Chapter

COVID-19 Pandemic: Analysis and Statistics of Confirmed Cases

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Abstract

Coronavirus COVID-19 started in December 2019, and it has spread rapidly across China and the whole world. In this chapter, we analyzed the number of confirmed cases in US, India, France, Russia and Brazil. Additionally, we took into account Latin American countries like Argentina, Colombia, Peru, Chile and Mexico. We noticed, how some countries got a low death rate, despite its high number of confirmed cases (US). Additionally, it is interesting, how some countries with a high percentage of obesity got the highest death rate (Mexico). Also, we noticed a decreasing number in confirmed cases after a intensive vaccination plan (US). Finally, we evaluated Weibull Long Short-Term Memory (W-LSTM) and Multiplicative Trend Exponential Smoothing (MTES) to predict confirmed cases, in this case, W-LSTM showed a more realistic forecasting.

Keywords: Coronavirus, COVID-19, Analysis, Forecasting, LSTM, MTES

1. Introduction

Coronavirus COVID-19 pandemic started in December 2019 in Wuhan, China. This virus has high viral infectivity [1], so it has spread rapidly across China and other countries. Furthermore, 140,849,925 confirmed cases and 3,013,217 deaths were reported in the whole world until the last April 20th [2].

This new coronavirus made huge strain on the health system around the world forcing to establish decisions like quarantines and social distances in a effort to contain the spread of the virus [3]. Some countries with high incomes like United Kingdom, Italy, Spain and United States of America had to take measures such as hiring retired health personnel to assist battle infections.

Also, countries like United States agreed with car and weapon manufacturers to provide ventilators to help in the pandemic fight. The situation in countries with low and middle incomes were challenged, because they already have poor and weak health systems before COVID-19. They had limited financial resources, unavailable medications and inadequate health personnel, also in these countries exist a gap on the socio-economic. A person of higher socio-economic standing are more likely to have access to quality health services and medications [4].

Since the identification of SARS-CoV-2 virus, the scientific community was starting to develop over 300 vaccines projects, 40 of them are now on undergoing clinical evaluation, 10 of these are in Phase III and 3 of them have passed the phase

III with effective outcomes. The existing data propound that the vaccine candidates can reduce the spread of the pandemic protecting individuals. On the other hand, the fast development of vaccines candidates carries with some unresolved issues (only time could clarify). Moreover, technical and ethical problems were added with the production of billions of doses [5]. Despite, there are dozens of potential vaccine candidates [6], the herd immunity has not achieved yet.

Nowadays, the scientist communities are publishing several papers of studies about COVID-19. For instance, a research team had published an analysis of confirmed cases with Multiplicative Trend Exponential Smoothing (MTES) and Long Short-Term Memory (LSTM) [7]. Nonetheless, other researchers made a comparison with Auto-Regressive Integrated Moving Average (ARIMA), Nonlinear Autoregression Neural Network (NARNN) and LSTM to predict the confirmed cases of Denmark, Belgium, Germany, France, United Kingdom, Finland, Switzerland and Turkey, they concluded that LSTM was the most accurate model [8]. In addition, LSTM had been used to predict the trends and possible ended time of COVID-19 [9]. Also, other research used LSTM to predict the cumulative recovered, fatalities and confirmed cases [10].

In this Chapter, we analyzed the evolution of COVID-19. We took into account countries with the major number of confirmed cases like US, India, France, Russia and Brazil. Additionally, we took into account Latin American countries like Argentina, Colombia, Peru, Chile and Mexico. We analyzed the evolution of confirmed cases, deaths, the effects of vaccination and finally, we evaluated some models to forecast the number of confirmed cases.

2. Analysis of confirmed cases and deaths

In this section, we analyzed the number of confirmed cases and deaths in some countries. We focused on countries like US, India, France, Russia and Brazil, because, they got the major number of confirmed cases around the world. Additionally, we focused in the some Latin American countries like Argentina, Colombia, Peru, Chile and Mexico. They also, got the highest number of confirmed cases in Latin America.

2.1 American countries

The number of confirmed cases, varies from each country to another. For example in **Figure 1**, we showed the evolution of confirmed cases in top countries with the major impact. In this case, United States (US), shows an increasing curve

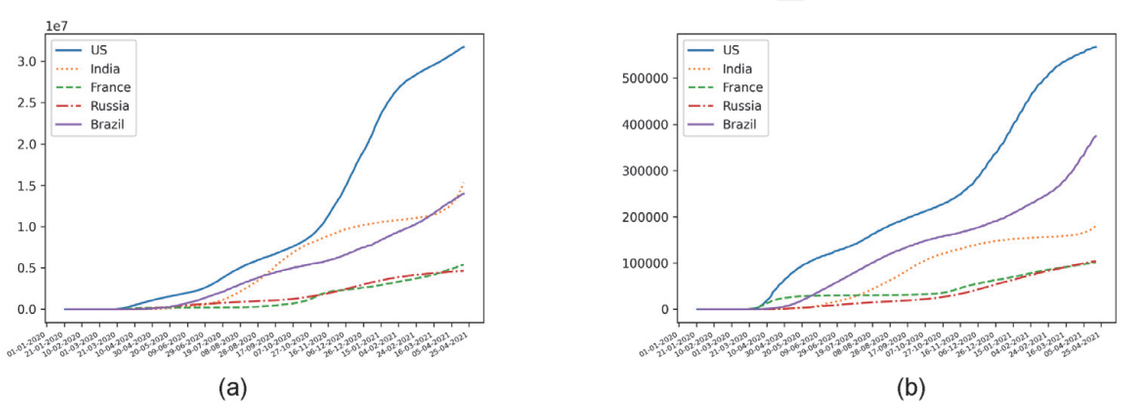

Figure 1.
Evolution of confirmed and deaths in US, India, France, Russia and Brazil. (a) Confirmed cases. (b) Deaths.

with 31,786,856 confirmed cases until April-20th. Furthermore, in **Figure 2**, we plotted the confirmed cases and deaths per million inhabitants. This shows a more realistic overview.

An interesting point is related to the differences between, confirmed cases and deaths in some countries. For instance, despite US got the major number of infected people, it has 1.77 of mortality rate (see **Table 1**), meanwhile France and Russia got 2.23 and 2.00 respectively. This difference between countries, could be related to the vaccinations, medical system, population's social behavior, etc. For example, meanwhile US has 5262 hospitals, Peru has 390, there is a huge difference. So, it is not adequate to use just one metric to measure the pandemic impact, we need to evaluate other metrics in order to understand this COVID-19 pandemic.

Brazil represents another interesting case. Brazil, has the highest public cost of health services in Latin America but it has 2.48% of death rate (the highest). The Brazil's president played a key role in the severity of the virus, at the beginning of the pandemic, he overestimated the virus.

