# A Review on COVID-19 Forecasting Models

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**Systematic Review**

**Keywords:** Forecasting, Analysis, COVID-19, SIR, SEIR, Time Series

**Posted Date:** September 29th, 2020

**DOI:** https://doi.org/10.21203/rs.3.rs-83965/v1



**Version of Record:** A version of this preprint was published at Neural Computing and Applications on February 4th, 2021. See the published version at https://doi.org/10.1007/s00521-020-05626-8.

# A Review on COVID-19 Forecasting Models

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**Abstract**

The Novel coronavirus (COVID-19) has distributed to more than 200 territory worldwide leading to about 24 million confirmed cases as of August 25, 2020. Several models have been released that forecast the outbreak globally. This work presents a review of the most important forecasting models against COVID-19 and shows a short analysis of each one. The work presented in this study possesses two parts. A detailed scientometric analysis was done in the first section that provides an influential tool for describing bibliometric analyses. The analysis was performed on data corresponding to COVID-19 using the Scopus and Web of Science databases. For analysis, keywords and subject areas were addressed while classification of forecasting models, criteria evaluation and comparison of solution approaches were done in the second section of the work. Conclusion and discussion are provided as the final sections of this study.

**Keywords-** Forecasting, Analysis, COVID-19, SIR, SEIR, Time Series.

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**Contents**

## 1. **Introduction**

First reported in December 2019, the Chinese government informed the rest of the world that a virus was spreading throughout China. Later, this virus spread very rapidly to other countries. The World Health Organization (WHO) reported a case in Thailand on Jan 13, which was the first time it had been identified outside China. On Jan 16, Japan confirmed the first case of this Novel coronavirus in the country and on Jan 20, the first confirmed case of the new coronavirus was identified in South Korea. Nowadays, most countries in the world have been affected by this virus. Putra and Khozin Mu'tamar (2019) used the Particle Swarm Optimization (PSO) algorithm to estimate parameters in the Susceptible, Infected, Recovered (SIR) model. The results indicate that the suggested method is precise enough and has low enough error compared to analytical methods. Mbuvha and Marwala (2020) calibrated the SIR model to South Africa after considering different scenarios for reproduction number (R0) for reporting infections and healthcare resource estimation. Qi, Xiao et al. (2020) proposed that daily temperature and relative humidity can influence the occurrence of Novel coronavirus.

Salgotra, Gandomi et al. (2020) developed two COVID-19 prediction models based on genetic programming and applied these models in India. Findings from a study by (Salgotra, Gandomi et al. 2020) show genetic evolutionary programming models are highly reliable for Novel coronavirus cases in India.

In January 2020, the first cases was identified in Australia. In this report, a short analysis focusing on Australia was addressed and reported and continued as a simulation for the next few sections.

The paper is structured into several sections. Section 2 depicts search method procedure. Section 3 shows main research areas. Generic illustrations are provided in section 4. Mathematical modeling, criteria evaluation, and solution approaches are described in sections 5–7, respectively. Conclusion, discussion, and future directions are presented at the end.

## 2. The procedure of methodology

The process used to find the documents in this work is presented in this section.

### 2.1 Search method

Web of Science and Scopus were used to find related publications. Therefore, combinations of the following keywords: “forecasting, prediction, COVID-19, and Coronavirus” were used. Classification of published works based on the subject area is displayed in Figure 1.

We used technical research articles result in, as of August 25, 2020, more than 330 published articles (Figure 2). However, this study focused more on those that were indexed by the Web of Science.

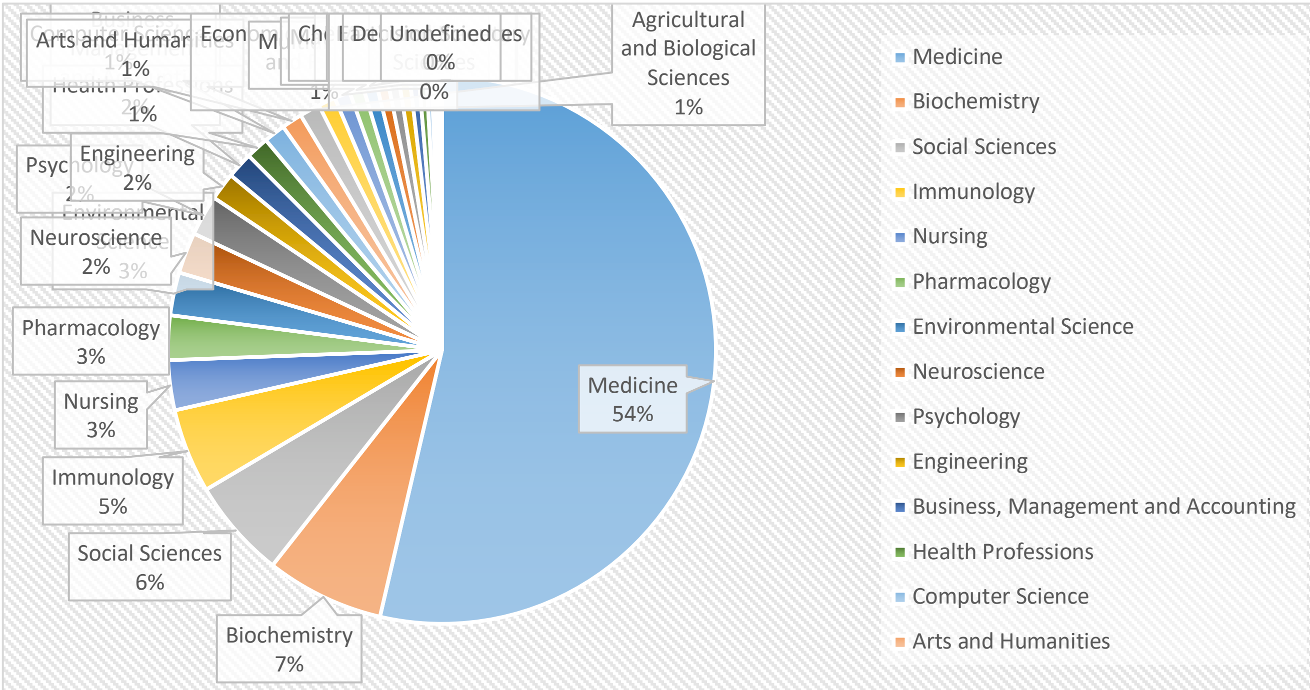


*Figure 1 Classification of scientific papers based on subject area*

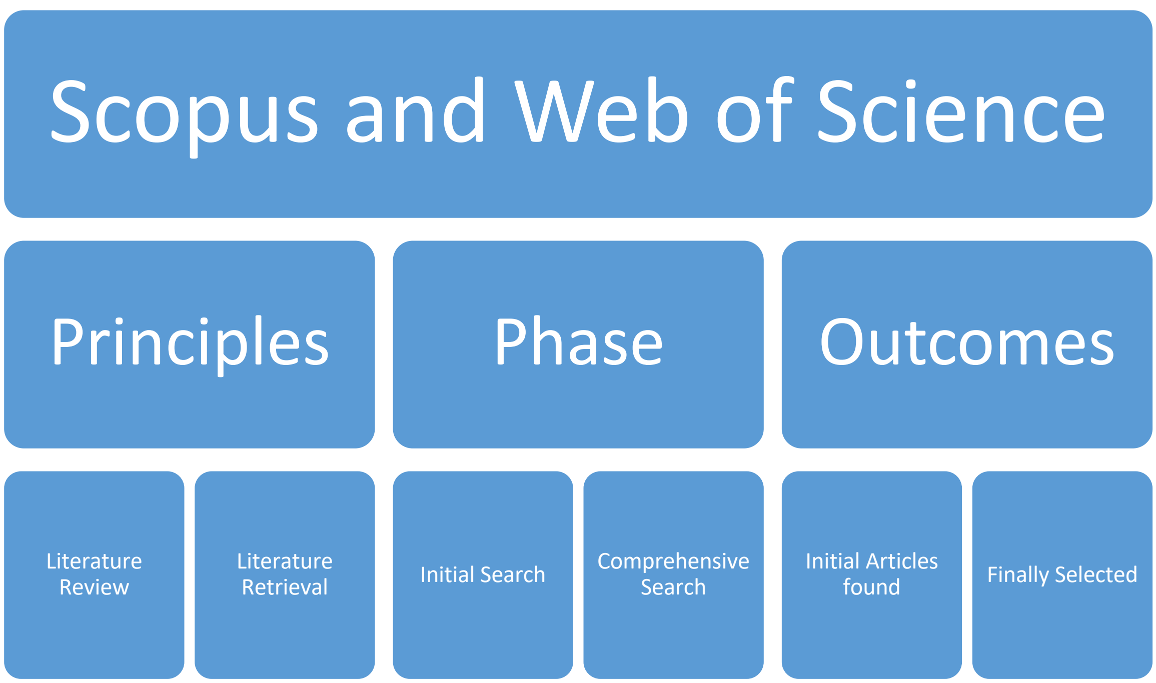


*Figure 2. Research procedure used in this paper*

### 2.2 Other reviews

Mahalle, Kalamkar et al. (2020) categorized forecasting models as mathematical models and machine learning techniques. (Mahalle, Kalamkar et al. 2020) used WHO and social media communications as datasets to be discussed.

