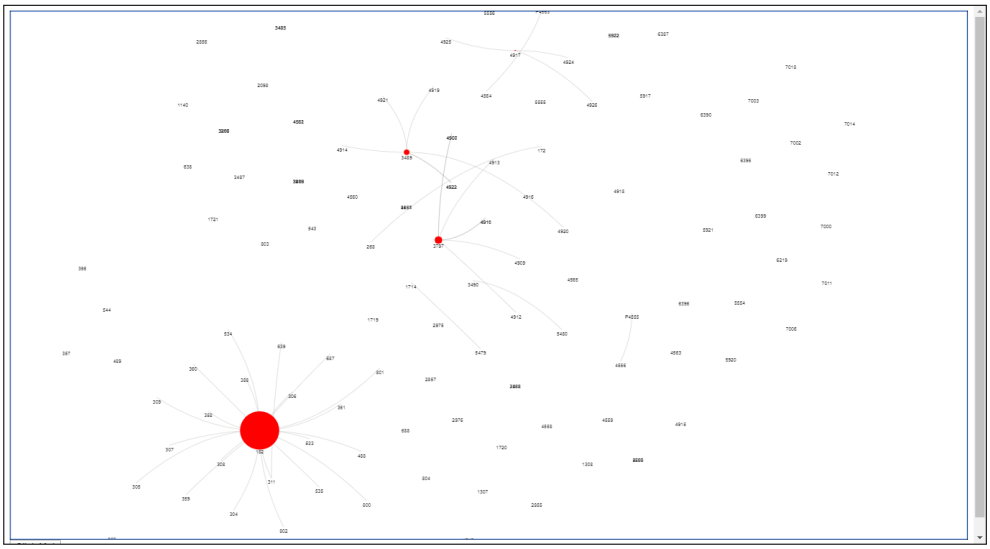
Fig. 11: Networks of Assam state, India



(a) Transmission Network of COVID-19 in Punjab, As of April 11, 2020

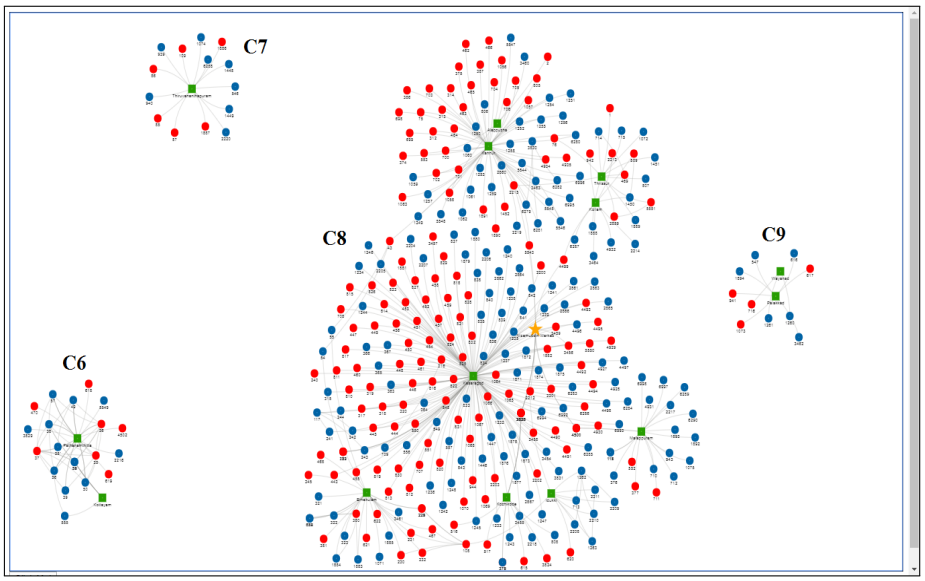


(b) Degree Centrality Network of COVID-19 in Punjab, As of April 11, 2020

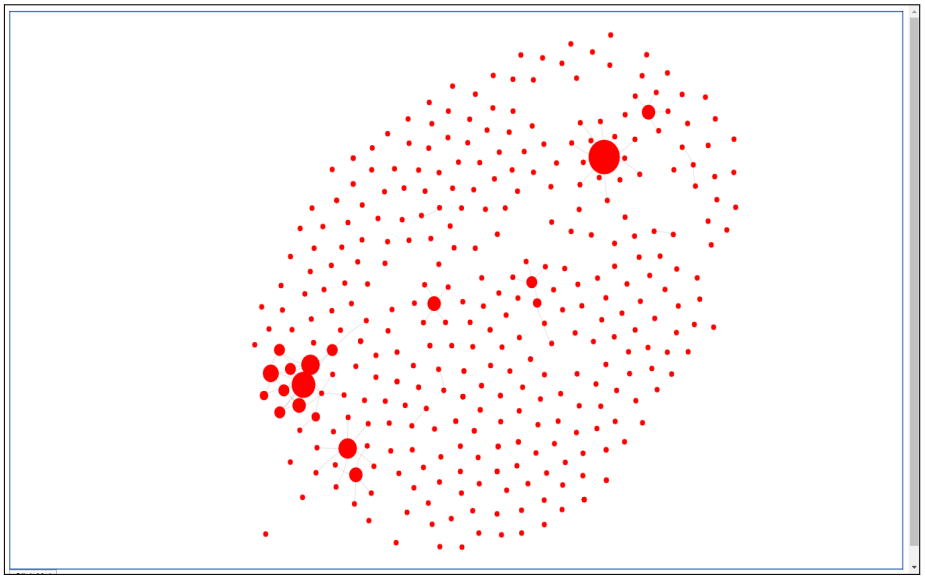


(c) Betweeness Centrality Network of COVID-19 in Punjab, As of April 11, 2020

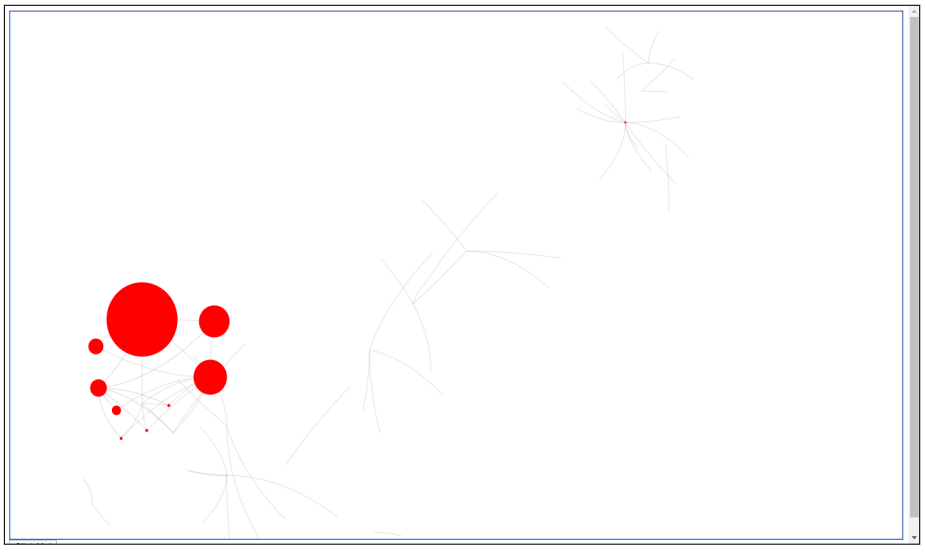
Fig. 12: Networks of Punjab state, India



(a) Transmission Network of COVID-19 in Kerala, As of April 11, 2020



(b) Degree Centrality Network of COVID-19 in Kerala, As of April 11, 2020



(c) Betweeness Centrality Network of COVID-19 in Kerala, As of April 11, 2020

Fig. 13: Networks of Kerala state, India

Table 3: Imported cases in Kerala

District	No. of Foreign Cases	Foreign Nations
Thrissur	3	Wuhan, Qatar, France
Alphuzza	2	Qatar,Wuhan
Kasaragod	84	Wuhan,Dubai,Sarjah,Middle East,
Ernakulam	12	UK,France,Dubai
Pathanamittha	8	Dubai, UK, Italy, Qatar
Thiruvananthapuram	6	Sarjah, Spain, Dubai, UK , Italy, Bahrain
Kannur	39	Sarjah,Dubai, Italy

3.5 Transmission Network of COVID-19 in Chandigarh

The transmission network of the disease is shown in Fig. 14a. Fig. 14b and Fig. 14c depict the centrality networks for Chandigarh. Node 172 is the most central in both the networks followed by 878. There were a total of 19 nodes with 9 connections in the centrality networks. 63.1% of the nodes in the network were having connections to some other nodes in the network. 36.9% of the nodes were isolated. However, node 225 is having significant value for betweeness centrality. Table 4 provides the statistics of the imported cases in the Union Territory.