2.2 Latin American countries

Additionally, in **Figures 3** and **4**, we shows the confirmed cases and deaths in Latin American countries. In this case, Mexico has an interesting behavior, this country got a death rate of 8.85 (see **Table 1**). According to some researches, the severity of COVID-19 is positively correlated with several factors, such as age and coexisting diseases. Moreover, obesity is considered as the main risk factor [11–13].

Obesity, is the key problem in Mexico. According to some surveys in 2000, 2006, 2012, and 2018, the adult obesity increased 42.2%. Moreover, the latest national survey (2018), concluded that 40.2% female adults and 36.1% male adults

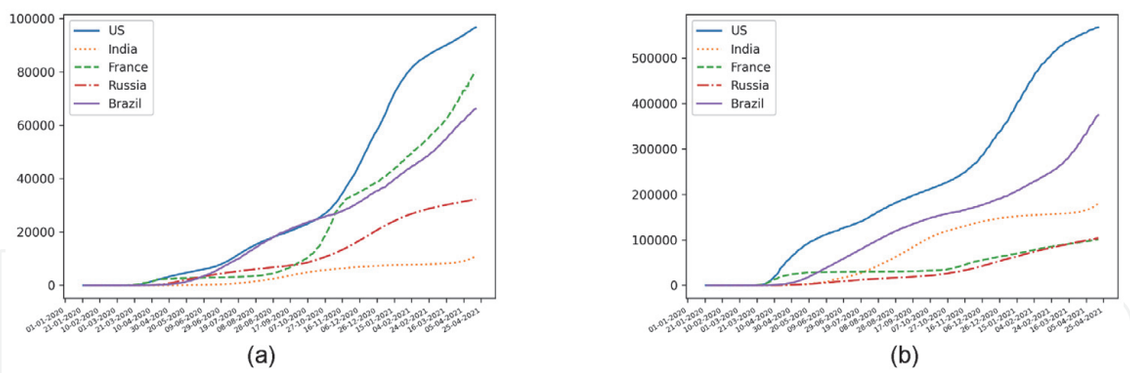

Figure 2.
Evolution of confirmed and deaths per million habitants in US, India, France, Russia and Brazil. (a) Confirmed cases. (b) Deaths.

Country	Death rate (%)[a]	Country	Death rate (%)[a]
US	1.77	Argentina	2.46
India	1.39	Colombia	2.61
France	2.23	Peru	3.52
Russia	2.00	Chile	2.47
Brazil	**2.48**	**Mexico**	**8.85**

[a]*We compute death rate as the mean of each day from 01 to 01-2021 to 20-04-2021.*

Table 1.
Death rate for US, India, France, Russia, Brazil, Argentina, Colombia, Peru, Chile and Mexico.

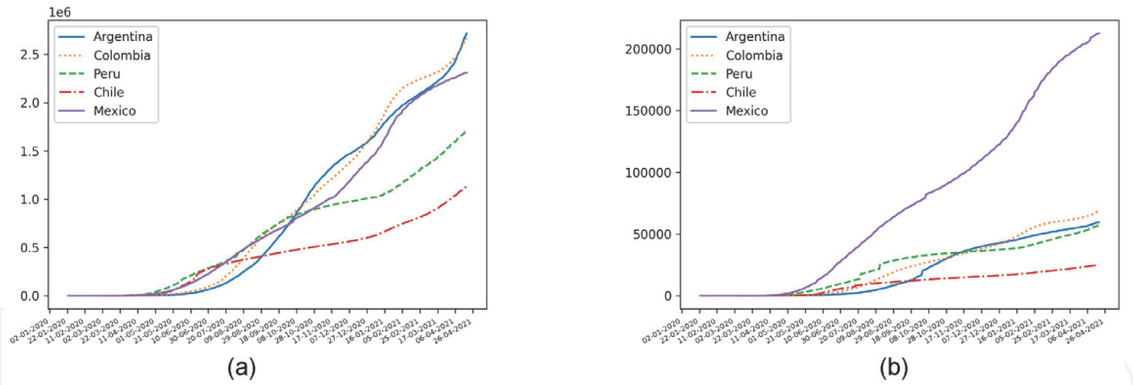

Figure 3.
Evolution of confirmed and deaths in Argentina, Colombia, Peru, Chile and Mexico. (a) Confirmed cases. (b) Deaths.

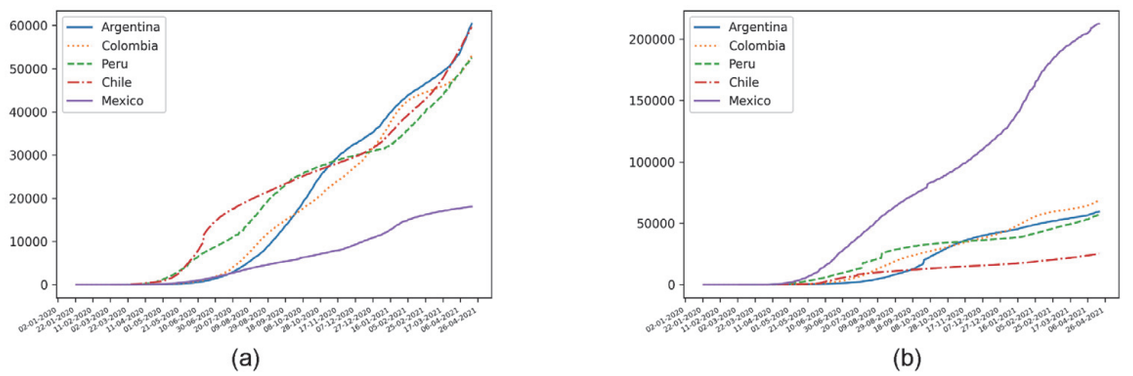

Figure 4.
Evolution of confirmed and deaths per million habitants in Argentina, Colombia, Peru, Chile and Mexico. (a) Confirmed cases. (b) Deaths.

suffer from obesity. More alarming, only 23.5% of the adult population had a healthy weight ($BMI <= 25 kg/m^2$) [14].

3. Vaccination against COVID-19

In this section, we review the main COVID-19 vaccination projects. The effects of virus variants and the impact of vaccination in US, India, France, Russia, Brazil, Argentina, Colombia, Peru, Chile and Mexico.

3.1 COVID-19 variants

Unfortunately, like other viruses, COVID-19 virus evolves over time. Normally, when the virus replicates, it makes copies of itself with little changes (mutations), a virus with one or more mutations is call a"variant" of the original virus. Moreover, the US government inter agency group developed a Variant Classification scheme: Variant of Interest (VOI), Variant of Concern (VOC) and Variant of High Consequence (VOHC) [15]. In **Table 2**, we describe each variant.