(Naudé 2020) provided a review of contribution of artificial intelligence (AI) against COVID-19. Some fields of AI that has contribution against COVID-19 have been identified by (Naudé 2020).

## 3. Main research fields

The VOSviewer 1.6.11 software was applied to provide a network of keywords. For this goal, bibliographic data from Scopus was used. Keywords of authors were used in order to generate a network of the keywords and 1931 keywords was found from the dataset. Table 1 presents parameter settings for visualization of keywords.

*Table 1. Settings for visualization of keywords*

| Parameter | Value |
|---|---|
| Minimum number of occurrences | 1 |
| Criterion met | 1931 keywords |

The resulting network contained 500 nodes and 4000 links as presented in Figure 3 that also presents the main fields of forecasting Coronavirus. (Van Eck and Waltman 2018). It can be seen in Figure 3 that Coronavirus, prediction, epidemic, human, and forecasting have connection links. Figure 4 presents the density map based on keywords showing Coronavirus, prediction, epidemic, human, statistical analysis, quarantine, hospitalization, mortality, and weather are among top keywords on which researchers focused. Figure 5 shows a details analysis of sum of cited by and number of records vs. affiliations. As it has been shown by legend in Figure 5, number of records and cited by have been filtered by minimum 1, 10, respectively. In Figure 5, the density of the rectangles is shown by color, and the high density belongs to affiliation with most citation.

