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Review Article

Public Health Section

How Data is Helping to Fight COVID-19 Pandemic

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ABSTRACT

Early in 2020, the COVID-19 pandemic emerged as a global public health concern requiring urgent attention, concerted efforts and intervention to avoid catastrophe. This necessitated optimal use of fast-emerging data to be analysed to draw out inferences that would shape our response. World Health Organisation (WHO) called this pandemic an infodemic where data played a crucial role. This paper reviews how data from varied sources and different types helped delay the outbreak, limit the spread, initiate social and public health measures, decide treatment regimes, optimise healthcare infrastructure and human resources and helped to initiate a multipronged strategy with emerging evidence for further course correction as the world progressed through the pandemic. The classical mathematical tools, i.e., Susceptible-Infected-Recovered (SIR) model and its variants, were the primary analytical techniques utilised to analyse such data. However, newer data analytical techniques utilising artificial intelligence and machine learning, were also extensively used. These techniques have the capability to handle large quantities of data and develop prediction models of various emerging situations that offer foreknowledge for policymakers and provide solutions. Data Science has witnessed a leap in the past few years, and the way it helped shape our response to this pandemic is a testimony to the promise that it holds for humankind.

Keywords: Algorithms, Artificial intelligence, Data analytics, Privacy

INTRODUCTION

In December 2019, a novel virus, Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2), emerged from Wuhan in China. Within a span of four months, the highly contagious virus made its way all around the world, and on 11th March 2020, the World Health Organisation (WHO) officially declared the Coronavirus Disease-2019 (COVID-19) as a pandemic [1]. The Spanish flu pandemic of 1918-19 affected about 25-30% of the world's population, with a mortality estimated at upto 40 million people [2]. The only methods available for mollifying the previous pandemic were preventive actions such as obligatory notification of suspected cases, surveillance, quarantine and isolation. Emergency measures to contain the epidemic, such as closing cinemas and theatres or prohibiting other types of gatherings, including funerals, were also put in place. However, the absence of antibiotics and antivirals promoted the spread of the pandemic.

Moreover, European countries involved in the First World War, largely censored the news and the data to avoid public alarm, thus further contributing to the spread of the pandemic [3]. The world is witnessing a pandemic after almost a century, and since the previously declared Spanish flu pandemic, medicine, technology and data analytics have undergone significant advancements. While many public health modalities continue to be the same, what has revolutionised the scene, is the ability to use data to predict, prevent, diagnose, treat and modify the course of the pandemic. Advanced data analytics can give meaning to enormous healthcare data, thus generating new knowledge which can be used for prediction, discovery, and comparative effectiveness of interventions. Novel data sources and new thinking have the potential to fuel data analytics based intervention in healthcare medicine [4].

The present paper explores the use of data and its analytical techniques in modifying the ongoing COVID-19 pandemic. To identify sources of literature, the Google Scholar database was initially used using broad research terms like COVID-19, data analytics in COVID-19, data in COVID-19, privacy COVID-19, COVID-19 sentiment, that aligned with the topic. More focussed terms were identified and utilised with the 'and' command to perform a database search in PubMed, Science Direct and IEEE Xplore. Cross-references were identified from the articles. These articles were analysed using the following criteria for inclusion:

1. The source article should be aligned with the purpose of review.
2. The article should be published in a peer-reviewed journal.

The Infodemic

The emergence of COVID-19 as a global pandemic led to the creation of vast amounts of data that needed to be analysed to draw out inferences. The pandemic was termed an infodemic by WHO suggesting that the right information is pivotal in fighting the virus [5]. The perspicacious analysis of epidemiological data resulted in timely interventions by the governments and saved many lives. Data-driven prediction models helped in the preparedness of health officials in resource management and planning [6]. Data was also crucial in taking decisions to streamline economic activities that had been disrupted due to COVID-19. The four V's- Velocity, Variety, Volume and Veracity of data, necessary to draw meaningful and actionable conclusions were utilised to their full capacity in the unprecedented fight against COVID-19 [7].