In **Table 3**, we resumed the VOI variant of COVID-19, some of them present a reduced neutralization by antibody treatments and convalescent and post-vaccination sera [16–19]. In **Table 4**, VOC variant are presented, for instance B.1.1.7 and B.1.351 have approximately 50% increased transmission [20, 21].

Variant type	Description[a]
VOI	"A variant with specific genetic markers that have been associated with changes to receptor binding, reduced neutralization by antibodies generated against previous infection or vaccination, reduced efficacy of treatments, potential diagnostic impact, or predicted increase in transmissibility or disease severity"
VOC	"A variant for which there is evidence of an increase in transmissibility, more severe disease (e.g., increased hospitalizations or deaths), significant reduction in neutralization by antibodies generated during previous infection or vaccination, reduced effectiveness of treatments or vaccines, or diagnostic detection failures."
VOHC	"A variant of high consequence has clear evidence that prevention measures or medical countermeasures (MCMs) have significantly reduced effectiveness relative to previously circulating variants."

[a]*The definition of each variant was extracted from Centers for Disease Control and Prevention [15].*

Table 2.
COVID-19 variant classification proposed by US government inter agency group.

Variant name	First detected	Variant name	First detected
B.1.526	United States (New York) - November 2020	B.1.526.1	United States (New York) - October 2020
B.1.525	United Kingdom/Nigeria - December 2020	P.2	Brazil - April 2020

Table 3.
COVID-19 VOI variants detected.

Variant name	First detected	Variant name	First detected
B.1.1.7	United Kingdom	P.1	Japan/Brazil
B.1.351	South Africa	B.1.427	United States (California)
B.1.429	United States (California)		

Table 4.
COVID-19 VOC variants detected.

Variants B.1.427 and B.1.429 have 20% increased transmissibility [22]. Moreover, all of VOC variants presents a reduction in neutralization by convalescent and post-vaccination sera. In order to see a detailed description of each variant, visit: SARS-CoV-2 Variant Classifications and Definitions [15].

3.2 Vaccination projects

In order to fight this pandemic, global vaccine development efforts have been accelerated. Clinical development consist of three phases. In Phase I, a small group of people receive the vaccine. In Phase II, the vaccine is delivered for people whose characteristics such as age and physical health are similar to which ones the new vaccine is intended. Finally, in Phase III, the vaccine is given to thousands of people and tested for efficacy and safety [23].

Approximately, there are 56 verified effective vaccines candidates for COVID-19, produced in China, North America, Europe and Australia [24]. Furthermore, thanks to new technologies, it is possible to develop different types of vaccines. In

Vaccine type	Description
DNA vaccine	"DNA vaccines consist in delivering genes or fragments of it, encoding immunogenic antigens to the host's cells by using DNA plasmids as a vector" [25]. Some of these candidates focused in the development of a synthetic DNA-based SARS-CoV-2 S protein [23].
RNA vaccine	RNA vaccines contains RNA, when it is introduced into a tissue, acts as a messenger RNA (mRNA), then it cause the cells to build the foreign protein and stimulate an adaptive immune response [26].
Sub-unit vaccine	A sub-unit vaccine delivers some antigens to the immune system without introducing pathogen particles [27]
Vector-based vaccines	"Viral vectors are commonly utilized together with virus vaccines, in which the genome of one virus is applied to transmit the antigen of another virus, facilitating the advancement of platform system for the creation of viruses" [24].
Inactivated SARS-CoV-2 vaccine	It is another candidate that simulates production of antibodies in rats, mice, rabbits and primates [23].

Table 5.
COVID-19 vaccine types.

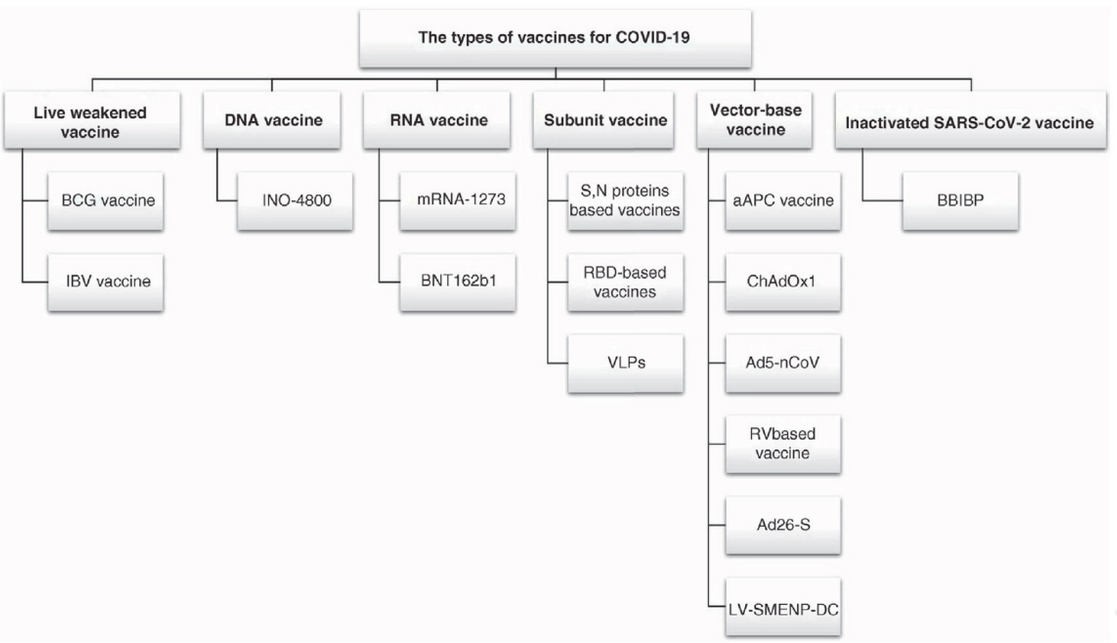

Figure 5.
Types of vaccines for COVID-19. Source: [23].

Table 5, we present the vaccine types for COVID-19. Finally, in **Figure 5**, we present the most important vaccines types against COVID.

