A Simple Dynamic Model for Daily New Cases of COVID-19

Abdallah Abusam[1]

1 Kuwait Institute for Scientific Research

Funding: No specific funding was received for this work.
Potential competing interests: No potential competing interests to declare.

Abstract

A simple dynamic model is proposed for modeling the COVID-19 pandemic based on the number of daily new cases rather than their cumulative sum. The developed model was tested using data from the pandemic in the GCC countries. The model was found to fit well both single and multiple waves when both smoothed and unsmoothed profiles of the pandemic were used.

Abdallah Abusam

Water Research Centre, Wastewater Treatment and Reclamation Technology Program, Kuwait Institute for Scientific Research, P.O. Box 24885, Safat 13109, Kuwait

(E-mail: aabusam@kisr.edu.kw)

Keywords: Epidemics, COVID-19, Modeling, Dynamics, Data filtering.

Introduction

Several types of logistic and other compartmental models have been used for modeling the cumulative numbers of individuals infected with the innovative Coronavirus (COVID-19) pandemic (Liu 2020; Ma 2020). However, most parameters of these models do not have a physical meaning and they cannot be accurately identified from the data (Abusam et al., 2020). Moreover, the simulation of the profiles of the cumulative sum of confirmed cases does not provide much information about the dynamics of the epidemic (e.g. growth rate, decline rate, turning point). Therefore, most of these models do not provide reliable predictions (Rod et al., 2020).

By contrast, the curves of cumulative numbers of cases, and the profiles of daily new cases can be used to estimate the growth and decline rates of epidemics (Musa et al., 2019; Li et al., 2020; Rasjid et al., 2021; Abusam, 2022). Moreover, the various growth phases of the epidemic (lag, exponential, stationary, and decline phases) can be identified from profiles of daily new cases (Abusam, 2022).

This paper presents a new simple dynamic model that can be used for modeling the COVID-19 pandemic from the number of daily new cases.

Model Development

It has been shown previously that the smoothed curves of COVID-19 daily confirmed cases show clear trends of exponential growth and decline rates of the pandemic waves (Musa et al., 2019; Li et al., 2020; Pinto et al., 2020; Abusam, 2022). Further, the smoothed profile of the daily cases is similar to the curve of bacteria growth in a batch reactor. It can also be described by the four basic growth: lag phase, exponential phase, stationary phase, and death phase (Abusam 2022). To develop a dynamic model for the COVID-19 outbreak based on the similarity with bacterial growth, the following assumptions were made:

1. At the start of an outbreak wave, the reported (recorded) number of infected individuals (x) is only a small part of the actual number of infected persons who were unreported (s). The unreported persons (s) represent the carriers who are undiagnosed.
2. Due to behavioral response and implementation of a control measure, the number of unreported cases (s) decreases constantly with time by a rate equal to λ,
3. The number of reported cases (x) grows exponentially with time at a rate equal to r_g. But it stops increasing when the number of unreported cases becomes zero (s=0). Beyond that point in time, the of daily infected persons starts to decrease exponentially by a rate equal to r_d.

The profile of the unreported cases (s) can thus be modelled by as:

$$\frac{ds}{dt} = -\lambda s \qquad (1)$$

To switch off the growth of the confirmed cases (x) when the number of unreported cases is zero (s=0), a simple switching function $\left(\frac{s}{k+s}\right)$, as in the Monod equation, can be used. With a very small value of k, this function will switch off the growth in confirmed cases when s is zero, while it will not affect values of x when it is greater than zero.
Therefore, the confirmed daily cases can be written as:

$$\frac{dx}{dt} = r_g x \frac{s}{k+s} - r_d x \qquad (2)$$

This model (equations 1 and 2) has only four unknown parameters (r_g, λ, k, k). Values of these unknown parameters can be estimated from data using the non-linear least square method.

Model Application

The developed model was tested using COVID-19 data from February 2020 to September 2021 for the GCC countries, (Worldometer 2020). First, the model was fitted to the smoothed profiles of the first wave in six GCC countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and UAE), using the Matlab function nonlinsq. The smoothed profiles of the pandemic were obtained using the Savitzky Golay filter (Fig. 1). For multiple waves, the model was then fitted to the multiple waves of the pandemic that occurred in Kuwait.

