Epidemiological Challenges in Pandemic Coronavirus Disease (COVID-19): Role of Artificial Intelligence

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Supplementary Material

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Supplementary Text

Databases for epidemiological studies

Here we are going to summarize some key characteristics of the publicly available data sets as follows.

COVID-19 open research data set[1]

The Allen Institute for AI[2] along with some leading research groups has shared the COVID-19 Open Research Data set (CORD-19). Such free resource comprises scholarly articles in order of thousands. The articles deal with the information on coronavirus family. One may apply natural language processing techniques to uncover the hidden relation among various findings. Such findings may help other researchers and doctors in assessing the outcome of some therapeutic procedure.

WHO COVID-19 data[3]

World Health Organization (WHO) has already started publishing and updating information about the affected cases over the world in regular interval. The numbers of death and recovery results are provided, which convey the speed of spreading of coronavirus into different parts of the world. Besides, WHO has been sharing various reports related to the study on applying candidate vaccines and several drugs.

ACAPS COVID-19[4]

Here various measures associated with coronavirus are integrated in a single platform. The data sets consider several issues, such as social distancing, movement restrictions, public health measures, social and economic measures and lock-down among others, for such measurement. Public health as well as socio-economic conditions are also considered here.

World Bank indicators data set[5]

Presently, World Bank has taken an initiative to share data related to recent COVID-19 with the help of Humanitarian Data Exchange (HDX). HDX is an open platform that shares data across organizations during crises. HDX allows sharing data conveniently, using them for analysis.

[1] https://pages.semanticscholar.org/coronavirus-research
[2] https://allenai.org/
[3] https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports/
[4] https://data.humdata.org/dataset/acaps-covid19-government-measures-dataset
[5] https://data.humdata.org/dataset/world-bank-indicators-of-interest-to-the-covid-19-outbreak

The data set can be broadly divided into three parts. Data are information related to health status of every individuals, basic hand sanitizing facility for the population with soap and water, and the population density with respect to a range of ages. Figures S1-S3 depict different entities and their attributes as well as relationship among them for the World Bank indicators database.

Kaggle[6]

Kaggle, one of the largest data science community in the world, has tried to involve a number of scientists to visualize the pattern of such pandemic activity worldwide. In response this emergency, they have prepared a COVID-19 Open Research Dataset (CORD-19)[7] by incorporating disease along with recovery/death related information in the form of tables. Moreover, they have developed a time series data set having the track of history of a large number of patients worldwide. Figure S4 depicts the entities and their attributes of a small portion of Kaggle databse.

Genetic sequence database[8]

Genetic sequence database is a compilation of all freely available annotated DNA sequences. DNA GenBank is the part of the International Nucleotide Sequence Database Collaboration, which comprises European Nucleotide Archive (ENA), GenBank at NCBI and DNA DataBank of Japan (DDBJ). These organizations exchange data among themselves regularly. The aim of GenBank database is to provide and promote access within the scientific community to the most recent and wide-ranging DNA sequence. National Center for Biotechnology Information (NCBI) has recently provided a set of SARS-CoV-2 sequences, accessible in the Sequence Read Archive (SRA) and GenBank. Currently, the repository contains 183 GeneBank sequences and 1 RefSeq sequence in Entrez Nucleotide, and the new NCBI Virus resource submitted from countries like China, Phillipines, Japan and Thailand.

Genomic database[9]

Nextstrain provides a frequently updated view of publicly available data of COVID-19. In addition, it contributes a set of alongside powerful analytic and visualization tools that allow epidemiological understanding of the disease and empower the researchers for the solution. A genome database can be described as a storehouse of DNA sequences from different species of plants and animals.

[6]https://www.kaggle.com/sudalairajkumar/novel-corona-virus-2019-dataset
[7]https://www.kaggle.com/allen-institute-for-ai/CORD-19-research-challenge
[8]https://www.ncbi.nlm.nih.gov/genbank/sars-cov-2-seqs/
[9]https://nextstrain.org/ncov

Drug Database

In order to support the prediction based on different AI models, many drug-related databases have been developed to contain several types of drug-target interaction (DTI) information. Simultaneously, drug related databases are vital resources for DTI predictions *in silico* [1]. Based on the content of databases, it can be subdivided into four categories, drug centered or target centered databases, DTI databases, DTI affinity databases, and other supporting databases. In the class of "drug centered or target centered databases", seven databases are generally used, such as, BRENDA [2], PubChem [3], SuperDRUG2 [4], DrugCentral [5], PDID [6], Pharos [7], and ECOdrug [8]. On the other hand, DTI database has been developed for collecting and validating the DTI and related information. ChEMBL [9], ChemProt 3.0 [10], DGIdb 3.0 , DrugBank [11], GtoPdb [12], KEGG [13], LINCS [14], PROMISCUOUS [15], STITCH [16], SuperTarget [17], and TTD [18] have commonly used databases in this category. The aim of "DTI affinity databases" is to focus on the various collection of binding affinity among drugs, some related molecules and target proteins. In this category, PDBBind [19], BindingDB [20], and PDSP Ki [21] have been frequently used as a repository of a more significant number of binding affinity data. Few other databases like FAERS [22], SIDER [23], and JAPIC [24] are being used to obtain the information related to country-specific adverse drug reaction (ADR) reports and medication error reports.