3.3 The impact of vaccination

In order to evaluate the impact of vaccination, we analyzed, how the number of total people vaccinated affects the number of confirmed cases and deaths. We took data from a data-set that store information about vaccinations [28] and other that daily store information about the number of confirmed cases and deaths around the world [29]. For instance, in **Figure 6**, we present the relation between the total number of people vaccinated and the total number of confirmed cases and deaths. In this plot, we evaluated US, India, France, Russia and Brazil. Moreover, we

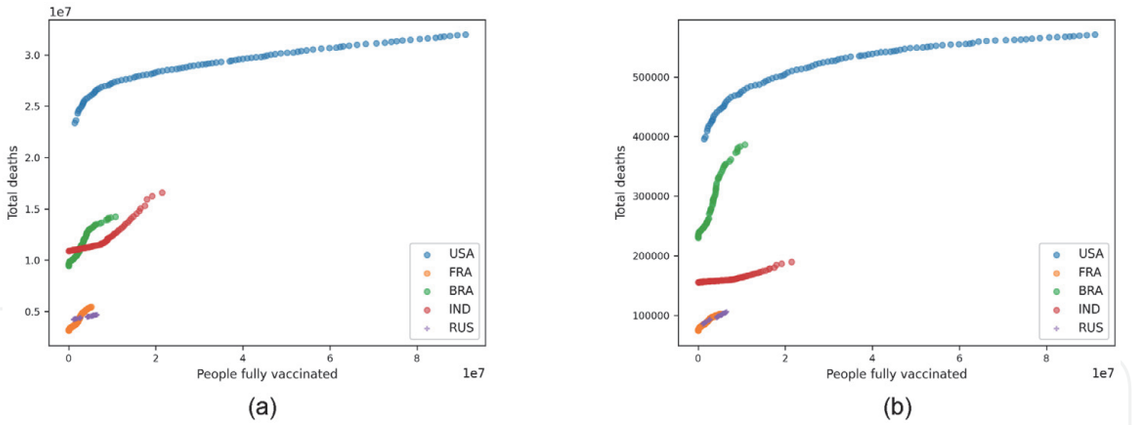

Figure 6.
The effect of vaccination in total confirmed cases and deaths in US, India, France, Russia and Brazil. (a) Confirmed cases. (b) Deaths.

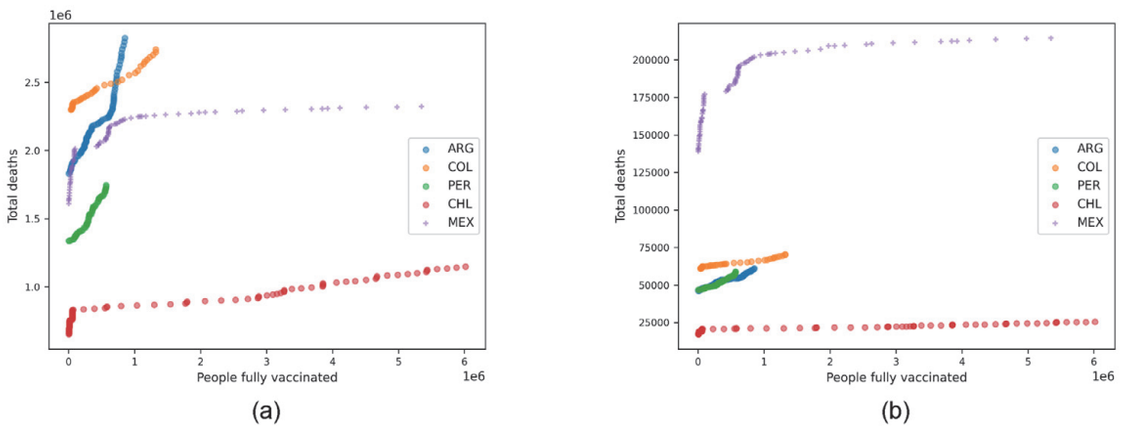

Figure 7.
The effect of vaccination in total confirmed cases and deaths in Argentina, Colombia, Peru, Chile and Mexico. (a) Confirmed cases. (b) Deaths.

noticed the differences between some countries (US is the country with the major number of people vaccinated). Furthermore, we noticed how the number of confirmed cases and deaths were reduced since the vaccination started.

Latin American countries, present a similar behavior. In **Figure 7**, we plotted, how the number of people vaccinated, affect the number of confirmed cases and deaths. In this case, Chile and Mexico are the leaders of vaccination in Latin America. Moreover, the number of confirmed cases and death seems to decrease in this countries.

4. Forecasting COVID-19 confirmed cases

In this section, we evaluated the accuracy of some methods to predict the confirmed cases of COVID-19. In this case we choose Multiplicative Trend Exponential Smoothing (MTES) and Long Short-Term Memory (LSTM), as it was proposed in a previous work [7].

4.1 Multiplicative trend exponential smoothing

The MTES method [30] is usually known to predict non-seasonality data as modeling with a trend in a multiplicative way, differing from the Hold (additive trend) method that considered the trend in a additive way [31]. It's known that on

the real world the majority series have multiplicative trends. The MTES method works with two smoothing parameters designing the local growth rate by smoothing successive divisions from the local level [32].

4.2 Long short-term memory

LSTM is a recurrent neural network [33]. This network introduces the concepts of memory cells (**Figure 8**), this unit is composed of a cell, an input gate, an output gate and a forget gate. This cell remembers values over time intervals, then the other gates regulate the flow of information.

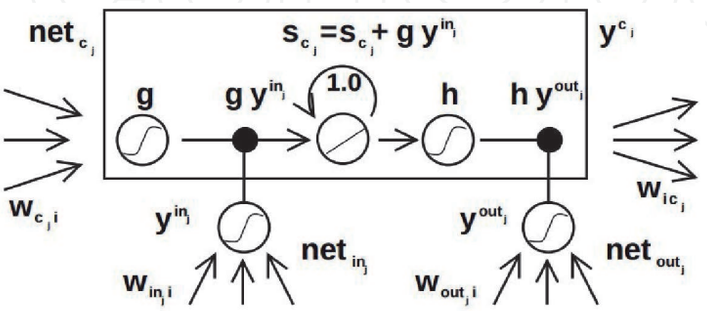

Figure 8.
Architecture of memory cell c_j and its gate units in_j, out_j. Source: [33].