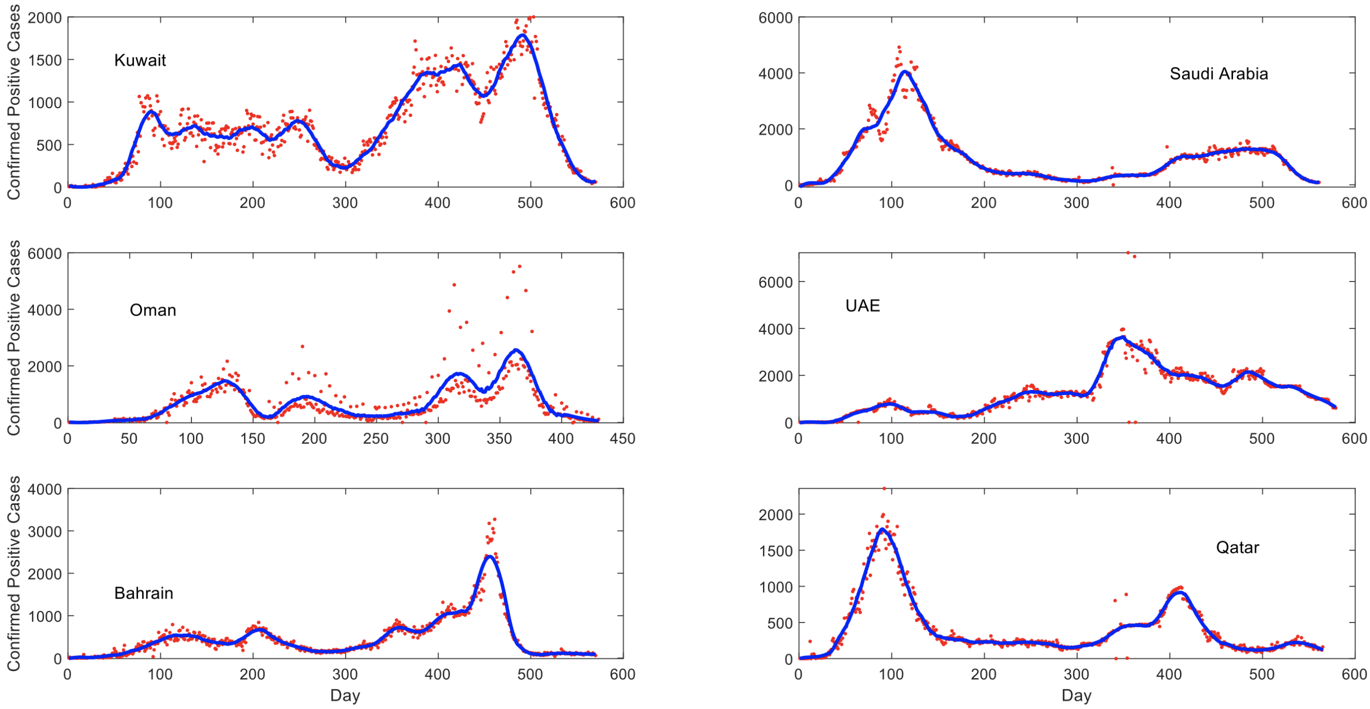

Figure 1. *Savitzky-Golay smoothed curves of daily data for COVID-19 in GCC countries (Source: Abusam, 2022).*

The initial guess values of r_g and r_d were calculated from the approximately straight lines of growth and decline phases for waves of the pandemic, as the natural log of the difference between two recorded values divided by the difference in time of occurrence. Initially, k was assumed to be equal to 0.03, while λ was assumed to be equal to 0.2.

At the start of each wave, initial number of confirmed cases (x_0) was assigned the value of the first recorded number of confirmed cases, while the initial number of unreported cases (s_0) was assigned an arbitrary number that is higher than x_0.

Discussion

The results from fitting the model to the first smoothed profiles of the pandemic in the GCC countries are presented in Figures 2 to 7. These figures illustrate how well the model fits the smoothed profiles of the first wave without excluding the lag phase. A further improvement in the fit can be achieved by excluding the lag phase.

In Table 1, it is shown that the value of the initially unreported cases (s_0) differed by country (ranging from 2,000 to 10,000 cases), while its rate of decline (λ) ranged from 0.12 to 0.17. Additionally, Table 1 shows that the rate of growth and decline rates (r_g and r_d) of the pandemic during the first wave ranged between 0.05-0.10 and 0.01-0.03. The value of k was found to be between 0.01 and 0.06. As a result of such a small value, the epidemic will only cease to grow once the turning point has been reached (s = 0), but it will not be affected prior to that point.

