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Predicting the Progress of COVID-19: The Case for Turkey

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COVID-19 has proven to be the worst pandemic in modern times in terms of both mortality and infectiousness since the flu pandemic that took place in the early 20th century, which is also known as the Spanish Flu. First being detected in China on December 8, 2019, the COVID-19 disease has spread swiftly into other countries and continents, which eventually led to its classification as "pandemic" by the World Health Organization (WHO) on March 12, 2020.[1,2]

After the first confirmed case in Turkey was detected on March 11, 2019, the number of confirmed cases has increased rapidly and reached 95,591 as of April 21, 2020, according to the Ministry of Health - Turkey.[3]

In order to devise an appropriate policy response, it is imperative to forecast the progress of the pandemic in the coming days, weeks, and months. For instance, if the maximum number of infected people can be predicted, then it will be easier to gauge whether the capacity of healthcare institutions will be sufficient, particularly in terms of ER units and ventilators. Another critical decision is the timing for easing and eventually lifting limitations such as curfews and closure of schools and businesses. If the limitations are eased and/or lifted prematurely, then there is a substantial risk of rebound. On the other hand, as long as such limitations remain, economic hardship for millions of people is exacerbated. Hence, the optimal policy response demands a prediction model, which is aimed in this manuscript.

We have employed the SIR model to forecast the progress of COVID-19 in Turkey. The SIR model is a deterministic compartmental model that tries to simplify the mathematical modeling of infectious diseases. Its origins date back to the early 20th century, the seminal work by Kermack and McKendrick.[4] Although deterministic models are simpler than their alternatives, such as stochastic models or agent-based simulation models, a deterministic model is more appropriate in this case. Stochastic models are more suitable for smaller populations, whereas agent-based simulation models require numerous parameters to be estimated, and they are also more difficult to interpret and perform sensitivity analysis on.[5]

The SIR model divides the population into three homogeneous compartments. S stands for the number of susceptible individuals, whereas I and R cor-

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respond to the number of infected and removed individuals, respectively. Removed individuals are those who either recovered or lost their lives so that they can no longer transmit the disease. The SIR model is governed by three differential equations which define the change in these variables with respect to time:

$$\frac{dS}{dt} = -\beta SI \qquad (1)$$

$$\frac{dI}{dt} = \beta SI - \gamma I \qquad (2)$$

$$\frac{dI}{dt} = \gamma I \qquad (3)$$

The parameters and have been estimated by fitting the model to the data disclosed by the Ministry of Health-Turkey as of April 21, 2020. In our modeling efforts, these parameters can be adjusted as new data become available.

The results of our simulations are depicted in the following graphs (Figure 1, Figure 2). Figure 1 is on a linear scale, whereas Figure 2 uses a logarithmic scale to provide more detail, especially in the initial exponential growth phase.

As depicted in the second graph, the number of infected people peaks on May 6, 2020. At this point, the maximum number of infected people is estimated at approximately 4.3 million.

The answer to the second question pertaining to the timing for easing and eventually lifting limitations is less obvious. A useful measure for the current infectiousness of a disease is the effective reproduction number, R_e, which is the number of people in a population who can be infected by an individual at any specific time. It is not constant and it changes as the pandemic further spreads. The developed model assumes immunization of recovered individuals only for the short term, as longer term immunization is still unknown.[6] It can also potentially be affected by social distancing and hygiene measures, among other cultural and country-specific factors.

WHO suggests that the value for R_e should be equal to or less than 1.0 to alleviate the measures imposed by governments without further potential distress on their healthcare systems. When R_e is larger than 1.0, the outbreak continues its growth exponentially. Meanwhile, subsequent to the various social distancing measures implemented for taking the COVID-19 spread under control, the German, Czech, and Norwegian authorities have declared this threshold level to be 1.0, 1.0, and 0.7, respectively.[7-9] By April 22, 2020, our model estimates the current value of R_e for Turkey as 1.4. It is probable that the social distancing measures implemented in Turkey will further decrease R_e as time proceeds for evidencing their impact; however, close monitoring of R_e is paramount.