Table 4: Imported cases in Chandigarh

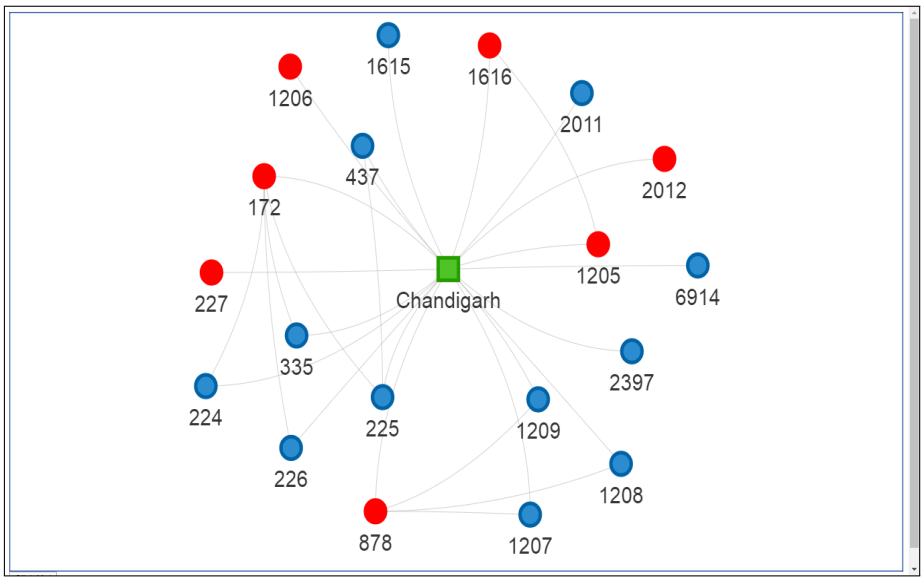
District	No. of Foreign Cases	Foreign Nations
Chandigarh	6	Canada,Dubai,UK

3.6 Transmission Network of COVID-19 in Karnataka

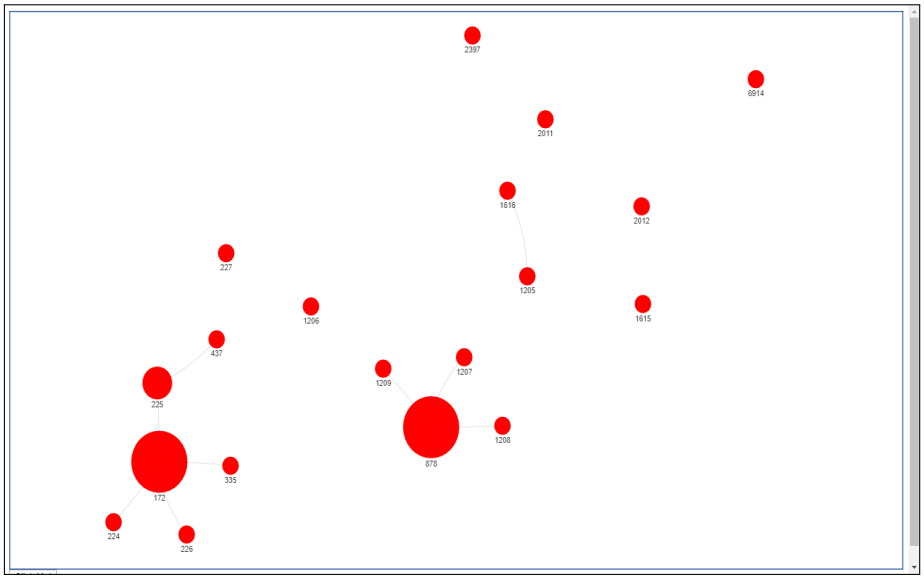
Karnataka recorded its first case on 9th March 2020 in a 42 years male employee who had a recent travel history to London. Since then the cases have spread to 17 districts. A large number of local transmission of the virus was done by a person from Mysuru who doesn't have any history of foreign visits in recent past but was in contact with the healthcare professionals. The patient 689 in the network infected a total of 14 others. Fig. 15a depicts the transmission network of the disease in the state whereas Fig. 15b and Fig. 15c depicts the respective centrality networks. There were a total of 215 nodes with 43 connections in the centrality networks. 34.4% of the nodes in the network were having connections to some other nodes in the network. 65.6% of the nodes were isolated. Table 5 provides the details of the imported cases district wise for the state Karnataka.