DATA SOURCES

In efforts to control the spread of the pandemic, data was utilised from a wide range and variety of sources, which provided a quintessential multipronged approach to the task at hand.

The First Data Confirming the Outbreak and Nature of the Disease

The initial cases of COVID-19 were identified through the "pneumonia of unknown aetiology" surveillance mechanism. Field level data like dates of onset of illness, visits to clinical facilities, hospitalisation, and clinical outcomes were collected and analysed to confirm the outbreak, human to human transmission and natural course of the disease [8]. This translatability was estimated by Zhao S et al., They used an exponential growth model to represent the epidemic curve of COVID-19 cases in mainland China between 10th January, 2020 to 24th January, 2020, which confirmed that the outbreak's initial growth stage followed an exponential growth pattern [9]. Moreover, Yan L et al., used a database of blood samples from 404 infected patients in Wuhan, China, and used machine learning tools to select three biomarkers to predict the survival rate of individual patients [10].

Utilising Data for Preventing the Spread of the Outbreak

Collecting and analysing data related to the spread of COVID-19 was paramount in understanding transmission patterns, recovery and mortality rates, and efficacy of various preventive measures. Li R et al., emphasised the value of existing data on health infrastructure, human resource, and patient health profiling, which proved to be significant sources of data for predicting the impact of the pandemic [11].

Moreover, Lai C et al., underscored that the data about seroprevalence on COVID-19 antibodies has helped monitor the pandemic, judiciously used the available resources and made appropriate policy decisions [12]. During the initial phase of the pandemic Lai S et al., used mobile phone-based population movement data, air passenger itinerary data, and historical travel patterns to estimate the spread risk across the world that proved essential in helping health preparedness and intervention [13]. Websites like worldometer [14] further helped keep track of dynamic data across the world that helped keep a close watch on the spread of the disease. Moris D and Schizas D used the worldometer data to study the impact of lockdown on the spread of COVID-19 and concluded that the early lockdown policy was essential in limiting the spread of the pandemic [15].

Data for an Evidence-based Approach

Novel methods for evidence-based detection of COVID-19 were made possible using various sources of data such as chest Computed Tomography (CT) and X-rays and sound data from coughing and other speech-based activities. Machine Learning algorithms were used to predict the patient's respiratory deterioration, which helped understand the need for a mechanical ventilator [16].

Alternative models analysed sound data from cough, sneezing, throat clearing and swallowing of patients to detect COVID-19 [17]. The outbreak of COVID-19 generated frantic efforts to search for a treatment option. In the absence of data available to develop a drug, drug repurposing was the only available option. Repurposing approved agents for different medical conditions is an effective strategy as it saves a considerable amount of time, money, and resources [18].

With steadily increasing database of randomised controlled trials across the world on treatment options for COVID-19, WHO started performing live systematic review and network meta-analysis with regular updates for drug treatments for COVID-19. This offers a dynamic way for guiding clinicians in the wake of continuous emerging data. The recent update (update-3) included 196 trials and concluded that corticosteroids and interleukin-6 inhibitors are beneficial in patients with severe COVID-19. Azithromycin, hydroxychloroquine, lopinavir-ritonavir do not confer any benefit; remdesivir has no effect on mortality. There is not enough evidence for any beneficial role of ivermectin as a potential treatment for COVID-19 [19]. The use of network meta-analysis as an analytical tool for developing clinical guidelines is increasingly being used. This is an excellent tool that helps in simultaneous analysis of potential treatment options with the use of available evidence, both direct and indirect [20]. Such live network-meta analysis is also being done for preventive interventions and vaccines for COVID-19 to assist policy makers (COVID-NMA) [21].

Internet of Things (IoT) based instruments and devices also took advantage of the data available. Hidayat A et al., designed an IoT based independent pulse oximetry kit for early detection of COVID-19 symptoms. Pulse oximetry monitoring was extensively used to monitor home isolated patients and patients in quarantine, thereby considerably reducing patient load from the hospitals [22]. Ekong I et al., in a paper, discussed the importance of Global Positioning System (GPS) in timely intervention and breaking the chain of disease transmission. It also cites an example of Israel where, despite privacy issues regarding the use of mobile data, an emergency law was passed overnight to authorise its use for contact tracing [23].