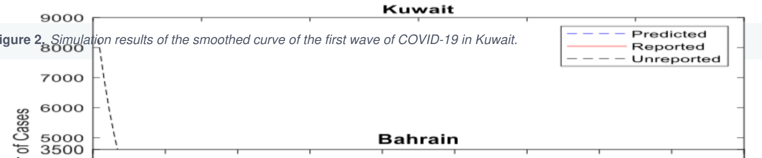

Figure 2. *Simulation results of the smoothed curve of the first wave of COVID-19 in Kuwait.*

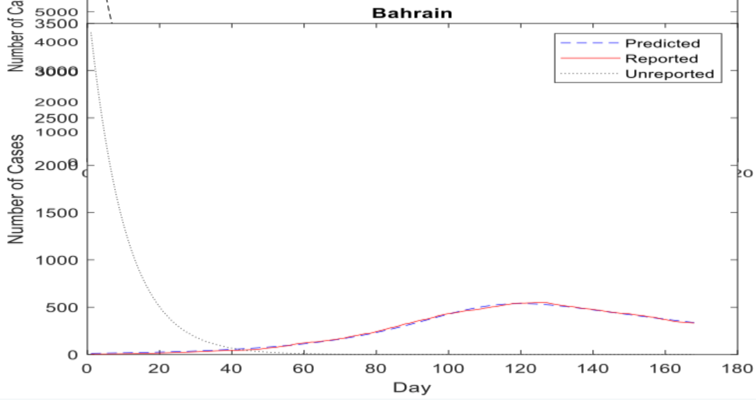

Figure 3. *Simulation results of the smoothed curve of the first wave of COVID-19 in Bahrain.*

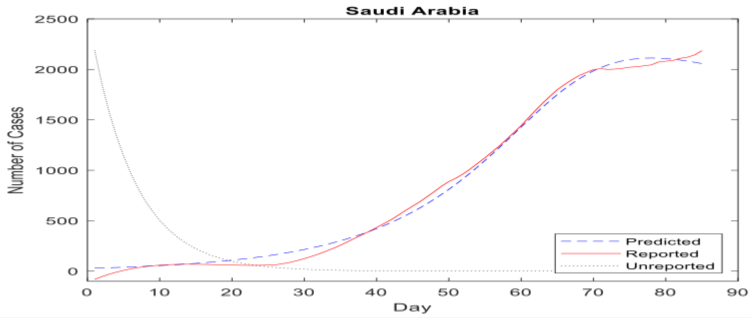

Figure 4. *Simulation results of the smoothed curve of the first wave of COVID-19 in Saudi Arabia.*

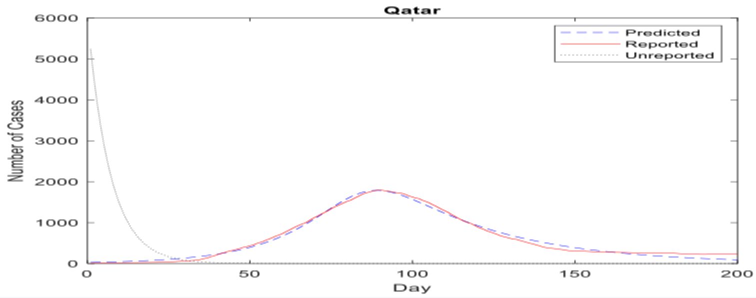

Figure 5. *Simulation results of the smoothed curve of the first wave of COVID-19 in Qatar.*

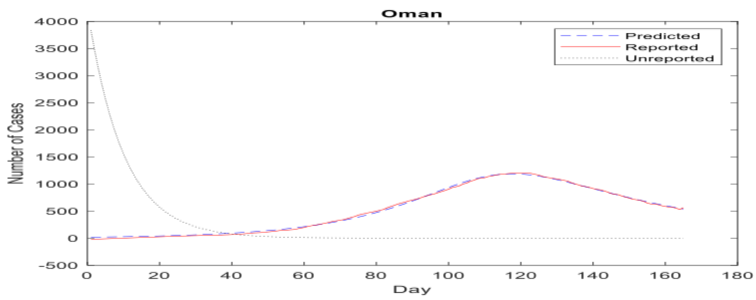

Figure 6. *Simulation results of the smoothed curve of the first wave of COVID-19 in Oman.*

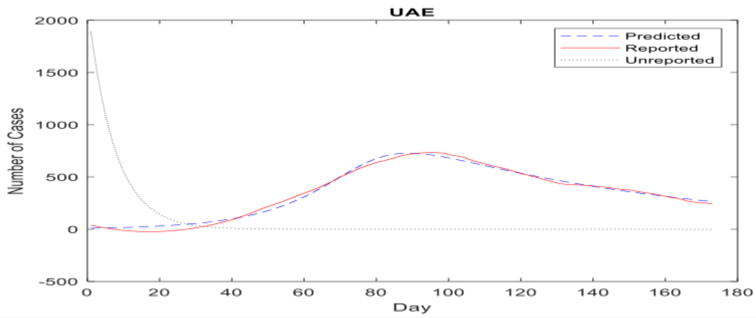

Figure 7. *Simulation results of the smoothed curve of the first wave of COVID-19 that occurred in UAE.*

