# Statistical Prediction of the Evolution of COVID-19 outbreak in Egypt

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Submitted to: JMIR Public Health and Surveillance
on: July 06, 2020

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## *Abstract*

**Background:** The number of confirmed cases of COVID-19 in Egypt has been on the rise.

**Objective:** The development of a reasonable statistical model to predict the evolution of the COVID-19 epidemic is essential in the effort to establish a strategy for flatting the infection curve.

**Methods:** Here we report on the results of the implementation of the susceptible-exposed-infectious-recovered (SEIR) mathematical model on the official data.

**Results:** These results suggest that the peak of the infection curve might be reached on July 27, 2020, with around 820,000 of the cases of infection. Due to restrictions of the diagnosis policy in Egypt, this number is predicted to be lower, i.e. , around 110,000. In addition, the reproduction number will continue to be reduced, largely due to the government countermeasures. It is predicted to achieve approximately 0.611 by the middle of November.

**Conclusions:** Given the continuation of the current measures, the first wave of the outbreak in Egypt is expected to subside. The computational model elaborated here could be readily applied to numerous other countries and their individual geographic regions. Clinical Trial: None

(JMIR Preprints 06/07/2020:22230)
DOI: https://doi.org/10.2196/preprints.22230

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# Original Manuscript

# Statistical Prediction of the Evolution of COVID-19 outbreak in Egypt

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**Abstract**

BACKGROUND The number of confirmed cases of COVID-19 in Egypt has been on the rise. AIMS The development of a reasonable statistical model to predict the evolution of the COVID-19 epidemic is essential in the effort to establish a strategy for flatting the infection curve. METHOD Here we report on the results of the implementation of the susceptible-exposed-infectious-recovered (SEIR) mathematical model on the official data. RESULTS These results suggest that the peak of the infection curve might be reached on July 27, 2020, with around 820,000 of the cases of infection. Due to restrictions of the diagnosis policy in Egypt, this number is predicted to be lower, *i.e.* , around 110,000. In addition, the reproduction number will continue to be reduced, largely due to the government countermeasures. It is predicted to achieve approximately 0.611 by the middle of November. CONCLUSION Given the continuation of the current measures, the first wave of the outbreak in Egypt is expected to subside. The computational model elaborated here could be readily applied to numerous other countries and their individual geographic regions.

**Keywords**: COVID-19; coronavirus; epidemic; outbreak; SEIR model

## 1. Introduction

The fast spread of the COVID-19 pneumonia caused by the SARS-CoV-2 respiratory virus represents a severe challenge for the health care systems worldwide. The outbreak started in Wuhan, China in December 2019, and quickly spread to the rest of the world. On June 4, 2020, the globally estimated cases reached 6,416,828, while Egypt recorded 28,615 confirmed cases and 1,088 total deaths [1]. This epidemic has become a serious threat towards the global public health owing to the extreme contagiousness and the severity of the symptoms of the infection [2].

COVID-19 displays high transmissibility and pathogenicity, and thus the transmission of the virus is thought to primarily proceed via the respiratory droplets. While COVID-19 shows a lower fatality rate (3.7 %) compared to SARS-CoV-1 (10 %), the rate of infection appears to be higher for COVID-19 than for other SARS viruses [3]. In particular, the daily reproduction factor, $R_{t,}$ in Wuhan was calculated to be 1.05 (0.41–2.39) on February 1, 2020 [4]. The early models of the viral transmission dynamics hypothesized that one infectious case could infect approximately two persons; however, the traveling restrictions may reduce this factor to one individual [5]. The high rate of asymptomatic infected individuals is thought to be a major factor that favors this high rate of infectiousness. Moreover, the fatality rate increases directly with age [6]. Despite the fact that the fatality rate is close to 0 % for less than 10 year olds, it increases to 1 and 20 % for people in the 6$^{th}$ and the 9$^{th}$ decades of life, respectively [6].