Table 5: Imported cases in Karnataka

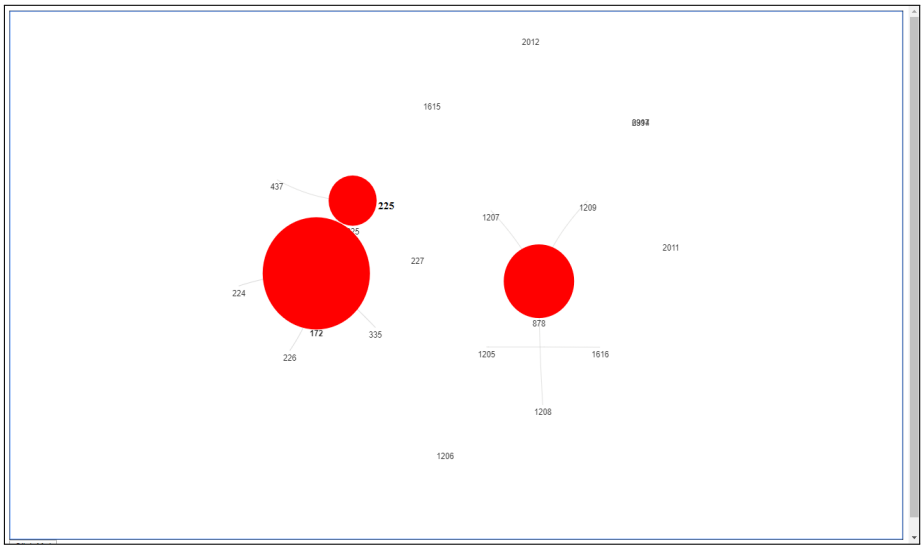
District	No. of Foreign Cases	Foreign Nations
Bengaluru	38	USA, UK, Greece, Dubai, Spain, Mecca, Switzerland, Germany, Brazil, France, Colombo
Mysuru	3	Dubai
Uttara Kannada	5	Dubai
Dakshina Kannada	8	Dubai