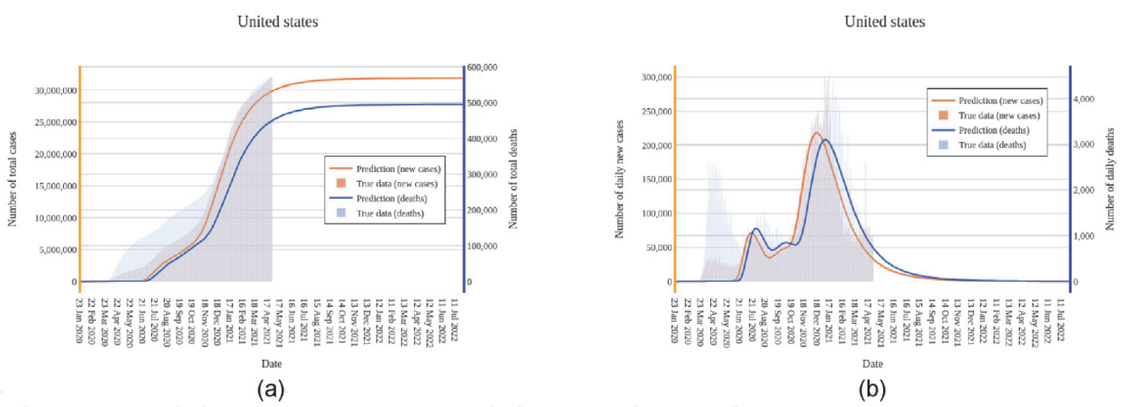

Figure 9.
Prediciton of total and daily confirmed cases in United States, using LSTM. (a) Total confirmed cases. (b) Daily confirmed cases.

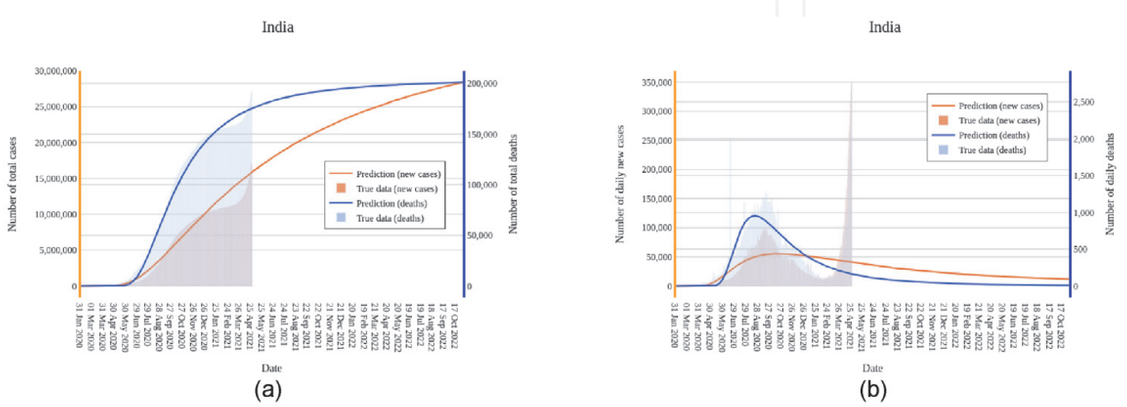

Figure 10.
Prediciton of total and daily confirmed cases in India, using LSTM. (a) Total confirmed cases. (b) Daily confirmed cases.

4.3 Forecasting results

For prediction, we used a Weibull based Long-Short-Term-Memory approach (W-LSTM) [34]. According to the author of W-LSTM, the model outperformed ARIMA and other LSTM variants. Moreover, the network got 82% of accuracy. In **Figures 9–12**, we show the predictions of total confirmed cases and daily cases for

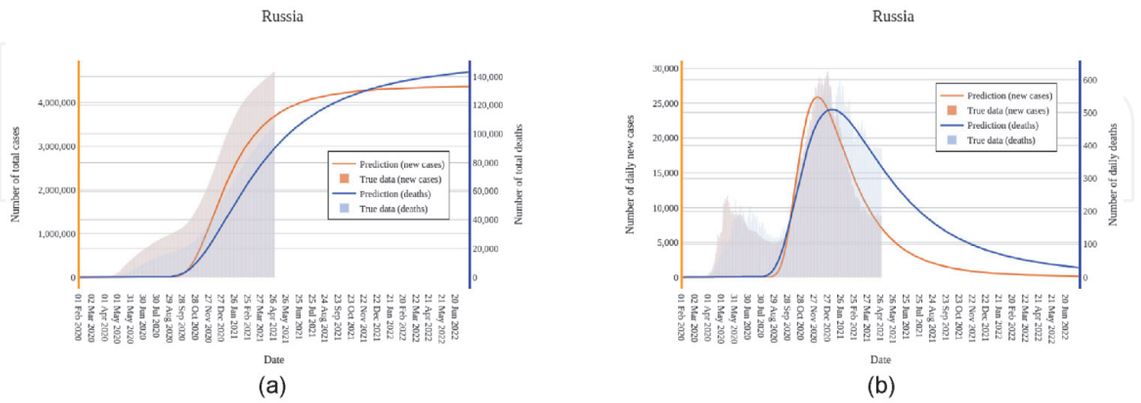

Figure 11.
Prediciton of total and daily confirmed cases in Russia, using LSTM. (a) Total confirmed cases. (b) Daily confirmed cases.

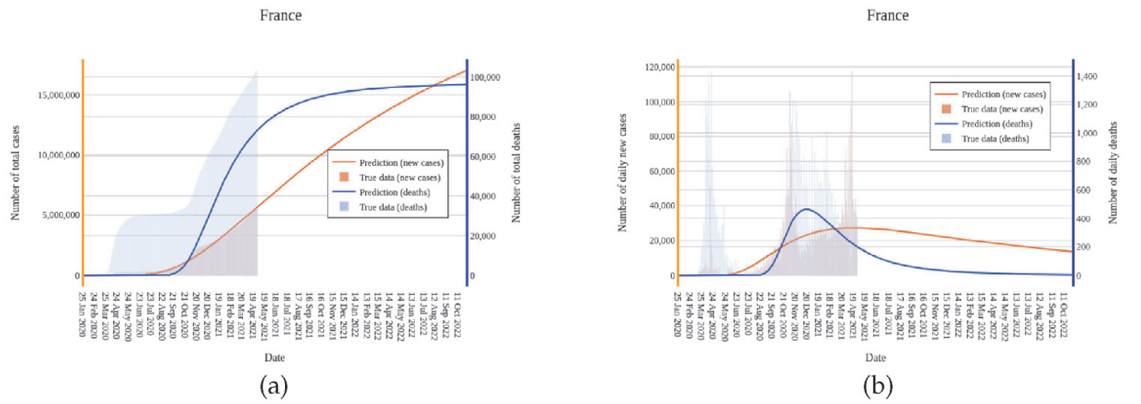

Figure 12.
Prediciton of total and daily confirmed cases in France, using LSTM. (a) Total confirmed cases. (b) Daily confirmed cases.