It was reported in numerous studies that people of all ages are susceptible to infection with COVID-19, and this may lead to mild or acute respiratory diseases, and even cause death [7]. Furthermore, it was reported by Lai *et al.* that the mortality rate depends strongly on the health care resources of the country. Therefore, the risk factors for COVID-19 should be carefully measured by the clinicians. An ideal metric should include the assessment of the critical and the early cases so as to allocate the medical resources accordingly. One such model is of a vital importance in the effort to design a reliable treatment plan so as to improve the health care system competency and reduce mortality risks [8]. By aiding in the understanding of the dynamics of the infection transmission, this model would introduce a grain of rigorous rationality to the current estimations of the epidemiological situation and conceiving of countrywide responses to it. It would allow for the factors that control the spread of the virus to be delineated and directly tackled. This could provide risk expectations and, hence, offer alternative interventions for governments to be taken into consideration.

The Italian population has reported high rates of infection in March and April 2020 [9]. Giordano *et al.* applied a mathematical model to predict the most prospective scenarios and determine the acceptable countermeasures against the outbreak. The model depended on different factors, including susceptible and infected cases, as well as diagnosed people and people under an imminent threat. The results showed that the ongoing social-distancing restriction is required and that it needs to be paired with widespread testing, alongside contact tracing, in order to reach the end of the pandemic [9].

Regarding Egypt, the first case was diagnosed on February 14, 2020. Soon thereafter, Egypt implemented social-distancing measures, prohibiting parties and exhibitions on March 9. Restrictions were then applied to reduce social congregations at work on March 16. The next day, cinemas and theaters were closed. Two days later, on March 19, restaurants, coffee shops, trade centers and night clubs were ordered to be open only during limited hours. On March 24, limited curfew and partial lockdown were applied, which was modified for different times starting from April 8 until present.

Upon the onset of the disease outbreak in Egypt, these preventive measures included carrying out RT-PCR tests using nasopharyngeal swabs for patients with the symptoms and for people who were in contact with the confirmed cases. Hassany *et al.* studied the development of infection in Egypt and demonstrated that due to the absence of open screening, the real number of infections might be higher than the recorded one. To avoid underestimation, the most reliable number, as the authors suggested, could be derived by multiplying the announced one with 7.3 [10].

To correctly predict the spread of the infection, different mathematical models can be used. One of them is the susceptible-exposed-infectious-recovered (SEIR) model, which produces a reliable view for the spread of an infectious disease by utilizing a minimum number of the input data. Herein, the SIR model was used in the form of a set of interdependent linear differential equations. It was developed for the study of the pediatric disease in Chernivtsi, Ukraine in 1988–1989.

Consequently, this work aims to investigate the behavior of COVID-19 and predict the peak of the first wave for the outbreak spread in Egypt with the use of the SEIR statistical model based on the numbers announced by the Egyptian government. The model could be readily applied to numerous other countries and subsets thereof.

## 2. Methods

The SEIR mathematical model was applied for the epidemic dynamics investigation, with the announced numbers being used as the input data. Microsoft Excel was used for data processing.

The SEIR model is expressed by the non-linear system of differential equations

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

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

where $I(t) = e^{(\beta S(t-1) - \gamma) t}$ equals the expected new infections.

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

where S(t), I(t), and R(t) are the number of susceptible cases, the number of infected cases, and the compartment of the removed cases from the disease, respectively, as the function of time, t. β and γ are the contact rate and the removed rate, respectively.

The initial conditions of this model assumed $R(0)=0$ and $S(t)+I(t)+R(t)=N$, where N is the population size. The basic reproduction number $R_0$ is the average number of secondary cases arising from an average number of primary cases in an entirely susceptible population, and it is given by $R_o=\beta/\gamma$, so that:

If $(t)>\frac{\gamma}{\beta}$, $I(t+1)>I(t)$, the epidemic grows;

If $(t)<\frac{\gamma}{\beta}$, $I(t+1)<I(t)$, the epidemic shrinks.