Recently, several unique techniques have been used to contain the virus. Drones are proving to be very helpful amidst the pandemic. These drones are being used for thermal scanning, monitoring, data collection using artificial intelligence, data analytics, archiving data, and medical resources transportation [24]. Furthermore, a study on the relation between weather and COVID-19 cases pointed out that the number of cases reduced with an increase in the temperature of the region. It also concluded that weather attributes such as temperature and humidity are much more significant than the variables like age, population and urbanisation in predicting the death rate [25]. Another study showed the correlation between wind speeds and the number of cases suggesting that lower wind speed caused an increase in the number of cases [26].

Data for Intervention in Social and Economic Measures

Sentiment Analysis based on Social Network Data during the Epidemic

Social media has been an outlook for expressing one's sentiment; and analysing the general sentiment among people during a pandemic helps gather insightful information for taking appropriate public health measures [27]. During such adverse conditions, sentiment analysis can be a useful tool not just for analysing and improving public health but can also be a mental health indicator. Investigating social media posts for sentiments such as negativity, fear, disgust and sadness along with other positive sentiments such as trust and sympathy can help gauge the factors that affect mental health during a pandemic [28].

Fake news detection: Fake news is obstructive in the process of battling against the pandemic. Hence, it is vital to detect and distinguish fake news from real news. Data mining is used in fake news detection, which consists of several steps. Wang R et al., have pointed out the variables such as special symbol usage, use of personal pronouns and tone of news (casual or proper) can be used to classify news as real or fake [29].

Economic impact: The global Gross Domestic Product (GDP) shrunk by 5.2% over the course of the pandemic. This has been the deepest global recession in decades. Per capita income in most countries has contracted substantially; the largest fraction of countries globally since 1870 to record this decrease. The period of 'lockdown' could not thus continue unending, despite the continued pandemic, and this data forced countries to re-evaluate their decisions on lockdown and re-opening up of economic activities [30]. Bonaccorsi G et al., analysed a mobility dataset before and after the Italian lockdown and explored how variations in mobility relate to economic variables. They concluded that lockdown would result in an unprecedented fiscal challenge and induce a further increase in poverty and inequality [31].

DATA ANALYTICS

The amount, the variety and the speed with which the data was being generated during the COVID-19 pandemic necessitated advanced data analytical techniques to be deployed to extract valuable trends that can translate to administrative actions and policy decisions in real time.

Classical Mathematical Models and their Variants

SIR Model

The model instantiates the first set of dependant variables which are functions of time. Here, $S(t)$ is the number of susceptible individuals, $I(t)$ is the instantaneous number of infected individuals and $R(t)$ is the number of recovered individuals, β is the transmission rate and γ is the recovery rate [29]. At any given instance of time S(t)+I(t)+R(t)=n, where n is the population of the region.

Susceptible equation:

$$\frac{dS}{dt}=-\beta * S(t) * I(t)$$

Infected equation:

$$\frac{dI}{dt}=\beta * S(t) * I(t) - \gamma * I(t)$$

Recovered equation:

$$\frac{dR}{dt}=\gamma * I(t)$$

Various other techniques of data analysis have helped track the spread of the pandemic and analyse disease patterns to improve response speed and surveillance. Data generated during the pandemic was analysed using two primary techniques.