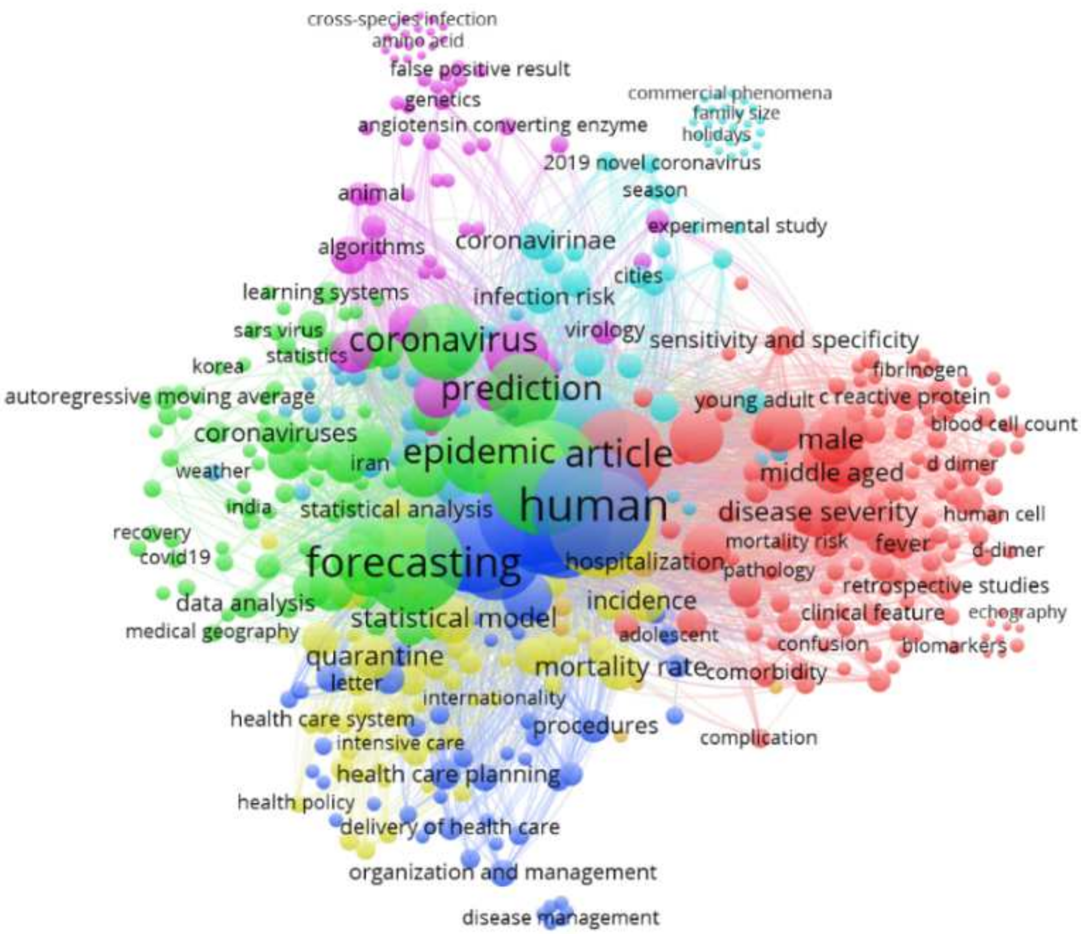


*Figure 3 Network across the links (Keywords analysis)*

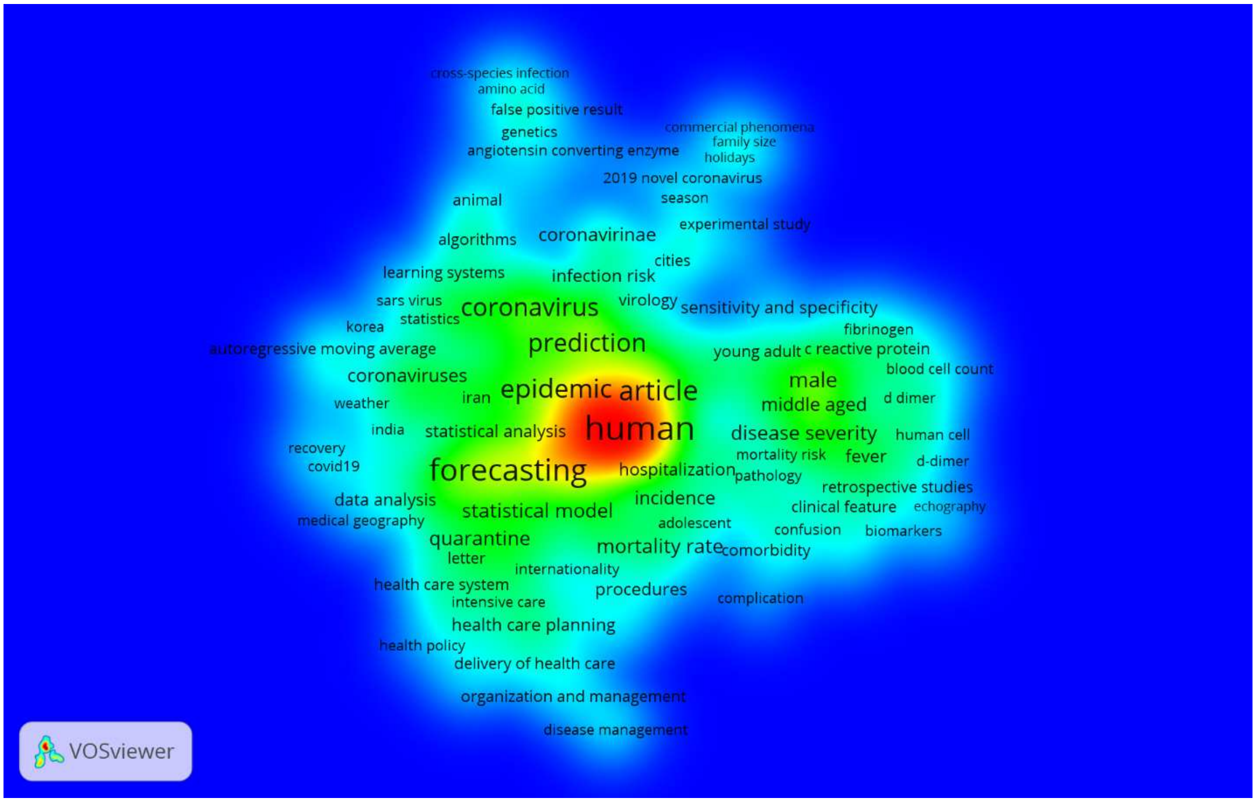


*Figure 4 Density analysis based on keywords*

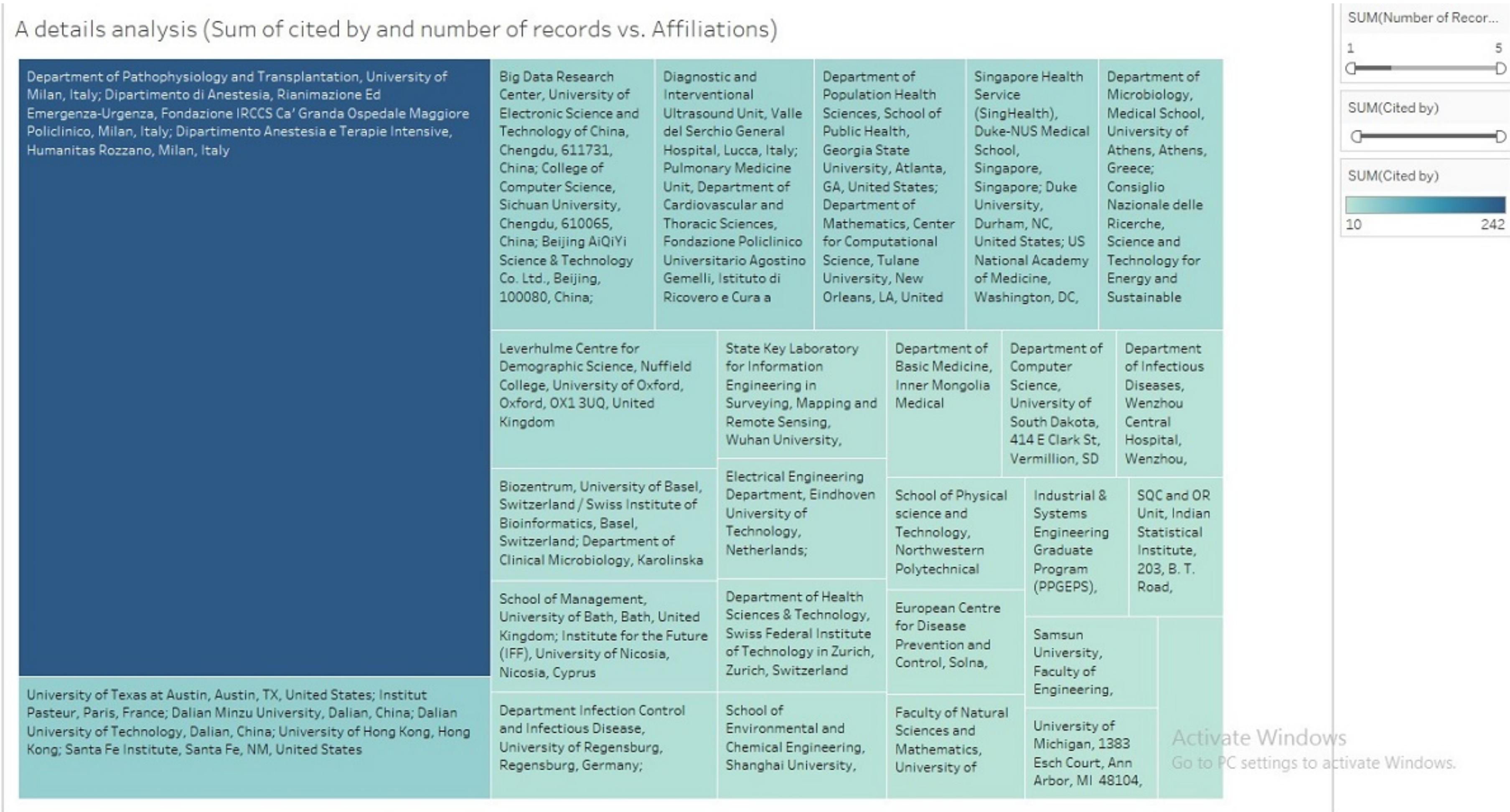


*Figure 5 A details analysis (Sum of cited by and number of records vs. Affiliations)*

## 4. Generic illustrations

Several epidemic models have been used by researchers to estimate the outbreak in the short- and long-term (Anastassopoulou, Russo et al. 2020, Cheng, Burcu et al. 2020, Dil, Dil et al. 2020, Fanelli and Piazza 2020). A famous epidemic model known as SIR model (Kermack and McKendrick 1932, Capasso and Serio 1978) can be described as shown in Figure 6:


*Figure 6 Susceptible, infected, and recovered (SIR) model*

In terms of mathematical modeling, the SIR model is shown below (Weiss 2013):

$$\frac{ds}{dt} = -\beta IS \quad (1)$$

$$\frac{dI}{dt} = \beta IS - \gamma I \quad (2)$$

$$\frac{dR}{dt} = \gamma I \quad (3)$$

in which S, I, and R are the number of susceptible, infected, and recovered individuals at time t, and $\beta$ and $\gamma$ are the transmission recovery, respectively. The SEIR model (Peng, Yang et al. 2020) is similar to SIR model except that E shows the fraction of individuals that have been infected but are asymptomatic. The SEIR model and its equations are shown below (Figure 7):

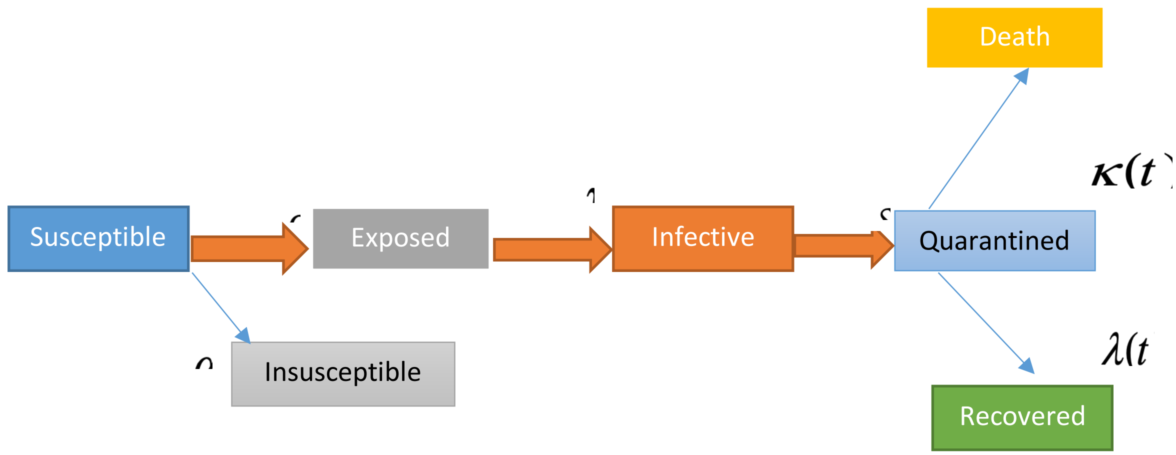


*Figure 7 The susceptible, exposed, infected, and recovered (SEIR) diagram (Peng, Yang et al. 2020)*

The equations of SEIR model are defined in Equations 4–10:

$$\frac{dS(t)}{dt} = -\beta \frac{S(t)I(t)}{N} - \alpha S(t) \qquad (4)$$

$$\frac{dE(t)}{dt} = \beta \frac{S(t)I(t)}{N} - \gamma E(t) \qquad (5)$$

$$\frac{dI(t)}{dt} = \gamma E(t) - \delta I(t) \qquad (6)$$

$$\frac{dQ(t)}{dt} = \delta I(t) - \lambda(t)Q(t) - \kappa(t)Q(t) \qquad (7)$$

$$\frac{dR(t)}{dt} = \lambda(t)Q(t) \qquad (8)$$

$$\frac{dD(t)}{dt} = \kappa(t)Q(t) \qquad (9)$$

$$\frac{dP(t)}{dt} = \alpha S(t) \qquad (10)$$

in which $\alpha$ depicts the protection rate, $\beta$ shows the infection rate, $\gamma$ and $\delta$ display the inverse of the average latent time and average quarantine time, respectively; $\lambda_0$ *and* $\lambda_1$ are coefficients used in the time-dependent cure rate, and $\kappa_0$ *and* $\kappa_1$ are coefficients used in the time- dependent mortality rate (Peng, Yang et al. 2020).