Here, $\frac{\gamma}{\beta}$ is the threshold, and as transmission coefficient, $\beta$, decrease, so does the epidemic shrink.

### 3. Results and discussion

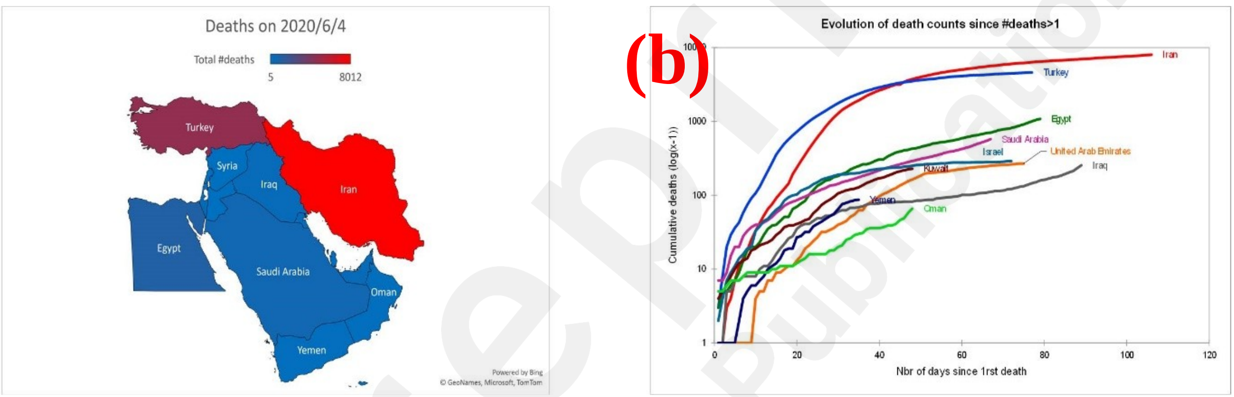


Fig. 1 A comparative representation of the number of deaths due to COVID-19 in selected countries in the Middle East.

As with all theoretical models, there are specific restrictions tied to the implementation of the SEIR model. The contact rate, for example, depends strongly on the province and age; in Germany, for example, it has varied from 7.95 to 19.77, achieving its highest average value of 13 for the younger population of 20 - 60 year olds, with its value being only around 8 for the older population group. In this case, the average value was considered to be around 13.4. The contact rate is highly sensitive to the community interventions; for instance, it was reported that the closing of the schools during the 1918 influenza epidemic had reduced the contact rate by 50 %. Furthermore, isolation of the infected families reduced the contact rate by about 35 %.

Another factor that affects the infection transmission rate is transmissibility, which was obtained from the comparison between the reproduction number ($R_o$) in a normal community setting (1.4 - 3.9) and the one belonging to the Diamond cruise ship, which recorded the highest contact rate (14.8). It was postulated that $R_o$ varies with time, while the transmissibility was constant.

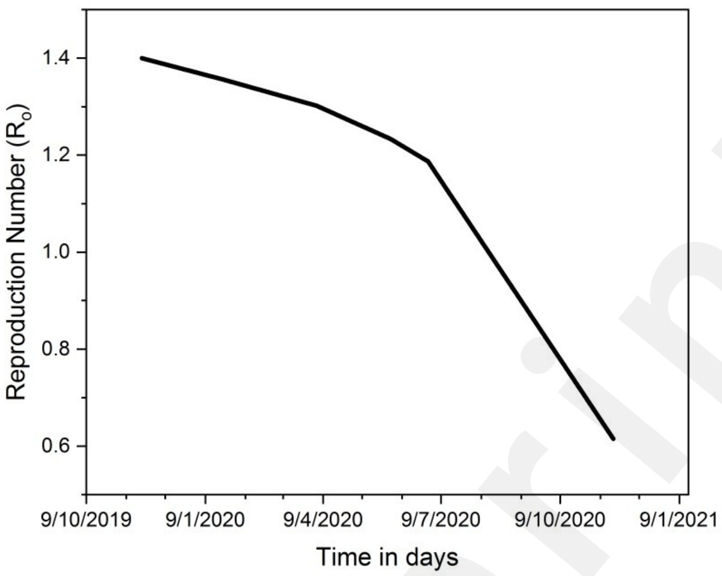


Fig. 2 Variation of the reproduction number ($R_o$) with time.