Socio-Economic Challenges

During the COVID-19 pandemic scenario, there are many comprehensive studies in detail to address the social and economic problems to be discussed in the following subsections.

Economic problem

Due to the outbreak of COVID-19, the entire world faces a major economic recession affecting entire global economy. Major economic challenges can be summarized as follows.

- **Financial Impact:** A huge disruption in the economic activities leads to a crash in the stock market from February 20, 2020. Global markets have become extremely volatile[10]. The oil price war between Russia and Saudi Arabia is one of the main reason of current stock market crash leading to drop the prices of US oil by 34% and crude oil by 26%[11].
- **Hampering economic growth:** In particular, in order to control the spread of COVID-19, the countrywide lock-down is imposed on several nations, leading to massive chaos in multiple sectors, such as, manufacturing and services among others. It will have a large scale implications in terms of economic growth prospects.

[10] https://en.wikipedia.org/wiki/2020$_{s}tock_{m}arket_{c}rash$
[11] https://en.wikipedia.org/wiki/2020$_{R}ussia\%E2\%80\%93Saudi_{A}rabia_{o}il_{p}rice_{w}ar$

- **Unemployment:** The outbreak serves as a massive incentive for the firms to rightsize. Specifically, people employed in aviation, tourism and hotel industry are on the verge of losing their jobs. Several nations have appealed to profit-based entities on reconsidering layoffs[12]. Globally, it has been observed an increase in the filing of unemployment benefits indicating a rise in the unemployment rate[13].

- **Inflation:** The outbreak causes a cut in supply leading to hike of prices of food items and other essentials in many states. Evidently, in such cases, state administration should be more effective in supplying stocks, and protecting the interests of the consumers from black marketing[14] Economists have also predicted a stagflation post-outbreak scenario due to the nearly stagnant economy with a sudden spurt in demand[15].

Socio-economic challenges for the less developed economies

Less developed countries (LDCs) have infrastructural barriers to sustainable development. Their economic growth is very sensitive to economic and environmental shocks. COVID-19 outbreak can affect the social framework in addition to break down of its economic backbone. In the case of an epidemic/pandemic, the major socio-economic challenges of an LDC can be mostly categorized into three types as follows.

- **Problems relating to infrastructure:** Almost every developing nation suffers from the problem of inadequate/weak infrastructure. The problem is most highlighted in the case of a disease outbreak. Developing nations, like India and Pakistan with high population density, are the most affected during such time as the ratio of medical and administrative personnel to people is very less [16]. In addition, due to an inadequate number of hospitals, Personal Protective Equipment (PPE) and other infrastructural weaknesses, the rate of contamination remains alarmingly high even after adopting certain precautionary measures[17].

- **Problems relating to the organized sector:** In the case of developing countries, a significant portion of the labor force is employed in the unorganized sector. During the nation-wide lock-down, shut down of such unorganized sector is affects these labor force facing great difficulty in

[12] https://en.wikipedia.org/wiki/Impact$_o f_t he_2$019%E2%80%9320$_c oronavirus_p andemic_o n_a viation$

[13] https://smartasset.com/financial-advisor/coronavirus-unemployment

[14] https://edition.cnn.com/2020/03/10/investing/stagflation-economy-coronavirus/index.html

[15] https://www.scmp.com/economy/china-economy/article/3074378/coronavirus-chinas-inflation-remained-high-february

[16] https://www.indiatoday.in/india/story/coronavirus-in-india-boosting-medical-infrastructure-top-priority-says-health-ministry-1659196-2020-03-24

[17] https://www.forbes.com/sites/ellistalton/2020/03/16/coronavirus-forces-us-to-rethink-infrastructure-for-an-age-of-biological-risk/bc291c68dd04

earning their daily bread. It is the duty of the government to provide some sort of financial security to such people in times of distress[18].

- **Problems of poverty:** The prevalence of poverty in developing nations renders them helpless at the time of crisis. Due to lower purchasing power (occupied by a large fraction in developing societies), poorer sections of the society, find difficulty to get access of prompt medical help along with essential items like food, clothes and shelter[19]. This scenario makes them more susceptible to infection[20].

A small case study of the Indian service sector

The service sector in India is a very dominant sector. The primary reason can be attributed to the fact that India has a huge population that generates sufficient demand for services[21]. With more and stronger infrastructure development, the capital-labor ratio for developing nations, like India, can continue to improve, leading to generate huge amounts of revenue subjected to proper utilization. As of 2018, 31.45% of the Indian population is employed in the service sector[22]. It is evident from Figure S9A that for any nation, the service sector contributes a lot to its GDP and consequently, its economic growth. A disruption in at least one of the services will trigger a chain of deadlocks that will adversely affect the economy[23]. The major impacts of the service sector in India can be summarized as follows.