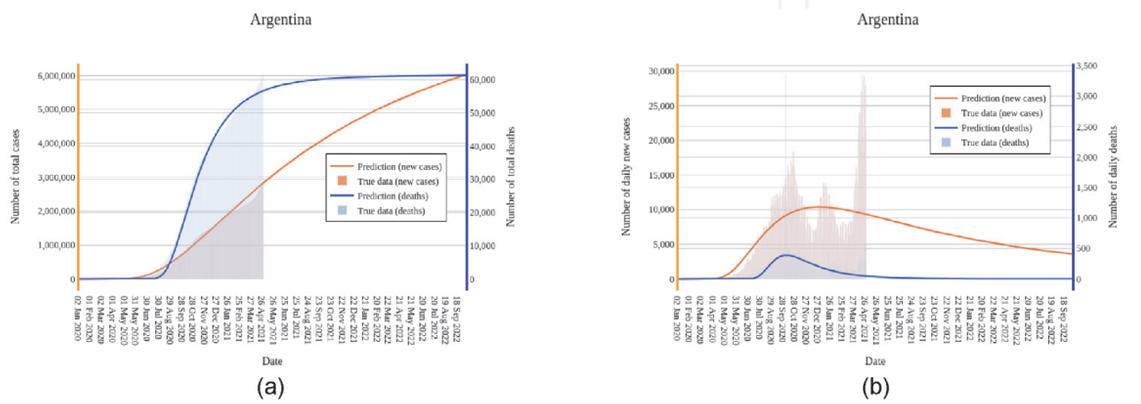

Figure 13.
Prediciton of total and daily confirmed cases in Argentina, using LSTM. (a) Total confirmed cases. (b) Daily confirmed cases.

US, India, Russia and France. Additionally, in **Figures 13–17**, we present the predictions for Latin American countries.

In **Figure 18a**, we plotted the total confirmed cases predictions for US, India, Russia, France and Brazil, using MTES algorithm. Additionally, In **Figure 18b**, we plotted the total confirmed cases predictions for Peru, Argentina, Colombia, Chile and Mexico. We know that, MTES is usually well used for short time series

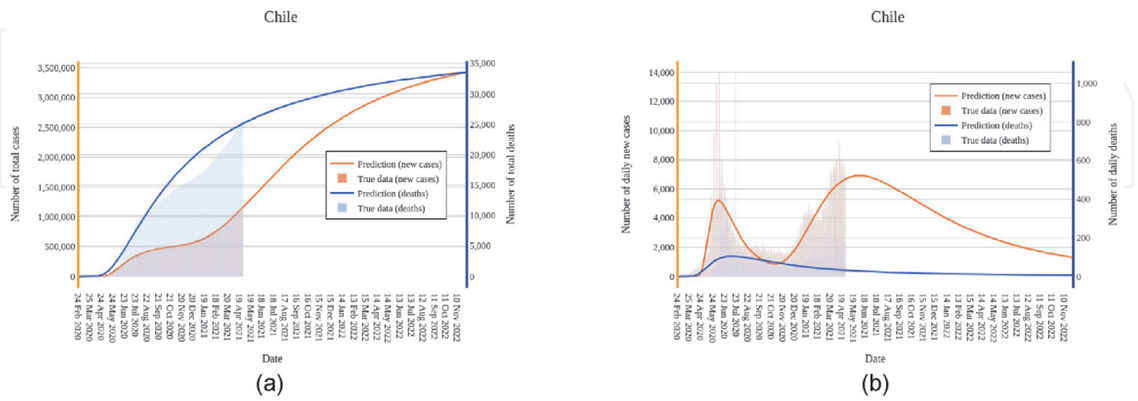

Figure 14.
Prediciton of total and daily confirmed cases in Chile, using LSTM. (a) Total confirmed cases. (b) Daily confirmed cases.

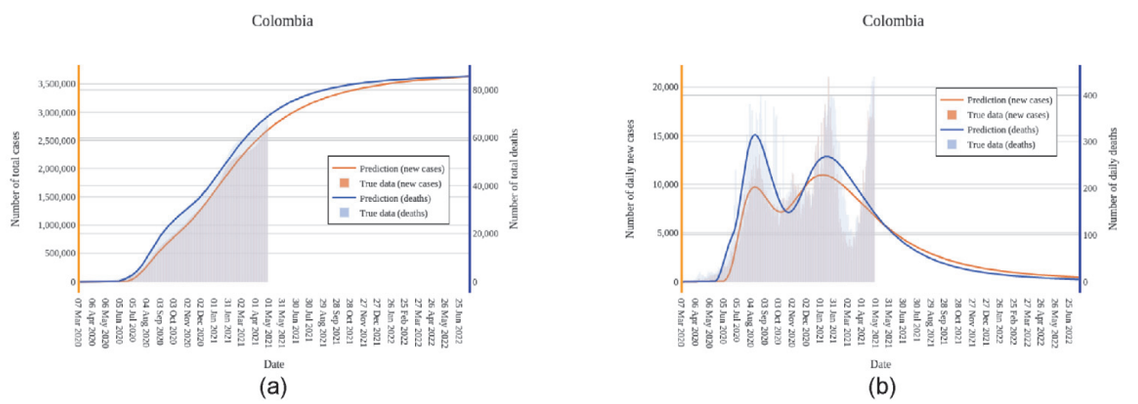

Figure 15.
Prediciton of total and daily confirmed cases in Colombia, using LSTM. (a) Total confirmed cases. (b) Daily confirmed cases.

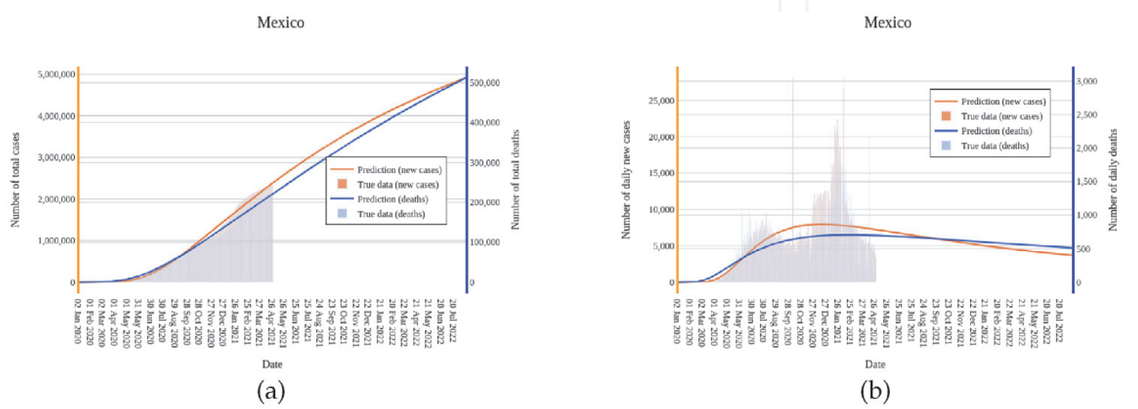

Figure 16.
Prediciton of total and daily confirmed cases in Mexico, using LSTM. (a) Total confirmed cases. (b) Daily confirmed cases.