## 5. Mathematical modeling

Ahmar and del Val (2020) used the SutteARIMA to estimate new cases of Novel Coronavirus and Spain Market Index (IBEX 35). This method was proposed by (Ahmar and del Val 2020), and when compared with ARIMA based on the MAPE values, SutteARIMA is more suitable compared with ARIMA for forecasting of confirmed cases in Spain. Al-qaness, Ewees et al. (2020) suggested an improved version of ANFIS based on the Flower Pollination Algorithm (FPA) by using the Salp Swarm Algorithm to forecast the number of confirmed cases of COVID-19 in China. The idea of (Al-qaness, Ewees et al. 2020) is to determine the parameters of Adaptive Neuro-Fuzzy Inference System using the hybrid of the Flower Pollination and Salp Swarm Algorithms. The performance of the algorithm proposed by (Al-qaness, Ewees et al. 2020) was validated by comparing with the existing modified ANFIS models, PSO, genetic algorithm (GA), approximate Bayesian computation (ABC), and FPA. Anastassopoulou, Russo et al. (2020) suggested a method for predicting the reproduction number (R0) from the susceptible, infected, recovered, and deceased (SIRD) model and other key parameters. Chakraborty and Ghosh (2020) presented a real-time forecast of confirmed COVID-19 cases for several countries as well as risk assessment of the novel COVID-19 for some affected territory using regression tree algorithm. A simple moving average approach was used by (Chaudhry, Hanif et al. 2020) to predict COVID-19 confirmed cases in Pakistan. (Chen, Chen et al. 2020) used a 5-parameter logistic model to reconstruct and forecast the COVID-19 cases in US; however, the authors claimed the accuracy of the model was also depend on policy decisions. Cheng, Burcu et al. (2020) introduced a platform, icumonitoring.ch, to provide hospital-level projections for intensive care unit (ICU) occupancy based on SEIR models. The platform provided by (Cheng, Burcu et al. 2020) help managers to estimate the need for resources and is updated every 3 to 4 days. Chimmula and Zhang (2020) applied long short-term memory (LSTM) networks as a deep learning technique for predicting COVID-19 outbreaks in Canada. The approach proposed by (Chimmula and Zhang 2020) found the key features for estimating the trends of the pandemic in Canada. A simple ARIMA model was suggested by (Chintalapudi, Battineni et al. 2020) to estimate the cases after lockdown in Italy.

Salgotra, Gandomi et al. (2020) proposed two COVID-19 prediction models based on genetic programming and used these models in India. Results from the study by (Salgotra, Gandomi et al. 2020) indicate that genetic evolutionary programming models are highly reliable for COVID-19 cases in India. Dil, Dil et al. (2020) used the SIR model to forecast confirmed COVID-19 cases in the Eastern Mediterranean Region.

A simple SIRD model proposed by (Fanelli and Piazza 2020) to predict COVID-19 outbreaks in China, Italy and France. Analysis by (Fanelli and Piazza 2020) estimated healthcare facilities, such as ventilation units, for peak requirements.

## 6. Criteria Evaluation

Forecasting confirmed cases, risk assessment, stock market, ICU beds, registered and recovered cases are top criteria in which scholars are interested.

## 7. Solution approaches

Several approaches have been addressed by researchers to predict the COVID-19 outbreak. Table 2 presents solution approaches proposed by researchers for forecasting COVID-19. SIR, SEIR, SIRD, and Moving Average are top approaches that have been suggested by scholars to forecast the COVID-19 outbreak. Also, some researchers (Al-qaness, Ewees et al. 2020, Singh, Parmar et al. 2020) preferred to use hybrid algorithms to enhance the power of forecasting algorithms.

*Table 2 Solution approaches proposed for forecasting Coronavirus 2019 (COVID-19)*

<table>
<tr><th colspan="6">Algorithm</th></tr>
<tr><th colspan="2">Epidemic Models</th><th colspan="3">Time Series Models</th><th>Nature Inspired Algorithms</th></tr>
<tr><td rowspan="3">SIR</td><td rowspan="3">(Dil, Dil et al. 2020)</td><td rowspan="3">Autoregressive model</td><td rowspan="2">Moving Average</td><td>Autoregressive Integrated Moving Average (Ahmar and del Val 2020, Chakraborty and Ghosh 2020, Chintalapudi, Battineni et al. 2020, Moftakhar, Seif et al. 2020, Singh, Parmar et al. 2020)</td><td rowspan="3">Genetic programming (Salgotra, Gandomi et al. 2020)</td></tr>
<tr><td>Simple Moving Average: (Chaudhry, Hanif et al. 2020)</td></tr>
<tr><td>Other models</td><td>(Maleki, Mahmoudi et al. 2020)</td></tr>
<tr><td>SEIR</td><td>(Cheng, Burcu et al. 2020, Reno, Lenzi et al. 2020)</td><td colspan="2">Exponential Models</td><td>Logistic Growth Model: (Chen, Chen et al. 2020, Li, Feng et al. 2020, Qeadan, Honda et al. 2020)</td><td>Flower Pollination Algorithm (Al-qaness, Ewees et al. 2020)</td></tr>
</table>

<table>
<tr><td rowspan="3">SIRD</td><td rowspan="3">(Anastassopoulou, Russo et al. 2020, Fanelli and Piazza 2020)</td><td>Deep Learning</td><td colspan="4">LSTM networks (Chimmula and Zhang 2020)<br>Polynomial Neural Network (Fong, Li et al. 2020)<br>Neural Network (Moftakhar, Seif et al. 2020, Tamang, Singh et al. 2020)</td><td rowspan="4">Ecological niche models (Ren, Zhao et al. 2020)</td></tr>
<tr><td>Regression Methods</td><td colspan="4">(Ji, Zhang et al. 2020, Ribeiro, da Silva et al. 2020, Sujath, Chatterjee et al. 2020)</td></tr>
<tr><td>Prophet Algorithm</td><td colspan="4">(Abdulmajeed, Adeleke et al. 2020)</td></tr>
<tr><td>Phenomenological model</td><td>(Roosa, Lee et al. 2020)</td><td>Other Models</td><td>Adaptive Neuro-Fuzzy Inference System: (Al-qaness, Ewees et al. 2020)</td><td>Regression Tree Algorithm: (Chakraborty and Ghosh 2020)</td><td>Support Vector Machine (Fong, Li et al. 2020, Parbat and Fractals 2020)</td><td>Iteration method (Perc, Gorišek Miksić et al. 2020)</td></tr>
</table>

## 7.1 Autoregressive Model

The autoregressive time series model is known as a useful instrument that has been applied to various real real-world problems (Maleki, Arellano-Valle et al. 2017, Maleki, Arellano-Valle et al. 2017, Maleki, Nematollahi et al. 2017, Hajrajabi and Maleki 2019, Zarrin, Maleki et al. 2019).

### 7.1.1 Moving Average

In statistic and economic, moving average is a way of calculation and analysis of data by providing a series of averages of various subsets of the data set (Sprinthall and Fisk 1990).

#### 7.1.1.1 Simple Moving Average (SMA)

The SMA model is defined as the unweighted mean of the previous data (in finance or in science & engineering) (Sprinthall and Fisk 1990). Example of application of simple moving average in COVID-19 could be found in (Chaudhry, Hanif et al. 2020).

#### 7.1.1.2 Autoregressive Integrated Moving Average (ARIMA)

The ARIMA model is a generalized form of autoregressive moving average model. As it is well-known for forecasting, some researchers have used ARIMA to predict the new pandemic (Alzahrani, Aljamaan et al. 2020, Kufel and Policy 2020, Moftakhar, Mozhgan et al. 2020, Roy, Bhunia et al. 2020, Singh, Parmar et al. 2020).

### 7.1.2 Two pieces distributions model

(Maleki, Mahmoudi et al. 2020) used a time series model based on two-pieces distribution to predict new COVID-19 cases. Compared with standard autoregressive time series model shows proposed algorithm by (Maleki, Mahmoudi et al. 2020) outperforms in estimating of new cases across the world.

## 7.2 Exponential Models

Exponential models are suitable in modeling of several phenomena, such as populations, interest rates, and infectious diseases (Smith 2020).

### 7.2.1 Logistic Functions

One of the famous S-shaped curve is logistic function with application in biology, chemistry, linguistics, political science, and statistics. (Chen, Chen et al. 2020, Li, Feng et al. 2020, Qeadan, Honda et al. 2020) are instances of application of logistic functions in COVID-19.

## 7.3 Deep Learning

Deep learning is a famous division of computer science that learning process could be supervised, semi-supervised, unsupervised (Bengio, Courville et al. 2013, LeCun, Bengio et al. 2015, Schmidhuber 2015). Application of different forms of deep learning in forecasting COVID-19 cases could be found in Long short term memory (LSTM) networks (Ayyoubzadeh, Ayyoubzadeh et al. 2020, Chimmula and Zhang 2020), Polynomial Neural Network (Fong, Li et al. 2020), Neural Network (Moftakhar, Seif et al. 2020, Tamang, Singh et al. 2020). Mousavi et al. (2020) proposed a novel platform (Recurrent Neural Networks) to estimate the new cases in India. In the work of (Mousavi et al. 2020), several factors such as transmission rate, temperature, and humidity are considered in training Recurrent Neural Networks.