- **Contribution of gross value added (GVA):** The service sector plays a crucial role in contributing to GVA of a nation. India has largest share of GVA coming from the service sector as estimated at 96.26 lakh crore INR in 2019. This was 54.40% of total GVA of India for 2018-19[24].

- **Employment generation:** As essential services, this sector requires both skilled and semi-skilled manpower. From 2018, India has entered a 37 year-long period of demographic dividend lasting till 2055. This has provided a larger section of the working-age population to the opportunity for employment in the tertiary sector along with human development prospects[25].

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[18] https://theprint.in/india/governance/coronavirus-lockdown-what-states-are-doing-to-help-the-poor-and-unorganised-workers/388156/

[19] https://en.wikipedia.org/wiki/Poverty

[20] https://www.usatoday.com/story/opinion/2020/03/23/coronavirus-spread-poverty-covid-19-stimulus-column/2899411001/

[21] https://www.ibef.org/industry/services.aspx

[22] https://en.wikipedia.org/wiki/Economy$_{o}f_{I}ndia$

[23] https://en.wikipedia.org/wiki/Tertiary$_{s}ector_{o}f_{t}he_{e}conomy$

[24] http://statisticstimes.com/economy/sectorwise-gdp-contribution-of-india.php

[25] https://economictimes.indiatimes.com/news/economy/indicators/india-enters-37-year-period-of-demographic-dividend/articleshow/70324782.cms

- **Contribution to trade:** With the improvement of the service sector, volume of trade is also rising. India is one of the principal economies contributing to the world services of export industry. As of October 2019, services export of India rose to 5.25% to USD 17.70 billion[26].

- **Contribution in foreign direct investment (FDI) inflows:** Along with necessary measures taken by government, such as, fixing a timeline for approvals and streamlining procedures towards improving ease of doing business in the country, the country has witnessed a large flux of FDI. This is an evident from the fact stating that foreign domestic investment in the services has been grown by 36.5% to become $9.15 billion in 2018-19 according to the Department for Promotion of Industry and Internal Trade (DPIIT)[27].

As per the prior discussion, it is clear that outbreak of COVID-19 has a far fetched implication on trade and tourism industry. As nations in locked down state, international trade has come to a standstill situation. The case study aims to highlight the impact of corona virus on these areas of the service sector. For the case study, monthly data of three consecutive months, relating to before onset of the outbreak and after the COVID-19 outbreak, has been considered. The data has been obtained from monthly economic reports as published by the Department of Economic Affairs, Government of India[28]. Based on that, we have prepared a final data set (illustrated in Table S3) according to the need of our analysis. Figure S9B depicts the visualization of the data in Table S3.

Based on the analysis as depicted in Figure S9B, it can be concluded that the ongoing COVID-19 outbreak affect mostly the trade hotel and storage part of the service sector. Prior to the crisis, it had a higher value of 6.9 in the month of November 2019. However, during pandemic scenario, major economies has put a temporary barrier on trade and commerce. Consequently, the estimated growth rate has slumped down to 5.9% in January 2020, and to 5.6% in February 2020. It can also be found that the crumbling tourism sector is one of the reason for the fall in growth rate. We expect that more data during ongoing pandemic situation in upcoming months will give everyone a deeper insight of the negative impact on the service sector.

Terminology

Some of key terminologies and related issues have been discussed here.

[26]https://economictimes.indiatimes.com/news/economy/foreign-trade/indias-services-exports-grew-by-over-5-to-usd-17-70-billion-in-october-rbi-data/articleshow/72542056.cms?from=mdr

[27]https://www.thehindubusinessline.com/economy/fdi-in-services-sector-up-37-per-cent-in-2018-19/article27499826.ece

[28]https://dea.gov.in/data-statistics

- **Inflation:** Inflation is defined as the rise of the general price level. Moderate levels of inflation are generally considered as healthy for the economy because, with the growth of the economy, demand for goods and services rises. The increase in demand pushes the price up, leading to prompt the suppliers for production of the demanding materials. It results an enhancement in economic growth, and consequently, labour demand and wages increase. Generally, workers have more purchasing power in accordance with higher wages. Even their more demands trigger the 'virtuous' cycle of economic growth. Thus maintaining moderate inflation is good for economy. However, the problem arises when inflation rate fluctuates vigorously[29], *i.e.*, when it becomes too high or low leading to economic stagnation, called as stagflation[30]. In general there are two kind of inflations: i) cost-push inflation, and ii) demand-pull inflation. Demand-pull inflation happens when demand is greater than supply resulting equilibrium price to increase. On the other hand, cost pull inflation happens when supply is restricted with corresponding demand[31].

- **Stagflation:** It is a combination of high inflation, unemployment and stagnant economic growth. Here, due to the attempts of reviving economic growth and lower inflation, it may aggravate unemployment.

- **Danger of very low inflation:** A very low inflation rate[32] generally implies that demand of goods and services is usually lower than it should be. As a result, it slows down economic growth and reduces real wages. Due to low demand, producers will lay off employees, leading to high unemployment rates. This is evident from the case of the great recession about a decade ago. Deflation also accounts for consumers delaying their purchases. Subsequently, it makes lenders reluctant to give loans because of lower interest rates[33].