(a) Transmission Network of COVID-19 in Chandigarh, , As of April 11, 2020

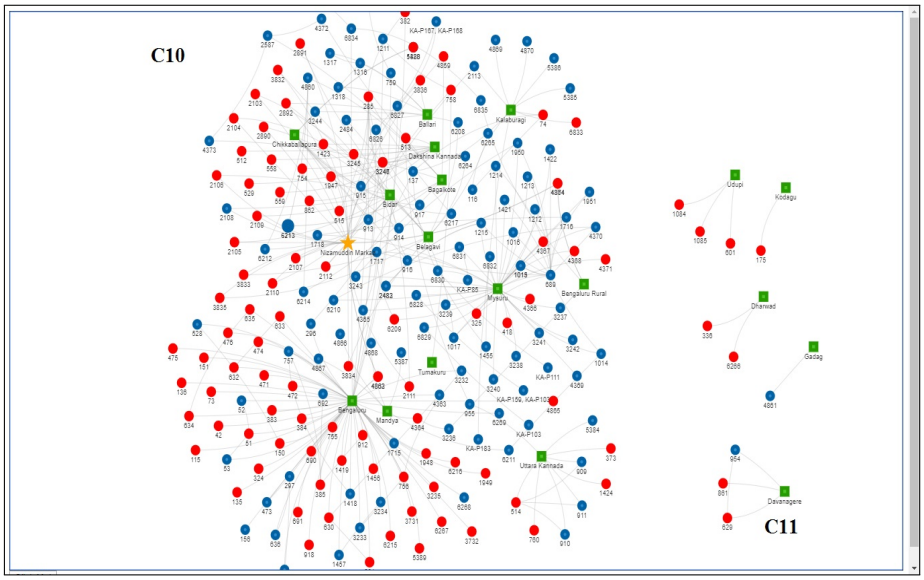


(b) Degree Centrality Network of COVID-19 in Chandigarh, As of April 11, 2020

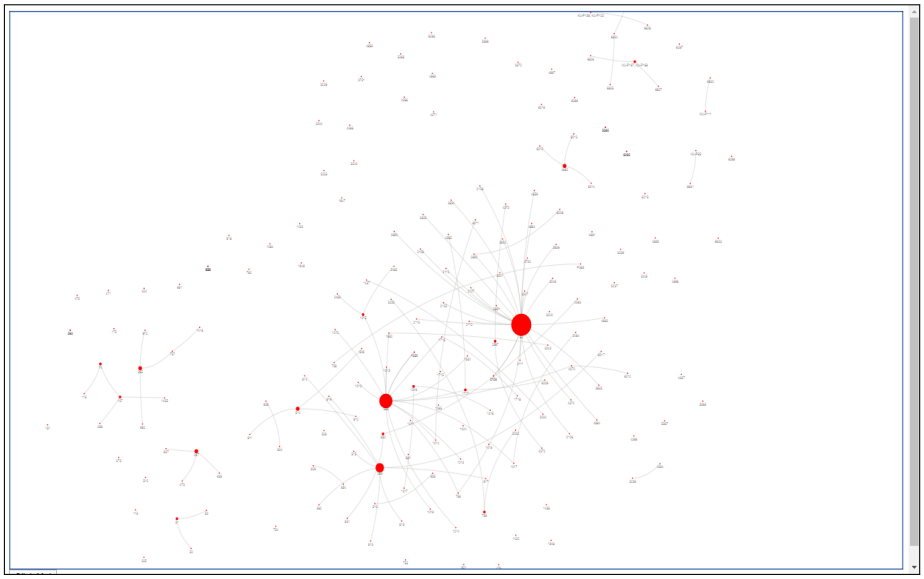


(c) Betweeness Centrality Network of COVID-19 in Chandigarh, As of April 11, 2020

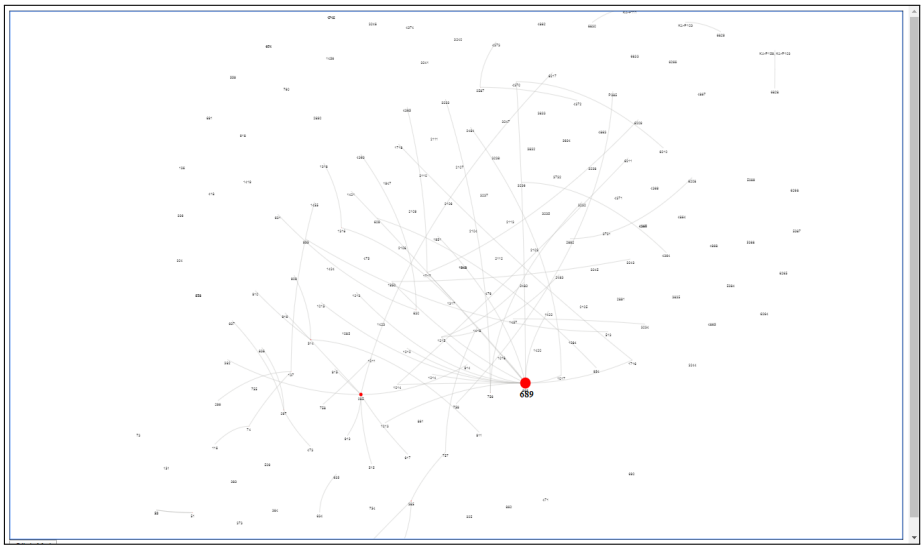
Fig. 14: Networks of Chandigarh Union Territory, India