The reproduction number ($R_o$) itself refers to the secondary infected patients from a single primary case of infection. It could be calculated from the known or postulated contact rate, transmissibility, and removal rate. On top of everything, it presents a good indicator of the efficiency of the community interventions. When $R_o$ decreases to less than 1.0, the virus transmission is in decay. The dependency of $R_o$ on time is illustrated in Fig. 2, from which it could be seen that the range for COVID-19 is 1.4 – 0.6.

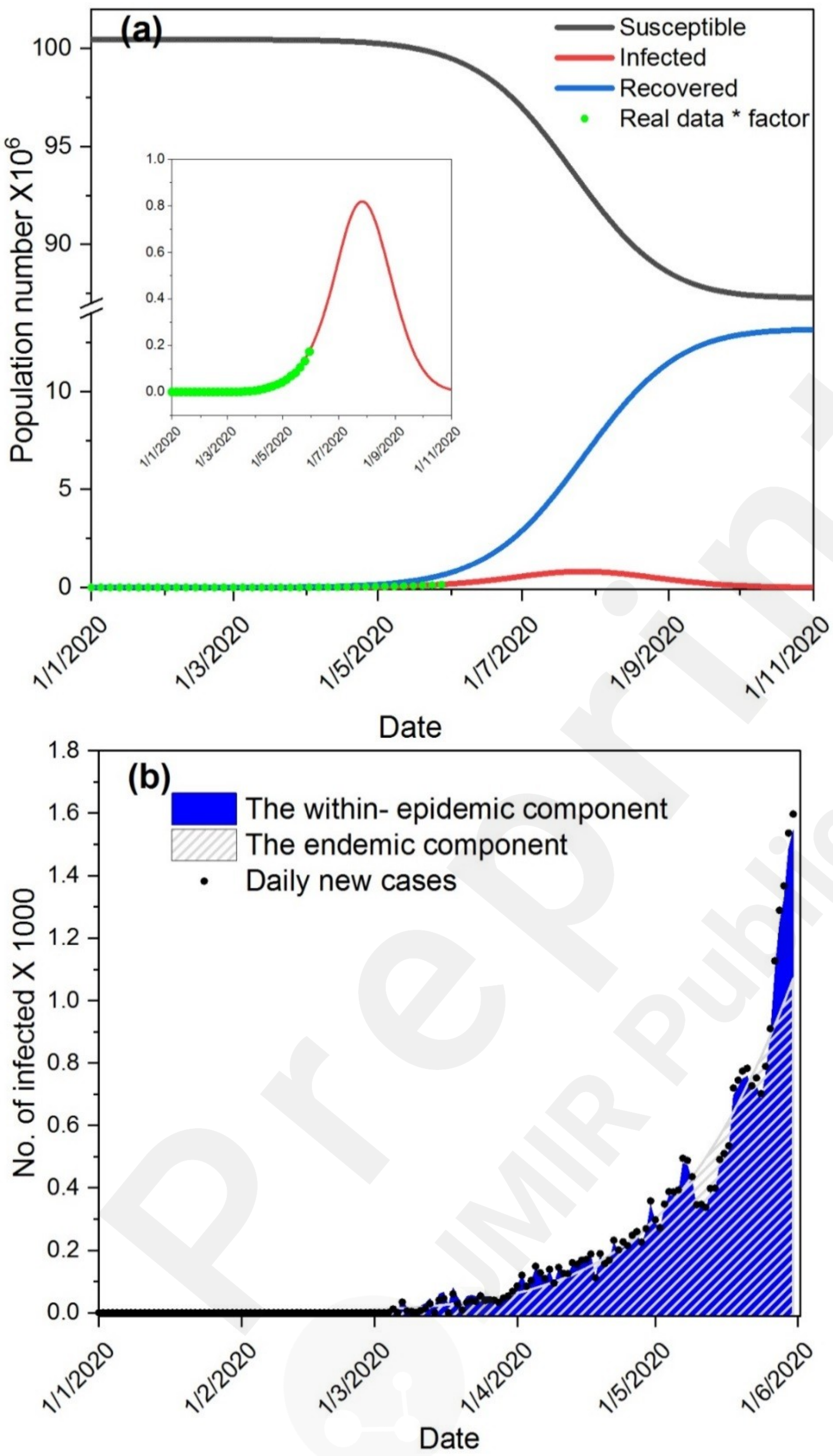


Fig. 3(a, b) The COVID-19 epidemic evolution, including the fitted and the predicted values using the SEIR mathematical model based on the announced data in Egypt.

For the purposes of the implementation of the model, the entire population of Egypt was partitioned into three groups: susceptible (uninfected), infected, and recovered [9]. Three more categories branched out of the infected category, including the patients requiring hospitalization, patients requiring treatment in the intensive care units (ICUs), and patients who succumbed to the disease (*i.e.*, death cases). Although there is a realistic concern that with the high degree of mutation of RNA viruses, the reinfections may occur, the probability of reinfection after the recovery was neglected in order to simplify the calculations. The interaction between the three main stages of the epidemic is clarified in Fig. 3(a, b). Given the timeline of the COVID-19 epidemic in Egypt, the earliest data points were dated February 14, 2020, and were used successively through June 4, 2020. The model predicted the possible scenarios upon the interventions, including social distancing through which the flatting of the epidemic curve could be reached for the first wave of the COVID-19 outbreak.