- **Danger of high inflation:** A very high inflation rate[34] can cause a similar kind of problem as of low inflation. Extremely high inflation rate may slow down the economy causing unemployment to rise. This combination of hyperinflation and high unemployment is called stagflation, a phenomenon feared by economists and policymakers all over the globe. Hence it is necessary to keep the inflation rate in moderate level.

[29] https://www.thebalance.com/inflation-impact-on-economy-3306102

[30] http://www.economicsdiscussion.net/inflation/top-6-effects-of-inflation-economy/26075

[31] https://www.investopedia.com/articles/05/012005.asp

[32] https://www.economicshelp.org/macroeconomics/low$_i nflation$/

[33] https://www.weforum.org/agenda/2019/06/inflation-is-healthy-for-the-economy-but-too-much-can-trigger-a-recession-7d37501704

[34] https://www.economicshelp.org/blog/140824/economics/what-are-the-effects-of-a-rise-in-the-inflation-rate/

Supplementary Figures

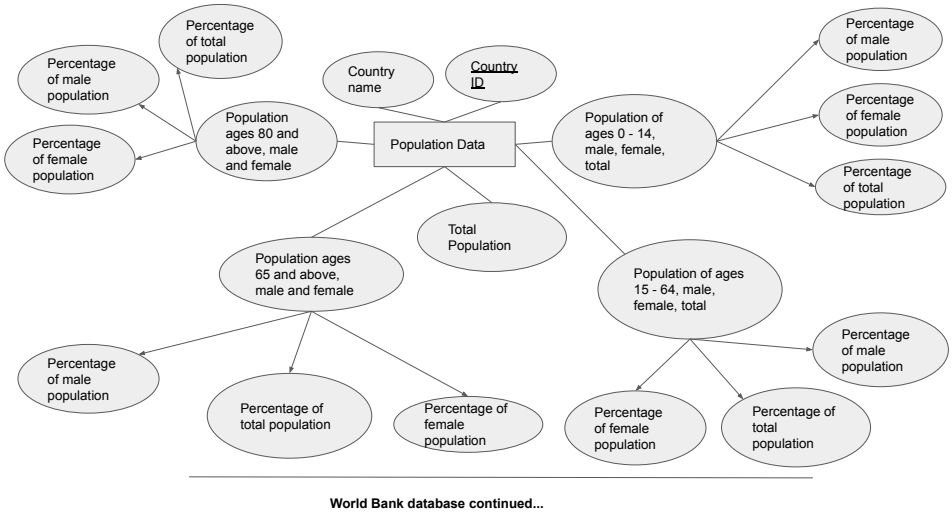


Figure S1: The figure illustrates the entity set of World Bank indicators database about COVID-19 and its attributes along with the relation among them (Part 1)

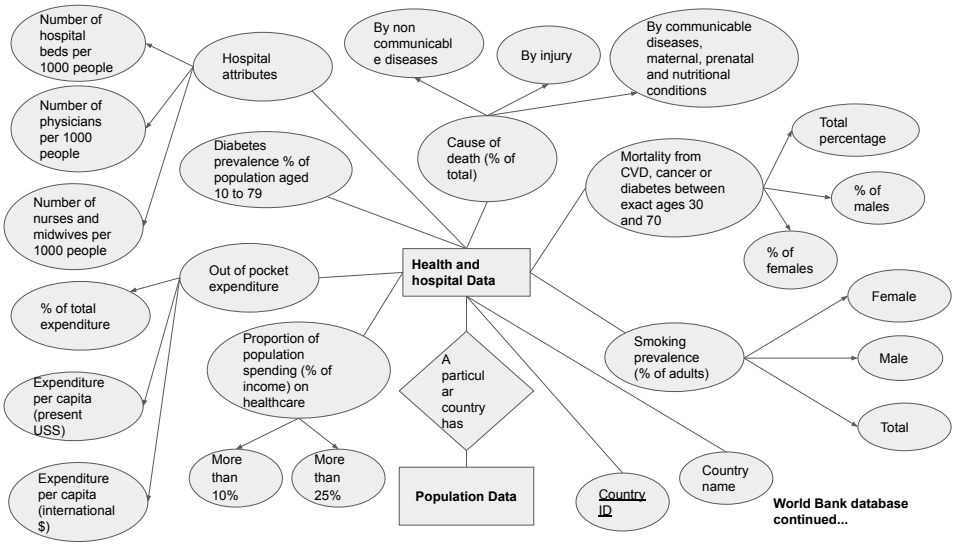


Figure S2: The figure illustrates the entity set of World Bank indicators database about COVID-19 and its attributes along with the relation among them (Part 2)