## 7.4 Regression Methods

In statistic, regression methods is a set of statistical modeling to forecast the link between a dependent variable and independent variable (s) (Cook and Weisberg 1982, Freedman 2009). As a power tool to forecast the pandemic, various regression methods have been addressed by researchers against COVID-19 (Almeshal, Almazrouee et al. 2020, Ji, Zhang et al. 2020, Ribeiro, da Silva et al. 2020, Sujath, Chatterjee et al. 2020, Velásquez, Lara et al. 2020).

### 7.5 Prophet Algorithm

The Prophet algorithm is an open-source tool that works well with time-series data that have seasonal effects. The algorithm has developed by Facebook' s Data Science team, and its main goal is business forecasting (Taylor and Letham 2017, Taylor and Letham 2018). The Prophet algorithm is robust in dealing with missing data (Ndiaye, Tendeng et al. 2020).

### 7.6 Genetic Programming

Genetic programming (GP) is a nature inspired algorithm that the keys of GP include program representation (tree structure), selection, crossover, and mutation (Banzhaf, Nordin et al. 1998). An example of GP in COVID-19 is available in (Salgotra, Gandomi et al. 2020).

### 7.7 SIR

One of the most applied epidemic models is susceptible, infected, and recovered case (SIR) (Kermack and McKendrick 1932, Capasso and Serio 1978) in which S, I, and R are the number of susceptible, infected, and recovered individuals at time t, respectively.

### 7.8 SEIR

The SEIR model (Peng, Yang et al. 2020) is an extended version of SIR model considering parameter E showing the fraction of individuals that have been infected but are asymptomatic.

### 7.9 SIRD

The SIRD model that is a modified version of SIR differentiates between recovered and Deceased cases (Anastassopoulou, Russo et al. 2020, Fanelli and Piazza 2020).

## 8. Strengths and Weaknesses of Forecasting Models

As discussed earlier, several algorithms have been used to forecast the new pandemic in various places of the world. Figure 8 presents the percentage of contribution of different of solution approaches applied in forecasting of Novel coronavirus confirmed cases. As it is clear from Figure 8, deep learning and regression methods have the most contributions while Prophet algorithm as a new branch of machine learning has the least contribution in the field.

There are many Pros and Cons by using machine learning algorithms. Some of important strengths and weaknesses of proposed machine learning algorithms have been proposed in Table 3.

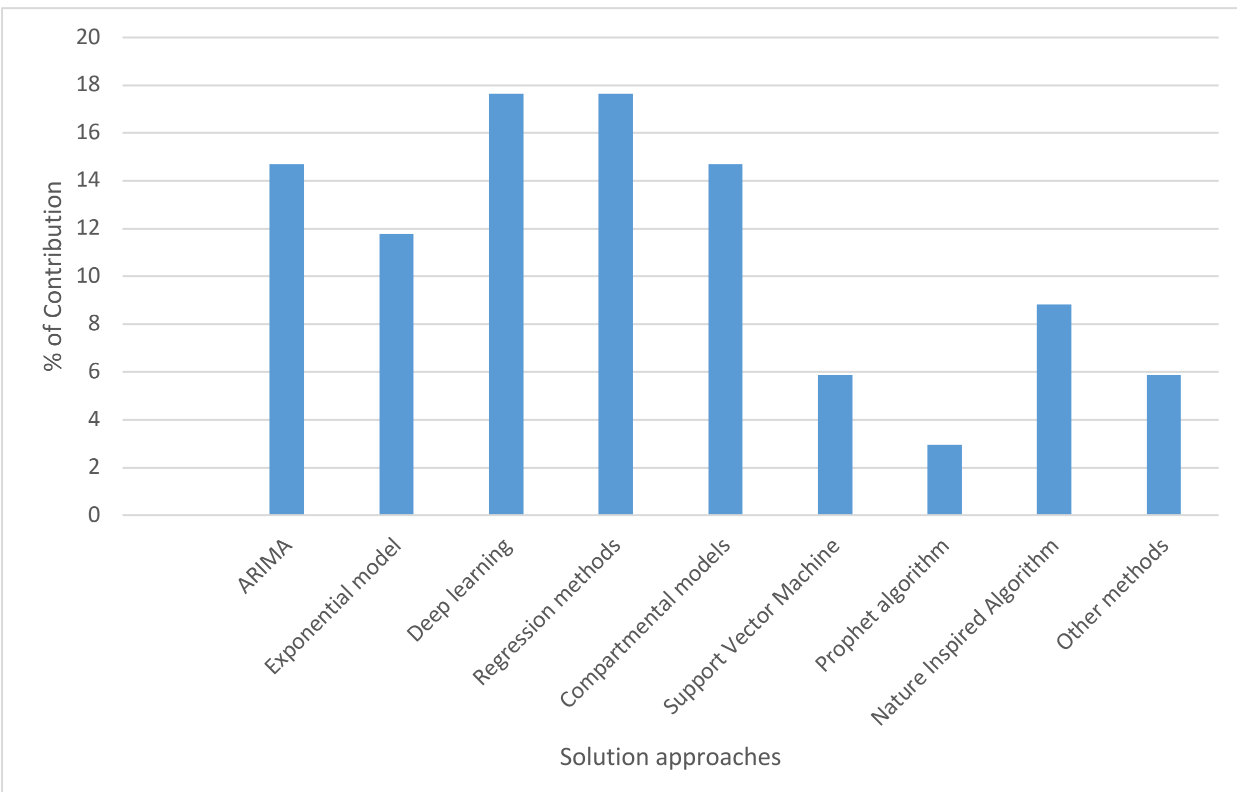


*Figure 8 % of contribution of different of solution approaches applied in forecasting of COVID-19 confirmed cases*

| Algorithm | Strength | Weakness |
|---|---|---|
| Artificial Neural Network | Could access to several training algorithms (Jalalkamali, Moradi et al. 2015). | The nature of being a black box (Jalalkamali, Moradi et al. 2015), overtraining (Wilamowski 2009). |
| Support Vector Machine | Can avoid overfitting and defining convex optimization problem (Jalalkamali, Moradi et al. 2015). | Choice of kernel as well as speed and size of training and testing sets (Jalalkamali, Moradi et al. 2015). |
| Compartmental models (SIR, SEIR, SIRD, etc.). | - Predict how the disease spreads.<br>- Present the effects of public health policies on the outcome of the pandemic (Hethcote 1989, Nunn, Altizer et al. 2006, Gao, Teng et al. 2007, Brauer, Castillo-Chavez et al. 2012). | The proposed models are mostly deterministic and works with large populations (Bartlett 1957). |
| Nature Inspired Algorithms (Genetic programming) | - Intelligent search (Glover and Laguna 1999).<br>- Can integrate with certain decomposition algorithms (Poojari and Beasley 2009) | - Several parameters should be set by the decision-makers.<br>- The algorithms are approximate and usually non-deterministic (Blum and Roli 2003) |
| Prophet Algorithm | - Are robust in dealing with missing data (Ndiaye, Tendeng et al. 2020). | - It is hard to use the algorithm for Multiplicative models.<br>- Pre-defined format is needed for data before using the algorithm. |
| ARIMA | - Works for seasonal and non-seasonal models.<br>- Outliers can be handled well. | - Changes in observations and changes in model specification makes the model unstable (Makridakis and Hibon 1997). |
| Deep Learning | - Results comparable to human expert performance (Ciregan, Meier et al. 2012, Krizhevsky, Sutskever et al. 2012). | - It needs very large data.<br>- The training process is expensive. |

## 9. Conclusion and Discussion

By now, COVID-19 has spread to about 200 countries worldwide leading to more than 18 million confirmed cases. Several works have been released in the field for predicting global outbreaks. This study tried to review the most important forecasting models for COVID-19 and showed a short analysis. A detailed scientometric analysis that is an influential tool for use in bibliometric analyses and reviews, was done. For this aim, keywords and subject areas were discussed while classification of forecasting models, criteria evaluation and comparison of solution methods were done in the second section of the work.

This study described some key arguments, which are worth discussing:

- In terms of subject area, medicine, biochemistry, and mathematics were top areas that were addressed by scholars.
- Analysis of keywords presents that researches of COVID-19 will increase in the next few months. Moreover, Coronavirus, prediction, epidemic, human, statistical analysis, quarantine, hospitalization, mortality, and weather instances are the most interesting keywords for scholars.
- Several criteria have been used by researchers:
  - Forecasting: confirmed cases, risk assessment, stock market, ventilation units, ICU beds, estimated registered and recovered cases.