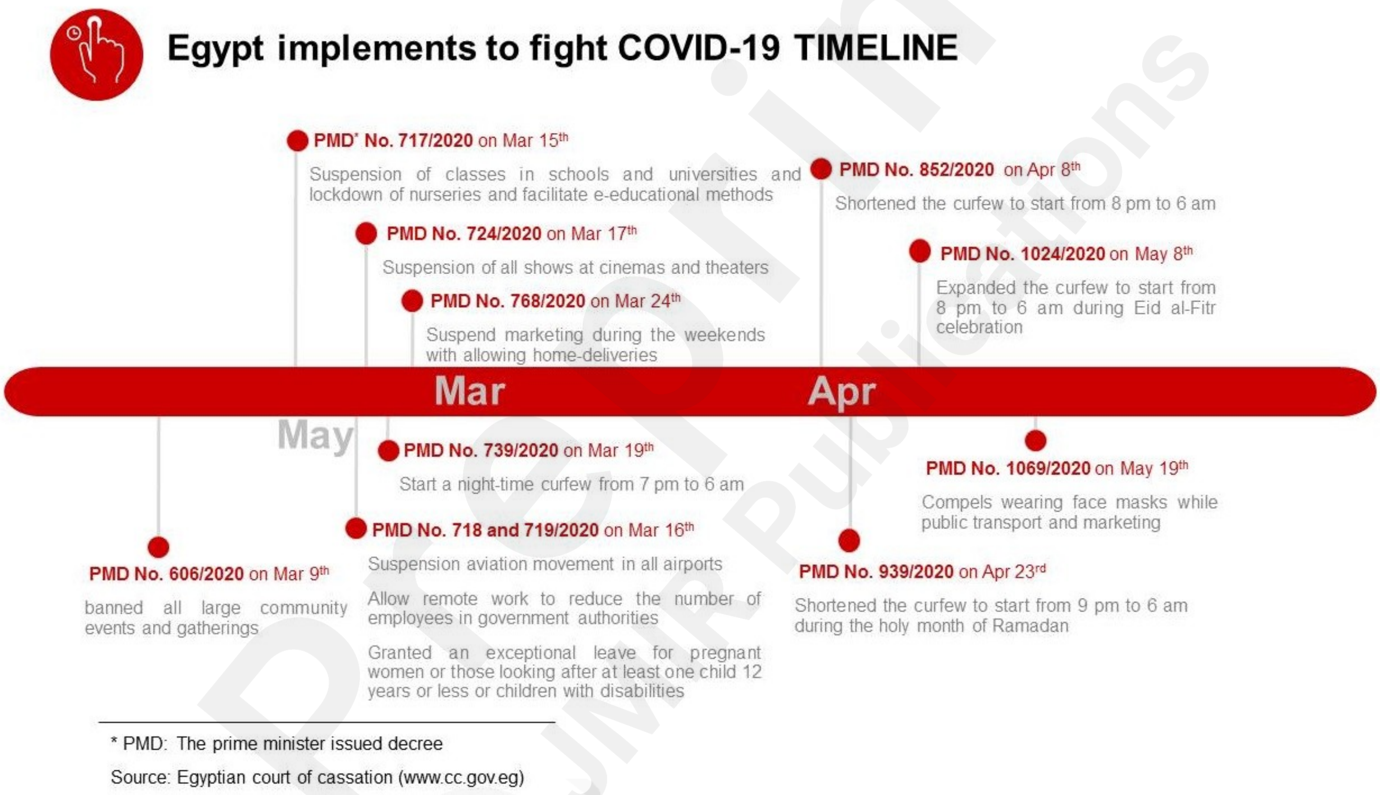


Fig. 4 Development of the official interpretation of the spread of COVID-19 in Egypt

The parameters of the model changed over time due to statewide restrictions, as it can be seen in Fig. 4. For instance, the reproduction number was considered to be 1.4 at the time of the first confirmed case on February 14, 2020, after which it got slightly reduced, reaching 1.3 by March 24, 2020, and then starting to decrease exponentially. The countermeasures, including basic social distancing, were implemented on March 9, 2020, meaning that after only two weeks of these interventions, the effects were measurable. Thanks to these continuously implemented measures, the reproduction number is expected to achieve 0.6 by the middle of November 2020.

It was assumed that the entire population of Egypt (100,459,200) is susceptible to infection with COVID-19. The daily increase in the number of infected cases follows a Gaussian curve, which is expected to reach the peak of the epidemic on July 27, 2020, with 818,900 cases based on the results of this analysis. This value represents the maximum real value of infections predicted by this statistical model. However, due to the restrictions of the diagnosis policy in Egypt, the announced number will be lesser than the expected. Taking into account these restrictions, the number of detected cases at the peak is expected to be 110,936. At this peak of the epidemic, the number of patients requiring hospitalization will not exceed 113,008 cases. In other words, it is predicted from Fig. 3a that 0.815 % of the total population of Egypt will contract the virus, 0.11 % of which will be diagnosed. Fig. 3b further illustrates that the daily number of infections will display a continuous rise in spite of the temporary fluctuations, such as the drops in the infected cases noted for the dates of April 18, May 12, and May 25, 2020, which are obviously associable with the strict restrictions applied countrywide.

## 4. Conclusion

In December 2019, the new human coronavirus, COVID-19, started its spread from Wuhan, China to the rest of the world, where the number of cases of infection has been rising exponentially ever since. The first confirmed case in Egypt was reported on February 14, 2020, and since that day, the daily number of infections has not reached a peak yet. Based on the reported infection numbers, the susceptible-exposed-infectious-recovered (SEIR) statistical model was applied here to predict the evolution of the COVID-19 epidemic in Egypt. The model demonstrated that the social distancing and the official statewide interventions reduced the number of infections significantly. Furthermore, the highest number of the infected cases is expected to be reached on July 27, 2020, with around 820,000 cases, translating to circa 110,000 diagnosed cases due to the restrictions of the diagnosis policy. The reproduction number is predicted to decrease exponentially, reaching 0.611 by the middle of November, indicating the inhibited spread of the virus.

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