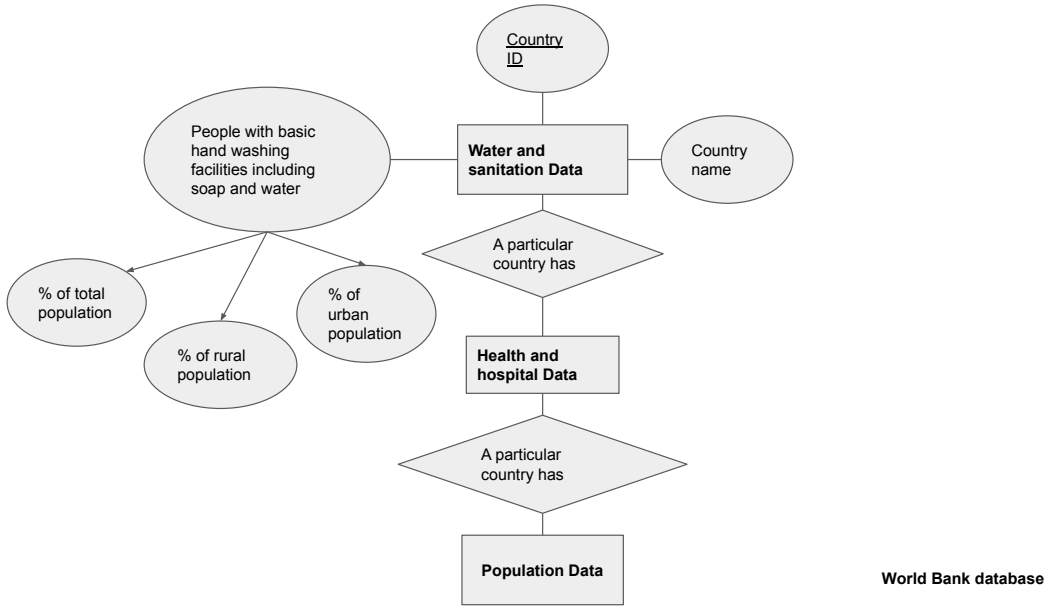


Figure S3: The figure illustrates the entity set of World Bank indicators database about COVID-19 and its attributes along with the relation among them (Part 3)

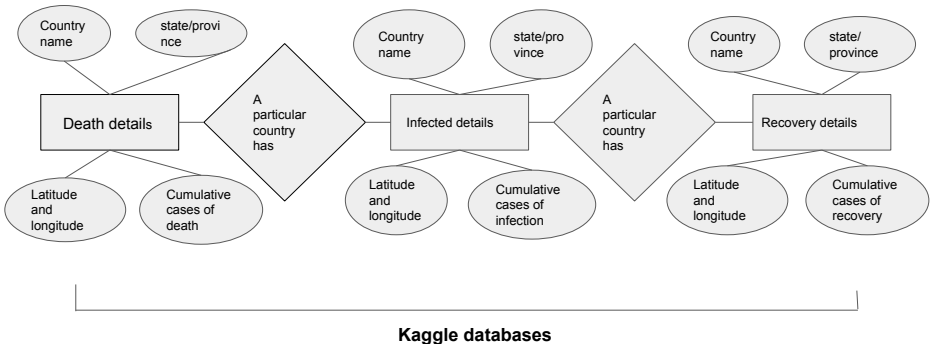


Figure S4: The figure illustrates the entity set of Kaggle databsase about COVID-19 and its attributes along with the relation among them