(a) Transmission Network of COVID-19 in Karnataka, As of April 11, 2020



(b) Degree Centrality Network of COVID-19 in Karnataka, As of April 11, 2020



(c) Betweeness Centrality Network of COVID-19 in Karnataka, As of April 11, 2020

Fig. 15: Networks of Karnataka state, India

4 Discussion:

In this study, we investigated the spread of the COVID-19 pandemic in India and the countermeasures taken to control the spread to date. Transmission networks were used to understand the disease spread in the country. A total of 6 Indian states/UTs were considered for the study. Two network centrality measures namely the degree centrality and the betweeness centrality were used to analyze the connections among the patients of COVID-19 in each state. We found Nizamuddin Markaz congregation to be a SSE, which significantly increased the number of cases in the country. Particularly, the state of Assam has all its cases directly or indirectly associated with the SSE. Also, we identified super spreader individuals throughout the states using the centrality measures. Such as Oman returnee of Siwan(Bihar) infecting 21 others, London returnee of Mysuru(Karnataka), the case of Pathanamthitta(Kerala) people returning from Italy. Family and friends component infections display higher inter-connectivity than other scenarios of disease transmission as seen in C6 of Fig. 13a. With the betweeness centrality, we find while a patient/individual is directly associated with others it is not always the pathway to further infections in the network. The node 172 in Fig. 14c exhibits much higher betweeness centrality in comparison to others in the network as it acts as the only pathway from node 225 to 226,224 and 335. Although, 172 itself was an infected node with imported infection and did infected others with its direct associations. However, the scenario would have been different if any other node say, 224 is infected thus in this setting the infection would have passed to others via 172. Therefore finding such middle nodes or the individuals will help to eliminate further infections. However, such an objective will require the contact information of each patient available. A network of contacts can be generated based upon the patient history and can be used in conjunction with the transmission network for mitigating large outbreaks in the region.

A limitation in this study lies in the data accuracy and completeness of the information. The data source is based on data made available from both the official such as news bulletins released by the government (both central and states) as well as crowd-sourced from a group of volunteers. The crowd-sourced data comes from sources such as Twitter handles of health ministry(both central and states). Information released by these sources is much limited in detail. This is one of the reasons of a significant number of isolated nodes present in our networks. Besides, the limitation in the information the publically available data source used in the work is much acknowledged, the results are meaningful and allow to map the spread of the disease across the districts of the Indian states. Much detailed information about the patients is required to answer some of the crucial questions of the hour:

1. Is community transmission happening in India ?
2. Who are the highly vulnerable individuals to be infected ?
3. Which contacts of the infected persons should be prioritized in monitoring and treatment to stop the further spread ?

References

[1] Coronavirus Updates. `https://www.worldometers.info/coronavirus/`. Accessed: 2020-04-15.

[2] Lirong Zou, Feng Ruan, Mingxing Huang, Lijun Liang, Huitao Huang, Zhongsi Hong, Jianxiang Yu, Min Kang, Yingchao Song, Jinyu Xia, et al. Sars-cov-2 viral load in upper respiratory specimens of infected patients. *New England Journal of Medicine*, 382(12):1177–1179, 2020.

[3] Chih-Cheng Lai, Tzu-Ping Shih, Wen-Chien Ko, Hung-Jen Tang, and Po-Ren Hsueh. Severe acute respiratory syndrome coronavirus 2 (sars-cov-2) and corona virus disease-2019 (covid-19): the epidemic and the challenges. *International journal of antimicrobial agents*, page 105924, 2020.

[4] Lockdown in India extended: . `https://economictimes.indiatimes.com/news/politics-and-nation/pm-modi-extends-national-lockdown-till-may-3/articleshow/75133926.cms`. Accessed: 2020-04-15.

[5] India Today update on transmission status of COVID-19 in India : . `https://www.indiatoday.in/india/story/community-transmission-has-begun-in-some-areas-aiims-director-on-coronavirus-spread-in-india-1663835-2020-04-06`. Accessed: 2020-04-15.

[6] Hongzhou Lu, Charles W Stratton, and Yi-Wei Tang. Outbreak of pneumonia of unknown etiology in wuhan china: the mystery and the miracle. *Journal of Medical Virology*.

[7] Alexander E Gorbalenya. Severe acute respiratory syndrome-related coronavirus–the species and its viruses, a statement of the coronavirus study group. *BioRxiv*, 2020.

[8] Kerala defeats coronavirus; india's three covid-19 patients successfully recover. https://weather.com/en-IN/india/news/news/2020-02-14-kerala-defeats-coronavirus-indias-three-covid-19-patients-successfully. Accessed: 2020-04-11.

[9] Icmr testing update. https://icmr.nic.in/sites/default/files/whats_new/ICMR_testing_update_10April_9PM_IST.pdf. Accessed: 2020-04-11.