- Several countries, including China, Pakistan, France, Italy, US, UK, Brazil, Nigeria, Iran, Germany, and India, were addressed as case studies.
- Among the epidemic models, deep learning and regression methods, the SIR, SEIR, and ARIMA are the top models that were used by the researchers.
- Hybrid algorithms are used to enhance the power of forecasting approaches.

- The majority of studies are deterministic approaches while there is an urgent need to provide robust approaches for tackling uncertain situations.

For future research directions, a comprehensive review in other fields, such as artificial intelligence (AI) and deep learning are encouraged. Moreover, more studies addressing the integrated approaches to tackle the problem is proposed.

**Compliance with Ethical Standards:**

- Sources of Funding: The authors confirm that there is no source of funding for this study.
- Conflict of Interest: The authors declare that they have no conflict of interest.
- Human Participants and/or Animals: None.

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# Figures

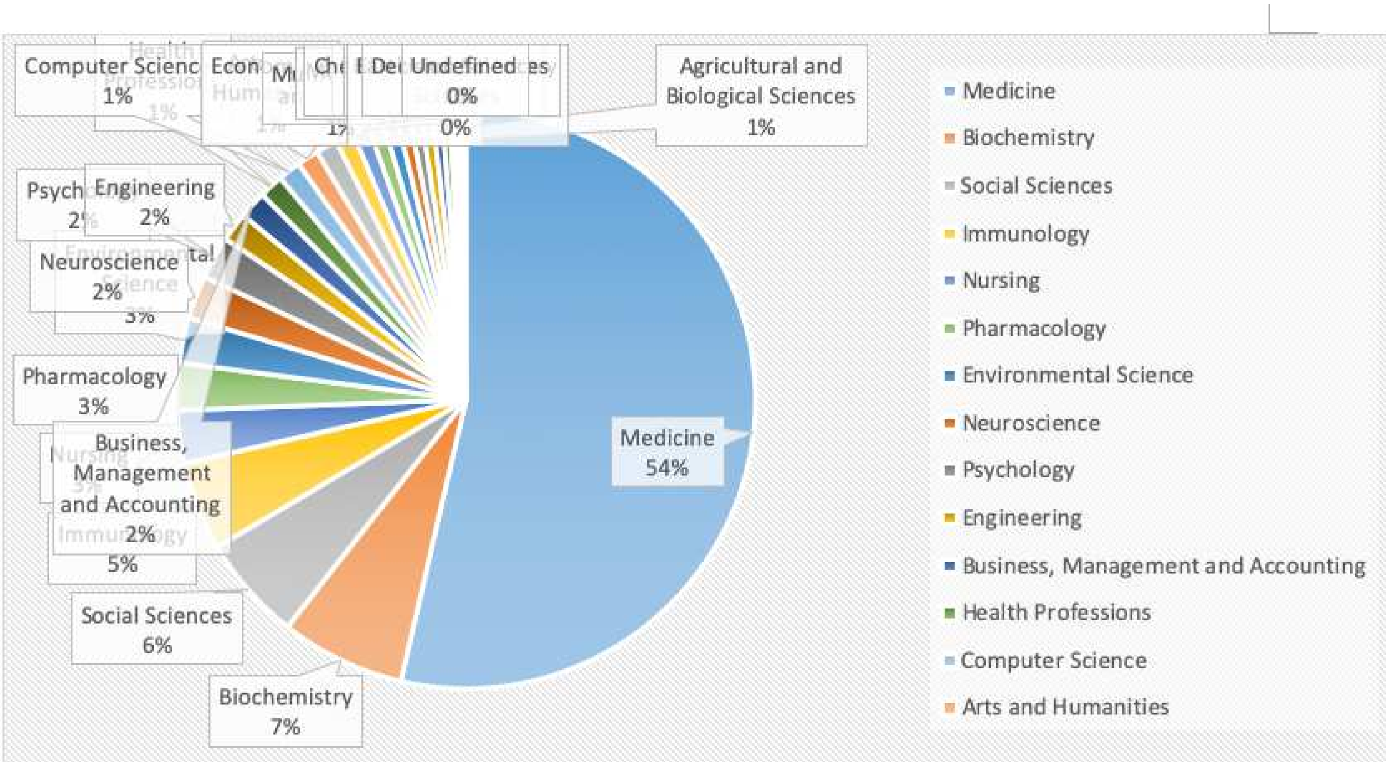



**Figure 1**

Classification of scientific papers based on subject area

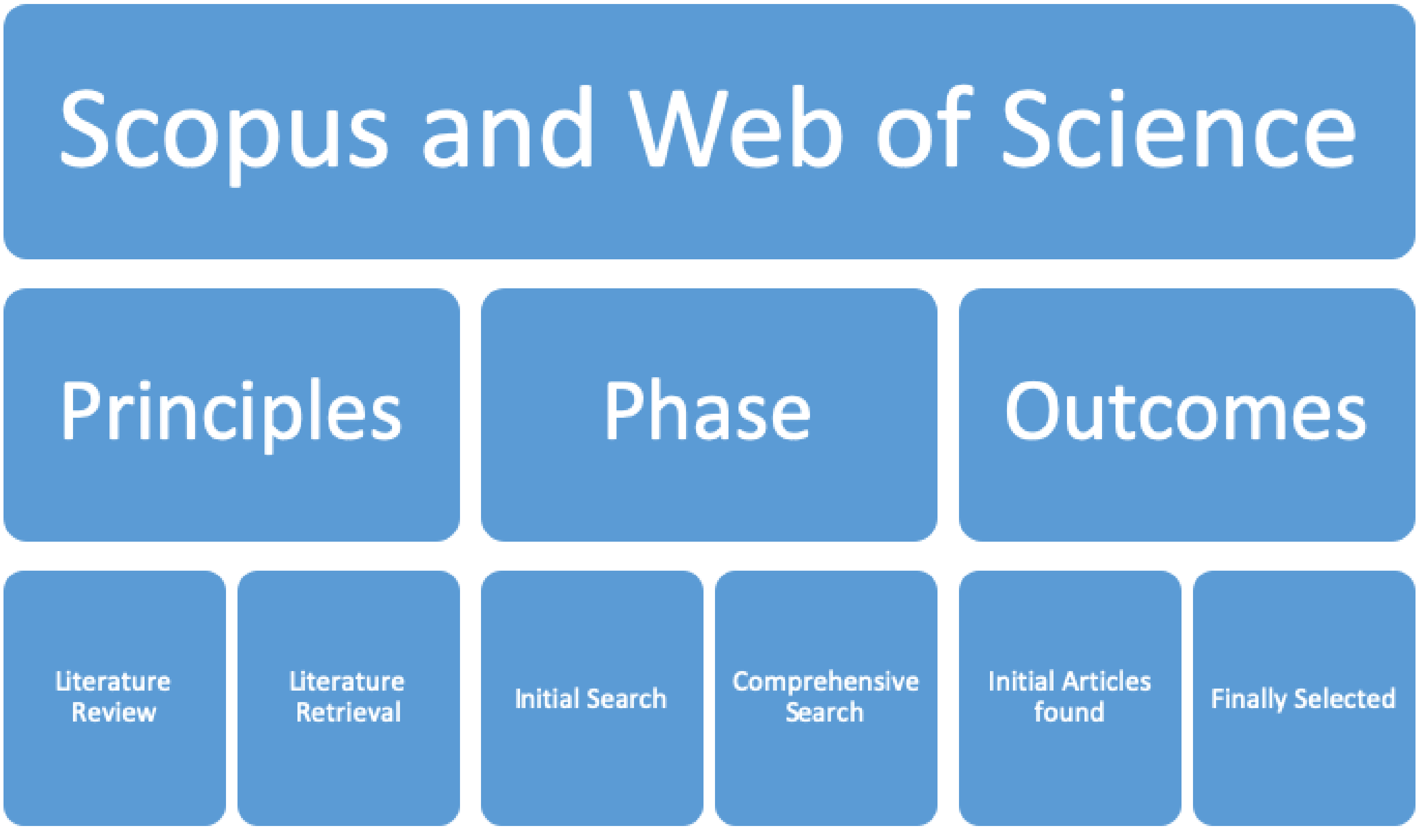
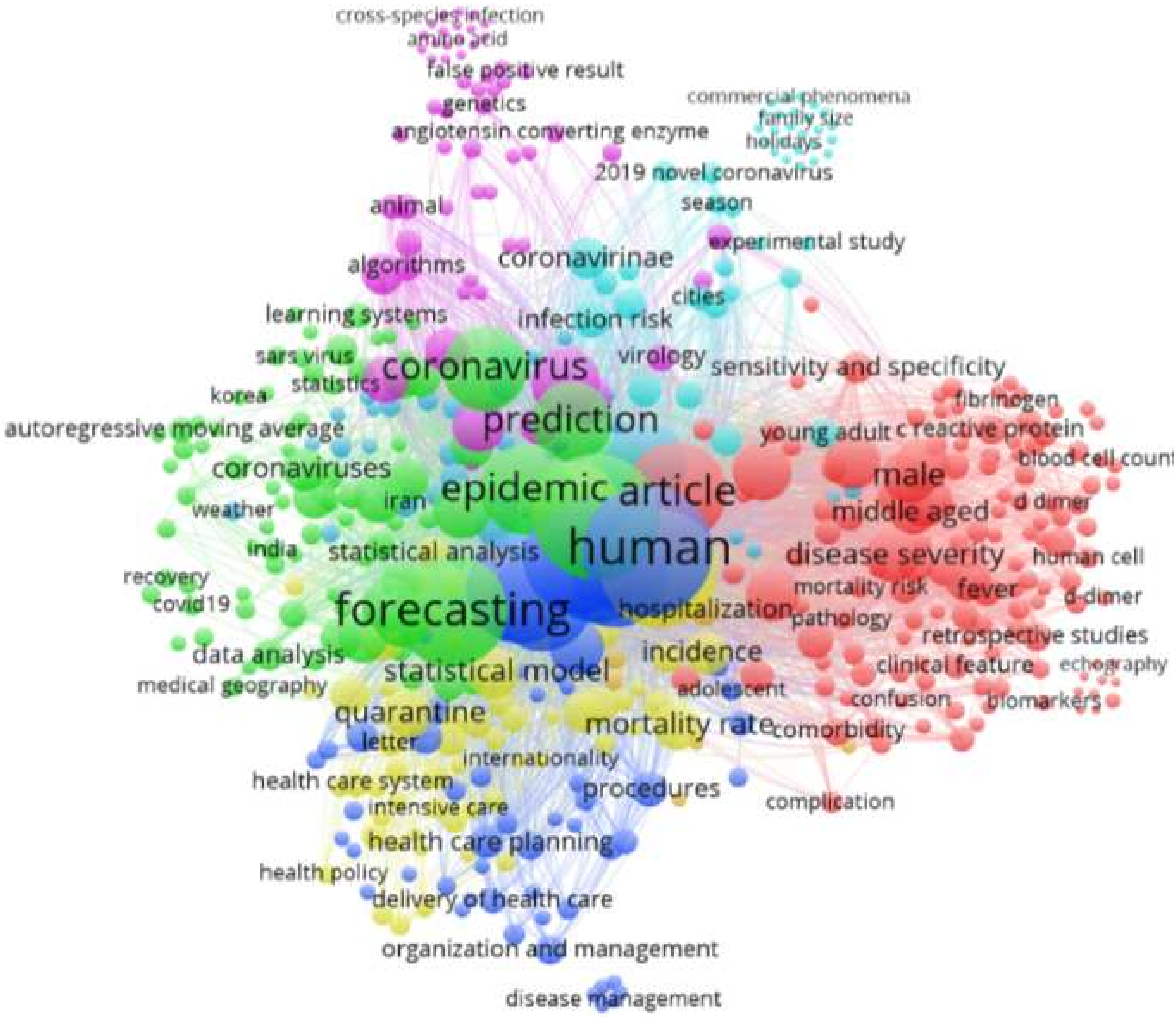