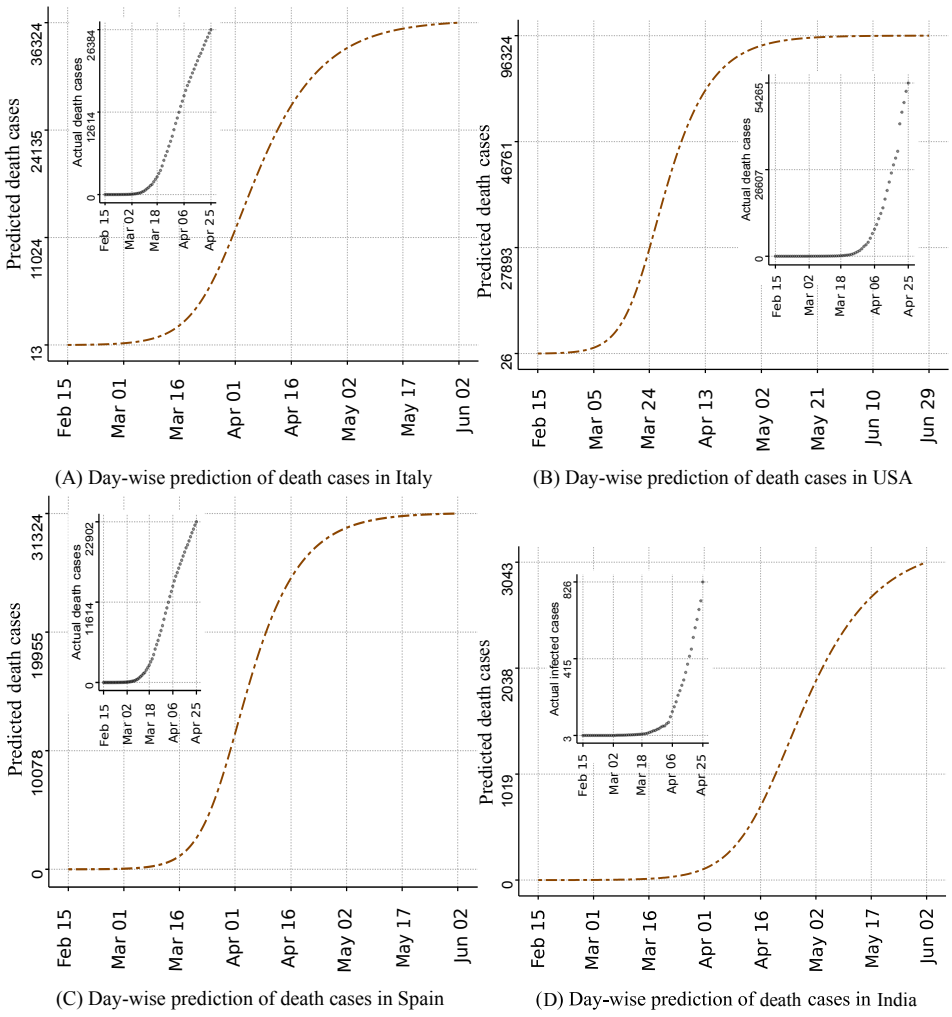


Figure S5: Our modified Susceptible-Infectious-Recovered-Death (SIRD) model predicts (initial result) the total number of COVID-19 death cases and saturation time for (A) Italy, (B) United States of America (USA), (C) Spain, and (D) India.

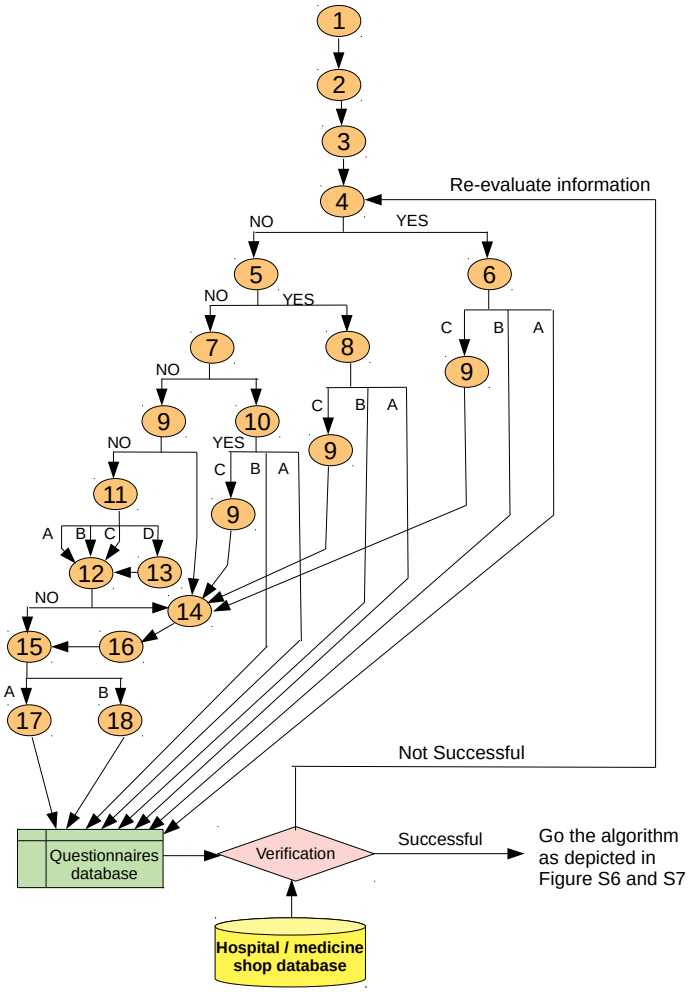


Figure S6: This figure illustrates the order of the questions to be asked. The answers should be verified with databases of local hospitals/medical shops/online delivery companies to track false health information of an individual in a particular area.