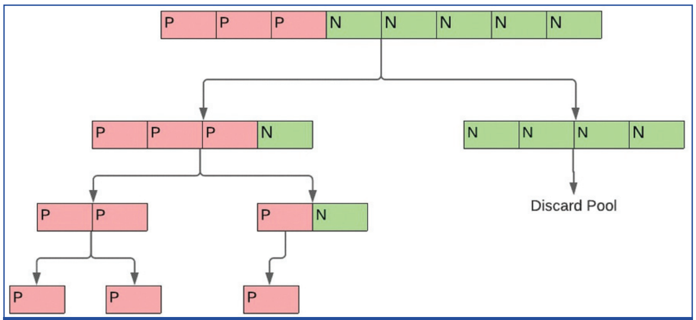
Differential equation-based mathematical modelling techniques: Theoretical modelling based approaches have been long associated with understanding and predicting outbreak probabilities and the seriousness of a disease. They provide critical information to control the intensity of the pandemic. Most of the mathematical models used to investigate the COVID-19 dynamics are based on variants of the classical deterministic model of SIR introduced by Kermack WO and McKendrick AG. [32]. In early February 2020, Wu J et al., predicted a potential domestic and international spread of COVID-19 by modelling the monthly flight booking data and human mobility data using the Susceptible-Exposed-Infected-Recovered (SEIR) model.

Moreover, they suggested that large cities overseas will become epicentres unless public health interventions are implemented immediately [33]. Further variations included a model by Liu P et al., which simulated the COVID-19 pandemic spread using the SEIR model coupled with network-driven dynamics based on domestic air traffic to predict the effects of modulating the air traffic on the occurrences of pandemic peaks in different areas of the US [34]. Fong S et al., proposed an alternative mathematical method. They proposed a composite Monte-Carlo model and coupled it with Group of Optimised and Multisource Selection (GROOMS) methodology to determine the best performing deterministic forecasting algorithm. According to them, this approach was crucial for early decision making in the initial stages of the epidemic when the data was scarce and incomplete [35].

Data Science and Machine Learning Approach

The branch of machine learning has recently opened the gateway for various novel methods for medical treatment and diagnosis. In the early phases of the pandemic, scientists in Wuhan developed algorithms that used chest scans of COVID-19 patients to differentiate COVID pneumonia from others. In addition, Wang X et al., used deep learning techniques to evaluate CT images of COVID-19 cases [36]. Other such attempts to use X-ray and CT images to detect lung lesions in COVID-19 patients were made by Xu X et al., Chen J et al., and Gozes O et al., [37-39]. These models used analytical techniques such as UNet++, 2D and 3D Convolutional Neural Networks (CNN) and 3D deep learning models with location attention. These studies implied that deep learning-based techniques could accurately differentiate COVID-19 pneumonia from other pneumonias. Moreover, a bibliometric analysis of publications during SARS and MERS epidemics could build network-based drug repurposing platforms [37-39]. Module detection and drug prioritisation algorithms could identify drugs that could be repurposed for the treatment of COVID-19 [17].

A novel pool-based approach conceptualised by de Wolff T et al., was utilised for testing COVID-19 cases. This is a multi-layered hierarchical procedure where the initial pool is split into two new sets of pools and pool testsare performed on both the sets [Table/Fig-1].



[Table/Fig-1]: Schematic representation of binary pool testing. P-Positive COVID-19 test; N-Negative COVID-19 test.

If a pool tests as negative, then no further testing is required in the full set. This procedure is repeated by creating subsets in case of a positive test. The best-case scenario will require just a single test, whereas the worst-case mandates 2N-1 tests (where N is the number of samples). This approach helps to minimise time, resources and human effort [40].

Analysis methods were not restricted to just medical data. Text mining from data on social networking sites like Twitter and Facebook were also areas of intense analysis. Sentiment analysis is one such technique to interpret the textual data on social networks and gain an insight into misinformation campaigns, fake news and rumours. Binary classification models can help divide news into authentic and fake by applying several steps such as data pre-processing, feature engineering, and news classification [17].

PRIVACY CONCERNS

While data has the power to transform the manner in which the problems of society are tackled, it also has the ability to intrude into personal privacy. During the pandemic, several concerns were raised regarding its unsolicited use. This may also pose a security threat to individuals.

There are primarily two approaches to manage privacy concerns [41]:

(a) The data-first approach

(b) The privacy-first approach

Different countries took different approaches; for example, South Korea took the data first approach for contact-tracing that included the patient's GPS location, thus creating a "virus-patient travel log" [42]. Similarly, Australia and France were amongst the countries that used the data-first approach. Further in Israel, despite privacy issues regarding the use of mobile phone data, an emergency law was passed overnight to authorise its use for contact tracing. On the other hand, countries like the US, Germany and Italy preferred a privacy-first approach and did not create any data repositories [41]. In India, the *AarogyaSetu* app was also criticised for intrusion intoprivacy even though enrolment was voluntary [43].