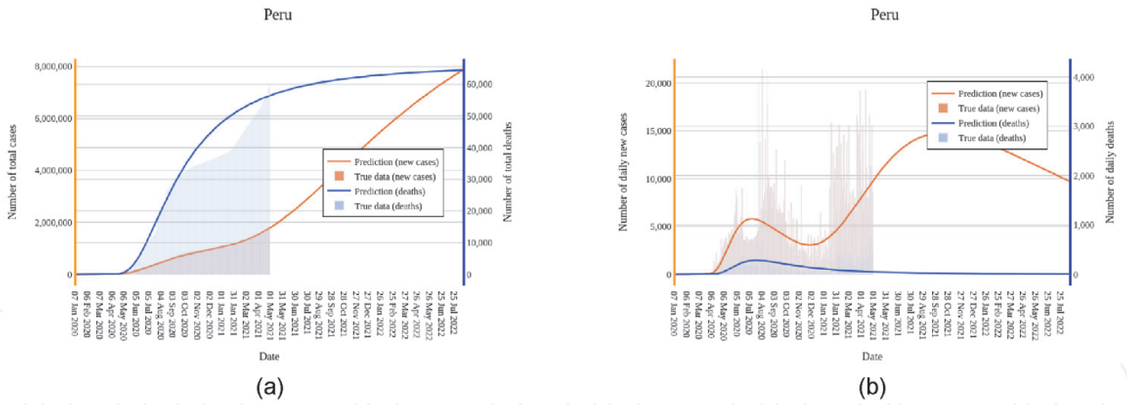

Figure 17.
Prediciton of total and daily confirmed cases in Peru, using LSTM. (a) Total confirmed cases. (b) Daily confirmed cases.

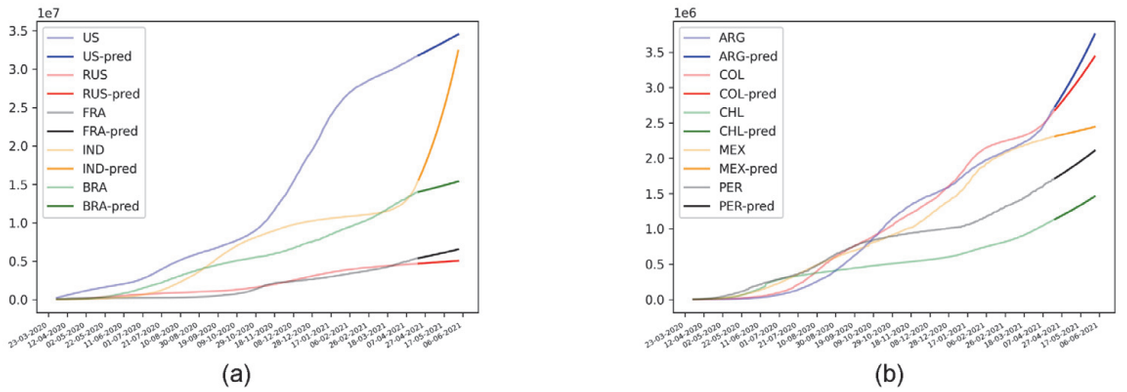

Figure 18.
Prediciton of total and daily confirmed cases in Peru, using LSTM. (a) Predicitons for US, India, Russia, France and Brazil. (b) Predictions for Peru, Argentinca, Colombia, Chile and Mexico.

prediction. For that reason, the India confirmed cases predictions shows an increased trend, due to the increasing behavior during the last weeks.

5. Conclusions

The coronavirus COVID-19 pandemic caused strain on all the world getting abundant deaths and forcing lock downs to contain the spread. However, the scientific community was not left behind because it was developed a lot of projects like vaccines candidates, analysis of the confirmed cases, and forecast of confirmed cases and deaths.

The behavior and evolution of confirmed cases is different for each country. Moreover, there are several factors that increase or mitigate the COVID-19 evolution like: population, health system, social behavior and the overestimation of some authorities. Moreover, in order to evaluate the impact of the pandemic, we need to evaluate the number of confirmed cases, population, deaths, etc. For instance, despite US has the major number of confirmed cases, it has a low death rate of 1.77%.

The death rate, is a good metric to evaluate the impact of COVID-19 over population. For example, we noticed that Mexico has the highest death rate in this study (8.85%). After review, we found out, that the reason of this high death rate, is

the percentage of over weighted people in Mexico (40.2% for males and 36.1% for females). According to researches, obesity is considered the main risk factor of death by COVID-19.

Additionally, we reviewed the variants and vaccination projects for COVID-19. Thankfully, we only have VOI and VOC variants. Furthermore, there are several vaccination projects around the world. Some countries, like US has started a massive vaccination plan, as a consequence, the number of confirmed cases and deaths, show a decreasing behavior.

Finally, we made some predictions. We used W-LSTM and MTES to predict the total and daily confirmed cases in US, India, Russia, France, Argentina, Colombia, Chile, Peru and Mexico. According to the results, W-LSTM showed a more realistic prediction than MTES.

Nomenclature

ARG	Argentina
BRA	Brazil
COL	Colombia
CHL	Chile
IND	India
FRA	Francia
LSTM	Long Short-Term Memory
PER	Peru
RUS	Russia
US	United States
UK	United Kingdom
USA	United States of America
VOI	Variant of Interest
VOC	Variant of Concern
VOHC	Variant of High Consequence

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References

[1] İsmail Kırbaş, A. Sözen, A. D. Tuncer, and F. Şinasi Kazancıoğlu, "Comparative analysis and forecasting of covid-19 cases in various european countries with arima, narnn and lstm approaches," *Chaos, Solitons and Fractals*, vol. 138, p. 110015, 2020.

[2] Google, "Google news covid-19," https://news.google.com/covid19/map?hl=en-US&gl=US&ceid=US:en, accessed: 2020-28-04.

[3] H. Legido-Quigley, N. Asgari, Y. Y. Teo, G. M. Leung, H. Oshitani, K. Fukuda, A. R. Cook, L. Y. Hsu, K. Shibuya, and D. Heymann, "Are high-performing health systems resilient against the covid-19 epidemic?" *The Lancet*, vol. 395, no. 10227, pp. 848–850, 2020.

[4] I. A. Kretchy, M. Asiedu-Danso, and J.-P. Kretchy, "Medication management and adherence during the covid-19 pandemic: perspectives and experiences from low-and middle-income countries," *Research in social and administrative pharmacy*, vol. 17, no. 1, pp. 2023–2026, 2021.

[5] G. Forni and A. Mantovani, "Covid-19 vaccines: where we stand and challenges ahead," *Cell Death & Differentiation*, vol. 28, no. 2, pp. 626–639, 2021.