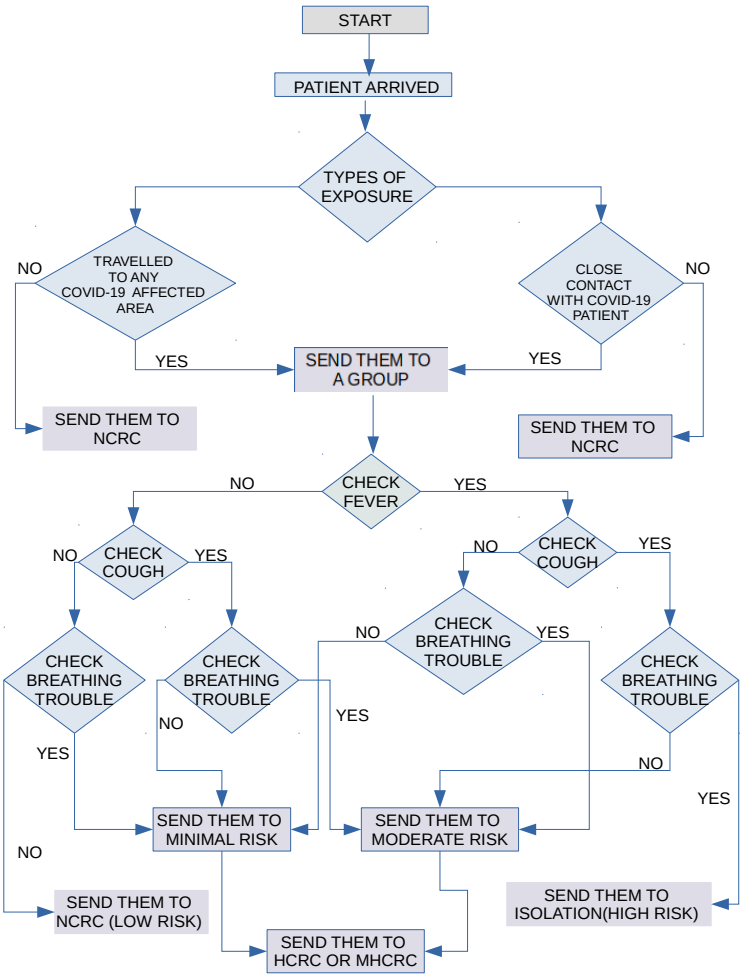


Figure S7: This flowchart shows how we can track mobile health check recommendation for COVID-19 (MHCRC/HCRC) and non-identified respondents (NCRC) people based various if-else condition (received answers from mobile based survey). Thus, using this artificial intelligence based approach, we can provide immediate isolation to high risk patients suffering from COVID-19 and prevent the spread of the disease.

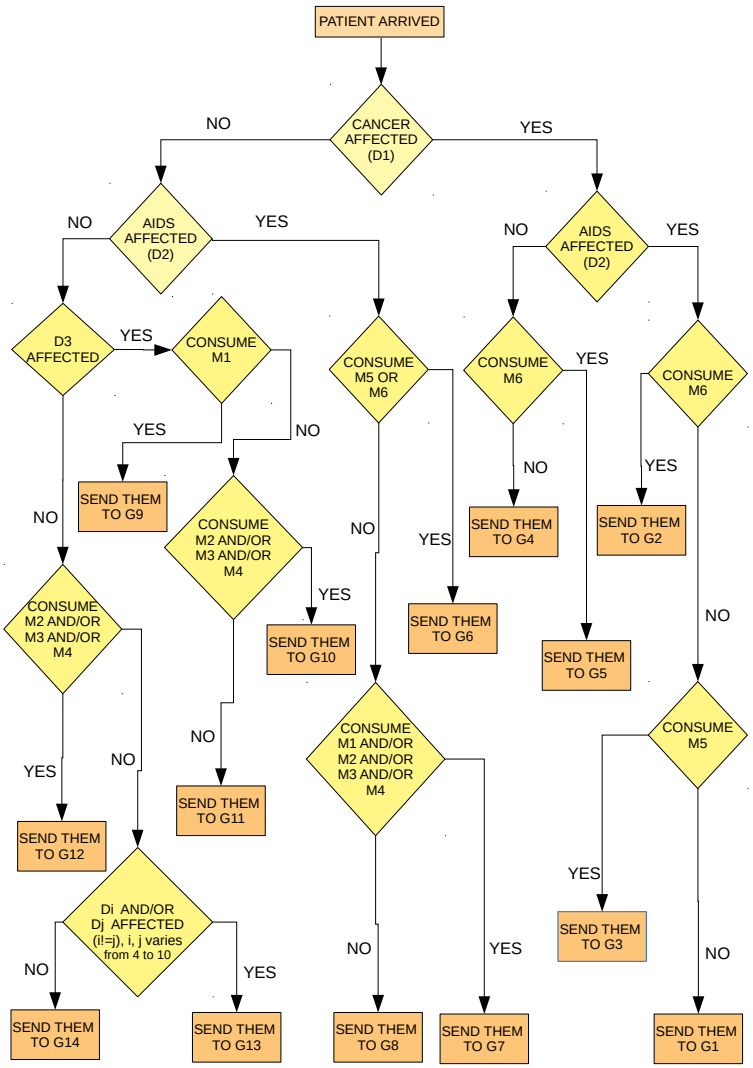
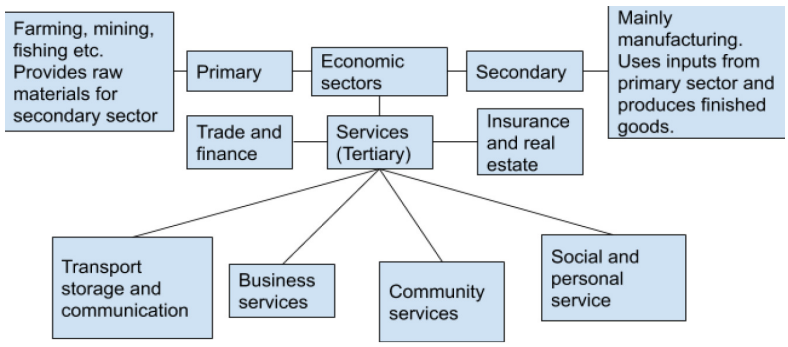


Figure S8: Flowchart of proposed EHR based survey using artificial intelligence technique to detect severity of COVID-19 affected patients as well as risk of being affected by the viral disease.