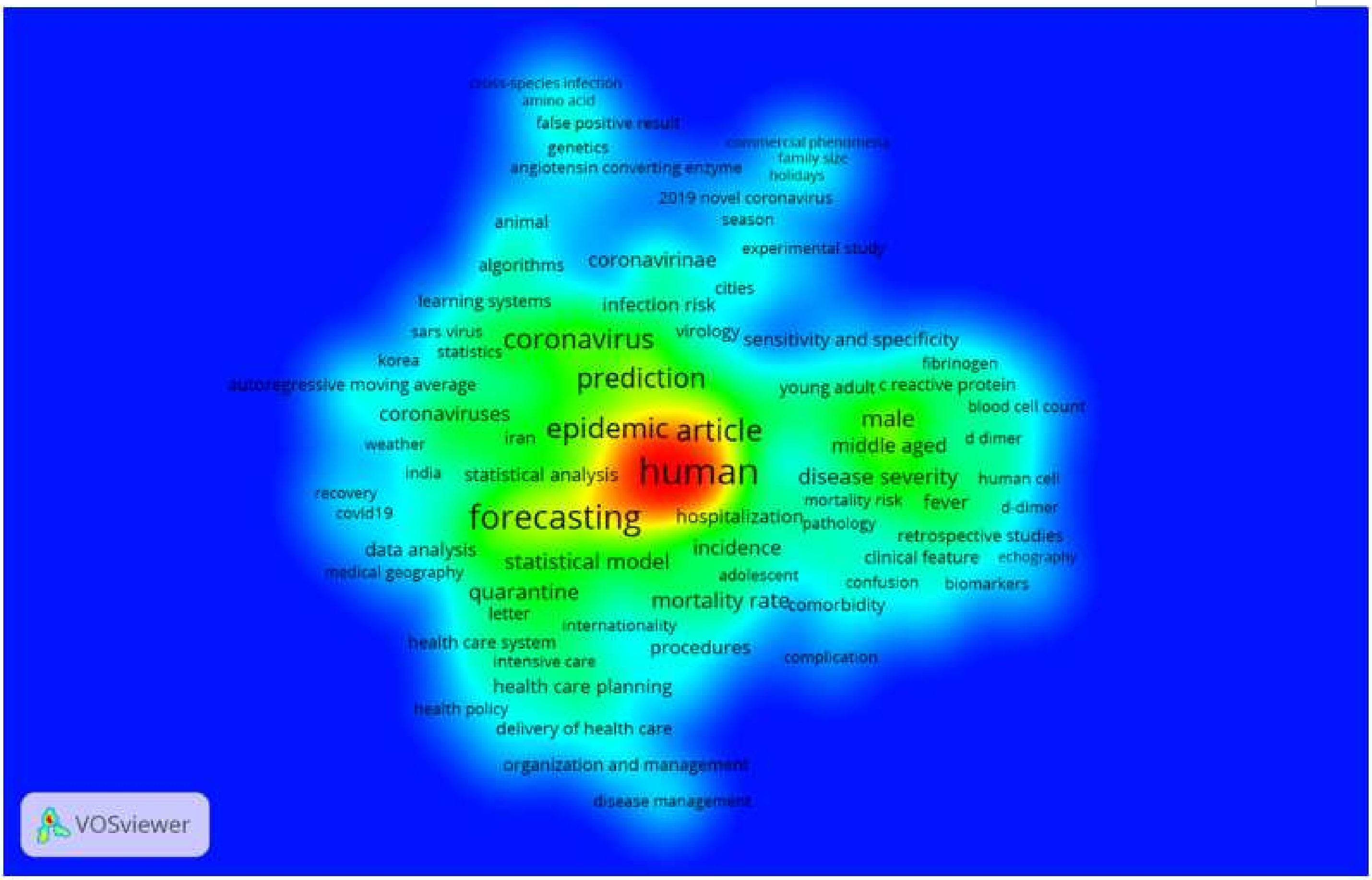

**Figure 2**

Research procedure used in this paper




## Figure 3

Network across the links (Keywords analysis)