[6] Covid-19 vaccine tracker. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0277953620308613

[7] M. M. Arceda, P. L. Laura, and V. M. Arceda, "Forecasting time series with multiplicative trend exponential smoothing and lstm: Covid-19 case study," in *Proceedings of the Future Technologies Conference*. Springer, 2020, pp. 568–582.

[8] İ. Kırbas¸, A. Sözen, A. D. Tuncer, and F. S¸. Kazancıoğlu, "Comparative analysis and forecasting of covid-19 cases in various european countries with arima, narnn and lstm approaches," *Chaos, Solitons & Fractals*, vol. 138, p. 110015, 2020.

[9] V. K. R. Chimmula and L. Zhang, "Time series forecasting of covid-19 transmission in canada using lstm networks," *Chaos, Solitons & Fractals*, vol. 135, p. 109864, 2020.

[10] K. ArunKumar, D. V. Kalaga, C. M. S. Kumar, M. Kawaji, and T. M. Brenza, "Forecasting of covid-19 using deep layer recurrent neural networks (rnns) with gated recurrent units (grus) and long short-term memory (lstm) cells," *Chaos, Solitons & Fractals*, vol. 146, p. 110861, 2021.

[11] W. Dietz and C. Santos-Burgoa, "Obesity and its implications for covid-19 mortality," *Obesity*, vol. 28, no. 6, pp. 1005–1005, 2020.

[12] N. Sattar, I. B. McInnes, and J. J. McMurray, "Obesity is a risk factor for severe covid-19 infection: multiple potential mechanisms," *Circulation*, vol. 142, no. 1, pp. 4–6, 2020.

[13] A. M. Rychter, A. Zawada, A. E. Ratajczak, A. Dobrowolska, and I. Krela-Kaźmierczak, "Should patients with obesity be more afraid of covid-19?" *Obesity Reviews*, vol. 21, no. 9, p. e13083, 2020.

[14] S. Barquera and J. A. Rivera, "Obesity in mexico: rapid epidemiological transition and food industry interference in health policies," *The Lancet Diabetes & Endocrinology*, vol. 8, no. 9, pp. 746–747, 2020.

[15] CDC, "Sars-cov-2 variant classifications and definitions," 2021.

[16] S. Jangra, C. Ye, R. Rathnasinghe, D. Stadlbauer, H. Alshammary, A. A.

Amoako, M. H. Awawda, K. F. Beach, M. C. Bermúdez-González, R. L. Chernet *et al.*, "Sars-cov-2 spike e484k mutation reduces antibody neutralisation," *The Lancet Microbe*, 2021.

[17] W. F. Garcia-Beltran, E. C. Lam, K. S. Denis, A. D. Nitido, Z. H. Garcia, B. M. Hauser, J. Feldman, M. N. Pavlovic, D. J. Gregory, M. C. Poznansky *et al.*, "Multiple sars-cov-2 variants escape neutralization by vaccine-induced humoral immunity," *Cell*, 2021.

[18] Regeneron, "Fact sheet for health care providers emergency use authorization (eua) of regen-cov."

[19] E. Lilly and Company, "Fact sheet for health care providers emergency use authorization (eua) of bamlanivimab and etesevimab."

[20] N. G. Davies, S. Abbott, R. C. Barnard, C. I. Jarvis, A. J. Kucharski, J. D. Munday, C. A. Pearson, T. W. Russell, D. C. Tully, A. D. Washburne *et al.*, "Estimated transmissibility and impact of sars-cov-2 lineage b. 1.1. 7 in england," *Science*, vol. 372, no. 6538, 2021.

[21] C. A. Pearson, T. W. Russell, N. Davies, A. J. Kucharski, C. C.-. working group, W. J. Edmunds, R. M. Eggo *et al.*, "Estimates of severity and transmissibility of novel south africa sars-cov-2 variant 501y. v2," *Preprint at https://cmmid. github. io/topics/ covid19/sa-novel-variant. html*, 2021.

[22] X. Deng, M. A. Garcia-Knight, M. M. Khalid, V. Servellita, C. Wang, M. K. Morris, A. Sotomayor-González, D. R. Glasner, K. R. Reyes, A. S. Gliwa *et al.*, "Transmission, infectivity, and antibody neutralization of an emerging sars-cov-2 variant in california carrying a l452r spike protein mutation," *medRxiv*, 2021.

[23] CDC, "Vaccines and immunizations," 2021.

[24] S. H. Shahcheraghi, J. Ayatollahi, A. A. Aljabali, M. D. Shastri, S. D. Shukla, D. K. Chellappan, N. K. Jha, K. Anand, N. K. Katari, M. Mehta *et al.*, "An overview of vaccine development for covid-19," *Therapeutic Delivery*, vol. 12, no. 3, pp. 235–244, 2021.

[25] M. M. Silveira, G. M. S. G. Moreira, and M. Mendonc¸a, "Dna vaccines against covid-19: Perspectives and challenges," *Life sciences*, p. 118919, 2020.

[26] S. Pascolo, "Vaccination with messenger rna (mrna)," *Toll-like receptors (TLRs) and innate immunity*, pp. 221–235, 2008.

[27] M. Mort, A. Baleta, F. Destefano, J. G. Nsubuga, C. Vellozzi, U. Mehta, R. Pless, S. A. Abdoellah, P. Yosephine, S. Karolina *et al.*, "Vaccine safety basics: learning manual," World Health Organization, Tech. Rep., 2013.

[28] B. Hasell J., Mathieu E., "A cross-country database of covid-19 testing," in *Sci Data*, 2020, p. 345.

[29] G. L. Dong E, Du H, "An interactive web-based dashboard to track covid-19 in real time," in *Lancet Inf Dis*, 2020, pp. 533–534.

[30] C. C. Pegels, "Exponential forecasting: some new variations," *Management Science*, pp. 311–315, 1969.

[31] C. C. Holt, "Forecasting trends and seasonals by exponentially weighted averages. carnegie institute of technology," Pittsburgh ONR memorandum, Tech. Rep., 1957.

[32] J. W. Taylor, "Exponential smoothing with a damped multiplicative trend," *International journal of Forecasting*, vol. 19, no. 4, pp. 715–725, 2003.

[33] S. Hochreiter and J. Schmidhuber, "Long short-term memory," *Neural*

computation, vol. 9, no. 8, pp. 1735–1780, 1997.

[34] S. Tuli, S. Tuli, R. Verma, and R. Tuli, "Modelling for prediction of the spread and severity of covid-19 and its association with socioeconomic factors and virus types," *Biomedical Research and Clinical Reviews*, vol. 1, 2020.