(A)



(B)

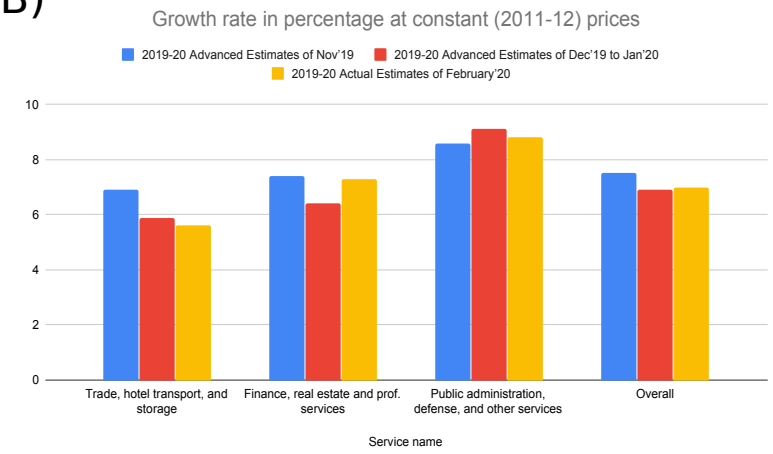


Figure S9: (A) A diagrammatic representation of the traditional sectors of an economy with the composition of the services sector. (B) The visualization of the data in Table S3.

Supplementary Tables

Table S1: Set of sample questionnaires for maintaining transparency and availability of right information related to health of an individual.

Serial number	Question	Question type	Option
1	What is your name ?	Short answer	Not applicable
2	What is your contact number ?	Short answer	Not applicable
3	What is your age ?	Short answer	Not applicable
4	Do you have fever more than 100° ?	Multiple choice	Yes No
5	If you have fever more than 100° then how many day you are facing such problem ?	Multiple choice	$<$ 1 week. $>$ 1 week and $>$ 2 week. $>$ 2 week.
6	Do you have dry cough ?	Multiple choice	Yes No
7	Do you have body pain ?	Multiple choicee	Yes No
8	If you have dry cough then how many day you are facing such problem ?	Multiple choice	$<$ 1 week. $>$ 1 week and $<$ 2 week. $>$ 2 week.
9	Have you taken any medicine in last two weeks ?	Multiple choice	Yes No
10	If you have body pain then how many day you are facing such problem ?	Multiple choice	$<$ 1 week. $>$ 1 week and $<$ 2 week. $>$ 2 week.
11	How many days ego you have visited the hospital ?	Multiple choice	$>$ 1 year. $>$ 1 month. $<$ 1 month. $<$ 2 week.
12	Please tell me the list of medicines, doctor advised.	Descriptive	Not applicable
13	If you have visited the hospital what 2 weeks then what was the symptom ?	Multiple choice	Cough Body pain Fever All of the above
14	Please tell me the list of medicines, you have consumed.	Descriptive	Not applicable
15	From where you have bought your medicine ?	Multiple choice	Yes No
16	Did your doctor advised to take vitamin tablet ?	Multiple choice	Yes No
17	If you select local shop, please provide the details of the shop.	Descriptive	Not applicable
18	If you select online delivery, please provide the details of the company.	Descriptive	Not applicable

Table S2: Set of decisions as per the flowchart of Figure S8

Serial number	Status	Groups
1	Very High Risk.	G-1, G-8
2	High Risk.	G-2, G-3, G-4, G-7
3	Moderate Risk.	G-5, G-6, G-11, G-13
4	Low Risk.	G-9, G-10, G-12
5	No Risk.	G-14

Table S3: Growth in the service sector of India (Dec 2019 to Feb 2020) (Growth rate in percentage at constant (2011-12) prices)

Service Name	**2019-20 Advanced Estimates of Nov 2019**	**2019-20 Advanced Estimates of Dec 2019 to Jan 2020**	**2019-20 Actual Estimates of February 2020**
Trade, hotel transport, and storage	6.9	5.9	5.6
Finance, real estate and prof. services	7.4	6.4	7.3
Public administration, defense, and other services	8.6	9.1	8.8
Overall	7.5	6.9	7

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[3] Kim, S. *et al.* Pubchem substance and compound databases. *Nucleic acids research* **44**, D1202–D1213 (2016).

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[7] Nguyen, D.-T. *et al.* Pharos: collating protein information to shed light on the druggable genome. *Nucleic acids research* **45**, D995–D1002 (2017).

[8] Verbruggen, B. *et al.* Ecodrug: a database connecting drugs and conservation of their targets across species. *Nucleic acids research* **46**, D930–D936 (2018).

[9] Bento, A. P. *et al.* The chembl bioactivity database: an update. *Nucleic acids research* **42**, D1083–D1090 (2014).

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