We recommend that the pace of the pandemic should be closely monitored by continuously estimating the effective reproduction number before any decisive decision regarding limitations. Even if the

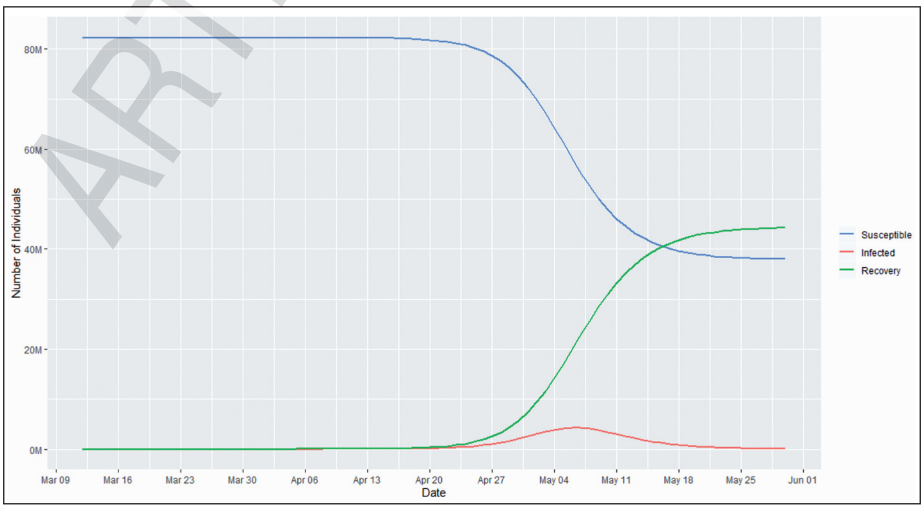

FIGURE 1: SIR Model for COVID-19 in Turkey (Linear Scale).

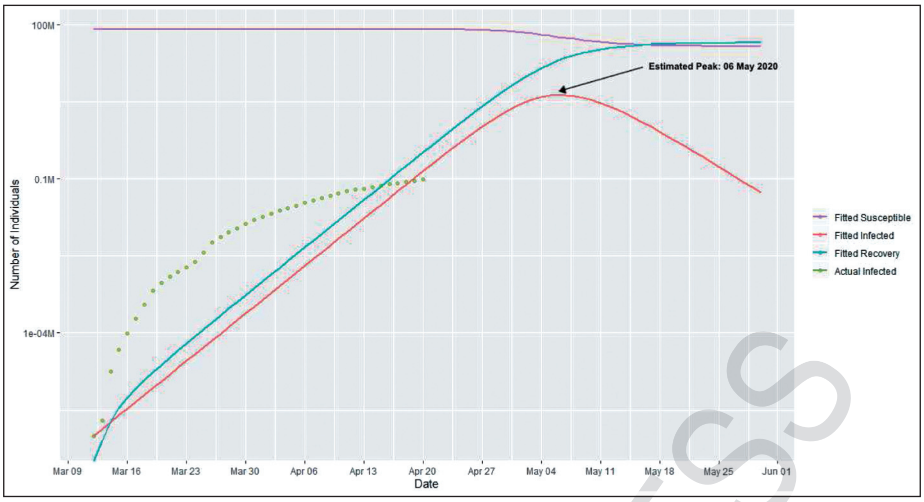

FIGURE 2: SIR Model for COVID-19 in Turkey (Logarithmic Scale).

pandemic subsides, it is not clear whether and/or when it will resurface again. Direct and indirect efforts such as detection of traces in wastewater should be focused on the estimation of near future R_e levels. Similarly, more research is needed for understanding the effectiveness of social distancing measures in reducing R_e levels considering different country and cultural contexts. Moreover, the question surrounding the identification of "*any human studies directly addressing whether infection with SARS-CoV-2 results in immunity and protection against re-infection*" persists.[10] If the case of COVID-19 is going to resemble that of common cold or influenza in terms of the lack of long-lasting immunity, the next phase of COVID-19 research should focus on models such as the SIS model which can account for the transition from the susceptible to infectious and, then, back to susceptible states upon recovery.

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