[10] Coronavirus: About 9,000 Tablighi Jamaat members, primary contacts quarantined in country, MHA says". The Times of India. PTI. 2 April 2020. https://timesofindia.indiatimes.com/india/coronavirus-about-9000-tablighi-jamaat-members-primary-contacts-quarantined-in-country-mha-says/articleshow/74948832.cms. Accessed: 2020-04-11.

[11] How Nizamuddin markaz became Covid-19 hotspot; more than 8,000 attendees identified. https://www.hindustantimes.com/india-news/how-nizamuddin-markaz-became-a-hotspot-for-covid-19-8-000-people-identified/story-zedKlaDNTPpbDLdMsgExAM.html. Accessed: 2020-04-11.

[12] 1445 out of 4067 Covid-19 cases linked to Tablighi Jamaat: Health Ministry". Hindustan Times. https://www.hindustantimes.com/india-news/how-nizamuddin-markaz-became-a-hotspot-for-covid-19-8-000-people-identified/story-zedKlaDNTPpbDLdMsgExAM.html. Accessed: 2020-04-11.

[13] Coronavirus — Tablighi-Jamaat. https://www.hindustantimes.com/india-news/as-tablighi-jamaat-linked-cases-rise-delhi-govt-gives-story-ucrdORKQl7ft1dy177t3CL.html. Accessed: 2020-04-11.

[14] Assam govt files a case against a COVID 19 positive patient for hiding his travel history . https://economictimes.indiatimes.com/news/politics-and-nation/assam-govt-files-a-case-against-a-covid-19-positive-patient-for-hiding-his-travel-history/articleshow/75086167.cms. Accessed: 2020-04-11.

[15] Septuagenarian Sikh priest infected 27 of total 38 coronavirus cases in Punjab. https://www.indiatoday.in/india/story/septuagenarian-sikh-priest-infected-27-of-38-coronavirus-cases-punjab-1660789-2020-03-28. Accessed: 2020-04-11.

[16] Coronavirus: India 'super spreader' quarantines 40,000 people. https://www.bbc.com/news/world-asia-india-52061915. Accessed: 2020-04-11.

[17] Coronavirus: 94,000 returnees to haunt Punjab, land of India's migrant workers. https://www.scmp.com/week-asia/health-environment/article/3076993/coronavirus-90000-nris-return-haunt-punjab-land-indias. Accessed: 2020-04-11.

[18] Punjab govt puts 30000 nris in isolation. https://news.abplive.com/videos/news/india-covid-19-outbreak-punjab-govt-puts-30000-nris-i Accessed: 2020-04-11.

[19] COVID-19 for India Updates. March 24, 2020. https://cddep.org/wp-content/uploads/2020/03/covid19.indiasim.March23-2-eK.pdf. Accessed: 2020-04-11.

[20] Hale, Thomas, Sam Webster, Anna Petherick, Toby Phillips, and Beatriz Kira. (2020). Oxford COVID-19 Government Response Tracker. Data use policy: Creative Commons Attribution CC BY standard. https://covidtracker.bsg.ox.ac.uk/stringency-scatter. Accessed: 2020-04-11.

[21] Joel O Wertheim, Andrew J Leigh Brown, N Lance Hepler, Sanjay R Mehta, Douglas D Richman, Davey M Smith, and Sergei L Kosakovsky Pond. The global transmission network of hiv-1. *The Journal of infectious diseases*, 209(2):304–313, 2014.

[22] Oyelola A Adegboye and Faiz Elfaki. Network analysis of mers coronavirus within households, communities, and hospitals to identify most centralized and super-spreading in the arabian peninsula, 2012 to 2016. *Canadian Journal of Infectious Diseases and Medical Microbiology*, 2018, 2018.

[23] Mark EJ Woolhouse, C Dye, J-F Etard, T Smith, JD Charlwood, GP Garnett, P Hagan, JLK Hii, PD Ndhlovu, RJ Quinnell, et al. Heterogeneities in the transmission of infectious agents: implications for the design of control programs. *Proceedings of the National Academy of Sciences*, 94(1):338–342, 1997.

[24] covid19india API : . https://api.rootnet.in/covid19-in/unofficial/covid19india.org. Accessed: 2020-04-11.