THE VACCINE ROLLOUT

The urgency to put breaks to the ongoing catastrophe led to accelerated development of vaccines for COVID-19 which was fuelled by machine learning based techniques like Vaxign-ML which predicts protegenicity score, reverse vaccine technology to predict potential protein targets and deep learning algorithm AlphaFold to predict distance and distribution of angles between amino acid residues [44-46]. The District Health Information Software 2 (DHIS2) toolkit is being extensively used to help countries to rollout vaccination programs. This platform incorporates data on vaccination, utilisation, wastage etc., generates immunisation e-registry for tracking and follow-up, monitoring adverse events and supply chain readiness [47].

[Table/Fig-2] shows a summary of various data analytical techniques being used to fight the COVID-19 pandemic.

Authors	Technique	Description
Zhao S et al., [9]	Exponential growth model	Confirmed the exponential growth pattern of the virus
Wang R et al., [29]	Natural Language Processing using Bidirectional Long Short Term Memory Loss (Bi-LSTM), Bert and Text Convolutional Neural Network (CNN)	This is used to analysis sentiments of general public during the course of the pandemic and also to detect fake news
Wang R et al., [29]	Susceptible-Infected-Recovered (SIR) model	A classical epidemiological model used to predict number of susceptible, infected, and recovered people from an infection.
Wu J et al., [33]	Susceptible-Exposed-Infected-Recovered (SEIR) model	An improvised SIR model which takes into account the Exposed population, meaning the people who have been exposed to the disease and might have the virus but have not shown symptoms yet. This is particularly important in case of COVID-19 in which people can be asymptomatic and still spread the virus
Fong S et al., [35]	Composite Monte Carlo (CMC) simulation+Group of Optimised and Multisource Selection (GROOMS) methodology	CMC is used to forecast outcomes of an event that is made uncertain by intervention of random variables for example travel mobility, population density, availability hospital beds etc. GROOMS ensures that input for the CMC simulation has the most accurate data source.
Chen J et al., [38]	UNet++	A Convolutional Neural Network (CNN) made for medical image segmentation used to analyse CT scans.
Gozes O et al., [39]	2D and 3D Convolutional Neural Networks (CNN)	To detect Coronavirus related changes from CT images
de Wolff T et al., [40]	Novel pool based approach	A binary pool approach to minimise resources and time for COVID testing
Ong E et al., [45]	Vaxign-ML	It is a reverse vaccinology-inspired machine learning-based vaccine candidate prediction and analysis system.
https://deepmind.com/research/open-source/computational-predictions-of-protein-structures-associated-with-COVID-19, [46]	AlphaFold	AlphaFold is a Google DeepMind-developed artificial intelligence software that makes protein structure predictions.
https://dhis2.org/covid-vaccine-delivery/, [47]	District Health Information Software 2 (DHIS2)	DHIS2 is an open source, web-based platform which is being used extensively for vaccination rollout for data capturing, analysis, storage and monitoring

[Table/Fig-2]: Summarising the various techniques of data analytics used to modify the courses of the pandemic.

CONCLUSION(S)

Data played a vital role in understanding and mitigating the COVID-19 pandemic. The wide-ranging applications made available by virtue of the various sources of data, types of devices (to collect the data), range of analytical methods including traditional mathematical approach, its variants and new analytical techniques using artificial intelligence and machine learning approaches have greatly influenced the trajectory of the pandemic. Data and its analysis helped restrict the outbreak outside its source in China, take appropriate public health and social measures, evaluate treatment options, prepare the vaccine in record time and guide governments in taking apt economic and other policy measures. The ease and speed at which the data is generated also reminds us that data is a double-edged sword, and its use has to be limited only for the benefit of humankind and not otherwise. The lessons learnt from this pandemic have underscored the importance of data analytics and how it can transform our ability to deal with public health crises.

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