## Figure 4

Density analysis based on keywords

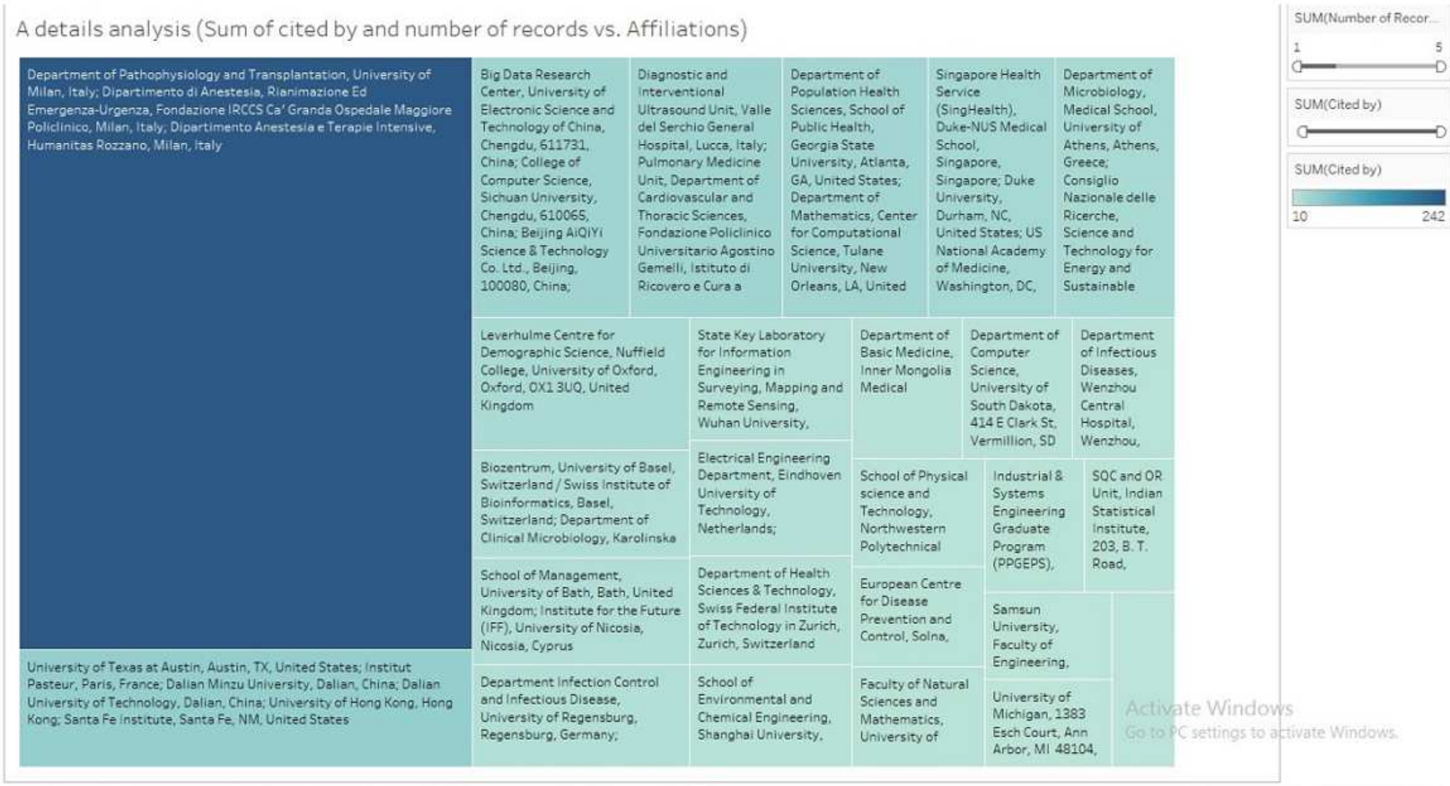



**Figure 5**

A details analysis (Sum of cited by and number of records vs. Affiliations)


**Figure 6**

Susceptible, infected, and recovered (SIR) model

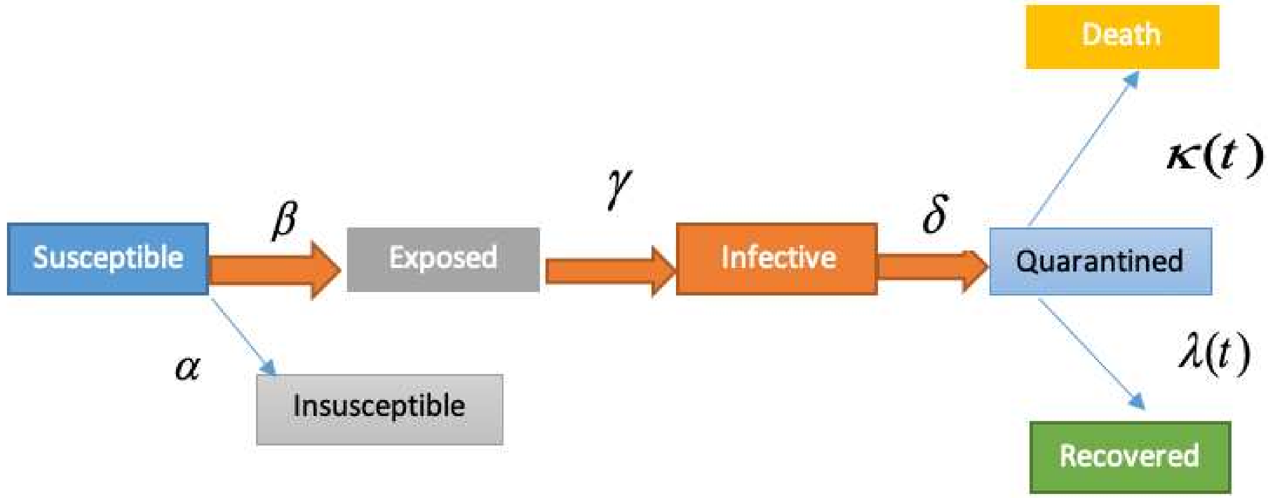



**Figure 7**

The susceptible, exposed, infected, and recovered (SEIR) diagram (Peng, Yang et al. 2020)

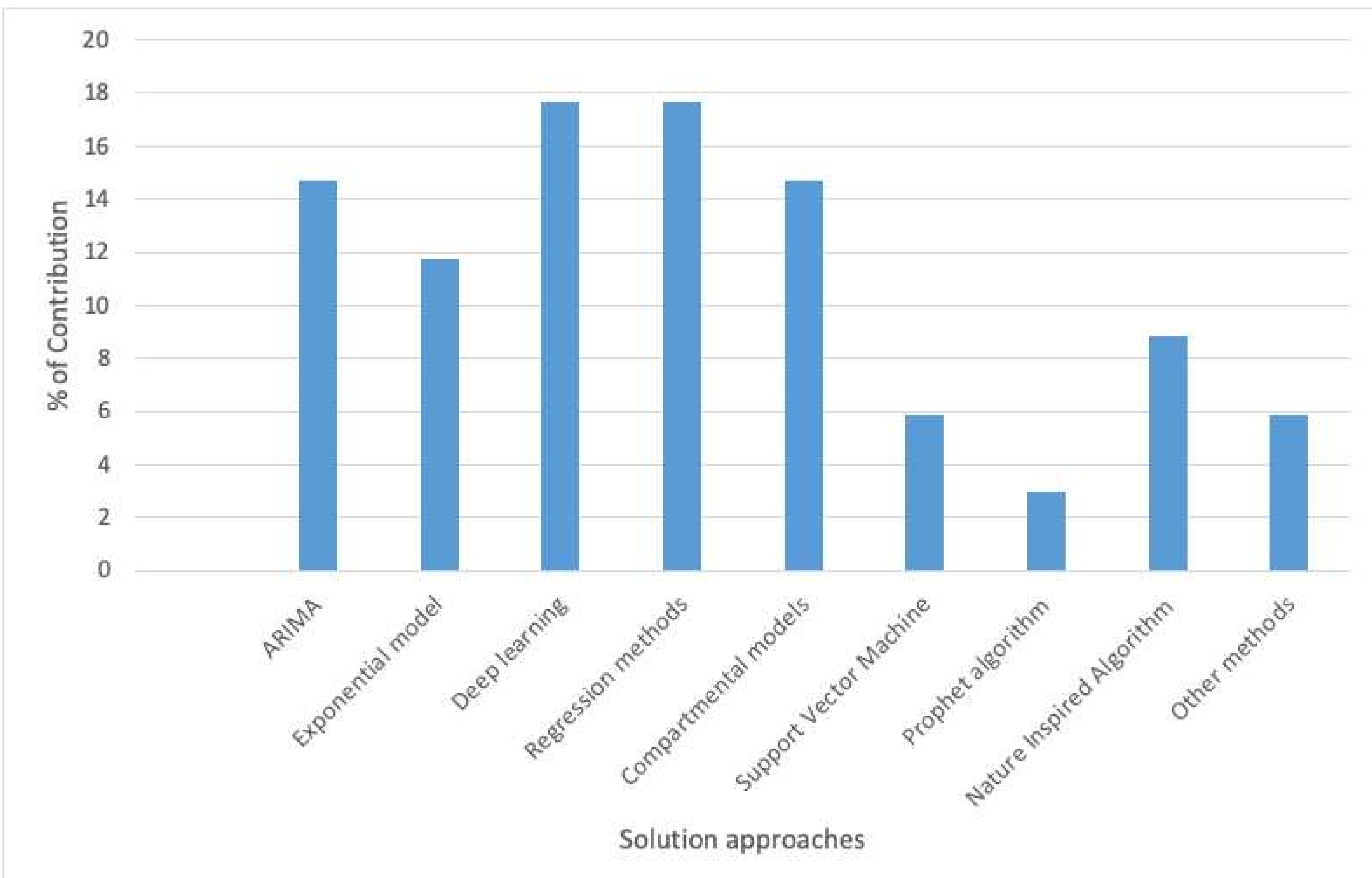



**Figure 8**

% of contribution of different of solution approaches applied in forecasting of COVID-19 confirmed cases