Table 1. Values of the model's parameters during the first wave

Country	s_0	r_g	r_d	λ	k
Kuwait	8281.28	0.10	0.02	0.17	0.01
Oman	3833.36	0.06	0.02	0.10	0.06
Bahrain	9722.27	0.05	0.02	0.12	0.01
Saudi	2186.46	0.08	0.01	0.16	0.05
Qatar	5235.31	0.08	0.03	0.14	0.03
UAE	8137.61	0.06	0.01	0.16	0.01

Fig. 8 illustrates the results of fitting the model to the multiple waves that occurred in Kuwait when a smooth profile of daily new cases was used to simulate the dynamics. The model appears to fit very well. As expected, this figure also reveals that the number of unreported cases differs from wave to wave.

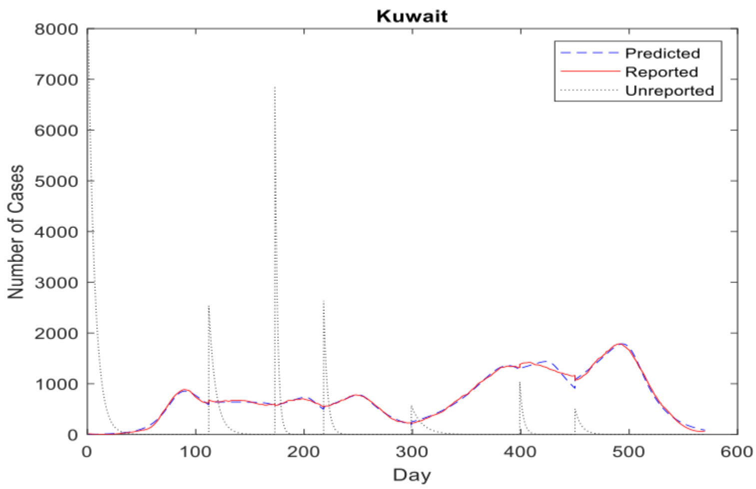

Figure 8. *Simulation results of the smoothed curves of the seven COVID-19 waves that occurred in Kuwait.*

Table 2 presents the estimated values of the model's parameters for the seven waves observed in Kuwait, as simulated by filtered data (case 1) and unfiltered data (case 2). During case 1, the initial values of unreported cases (s_0) varied from one wave to another and ranged from about 500 to 8,3000. However, the decline rate of unreported cases during wave 4 was higher than that estimated for the first wave in all GCC countries (Table 1). The estimated values for the other parameters are within the same ranges as those reported above for the first wave of the pandemic in the GCC countries.

Table 3. Values of model parameters for the seven waves occurred in Kuwait, when fitted to smoothed data (case 1) and unsmoothed data (case 2)

Wave	s_0		r_g		r_d		λ		k	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
1	8281.28	7612.82	0.10	0.09	0.02	0.03	0.17	0.16	0.01	0.01
2	6827.10	4115.50	0.05	0.05	0.06	0.06	0.10	0.10	0.01	0.02
3	4683.19	9872.13	0.06	0.03	0.05	0.02	0.10	0.51	0.01	0.01
4	2637.34	500.13	0.05	0.05	0.03	0.04	0.30	0.24	0.06	0.07
5	572.70	7224.57	0.04	0.03	0.02	0.01	0.10	0.16	0.08	0.01
6	4867.69	4427.85	0.06	0.03	0.05	0.03	0.13	0.35	0.03	0.03
7	505.28	2953.75	0.06	0.06	0.05	0.05	0.17	0.23	0.07	0.07

Case 1: smoothed data; Case 2: unsmoothed data.

The results of the simulations of all seven waves that occurred in Kuwait are presented in Figure 9. This figure illustrates that the developed model can also be used to fit unfiltered daily new case data. In spite of the relatively different values of s_0 and λ, estimates of the growth and decline rates of the epidemic were within the same range as the estimates obtained when filtered data was simulated (Table 2). According to figure 10, the same growth rate, decline rate, and turning points were obtained when unfiltered and filtered data were used in the simulation. This may indicate that the model can be used to simulate unsmoothed data as well.

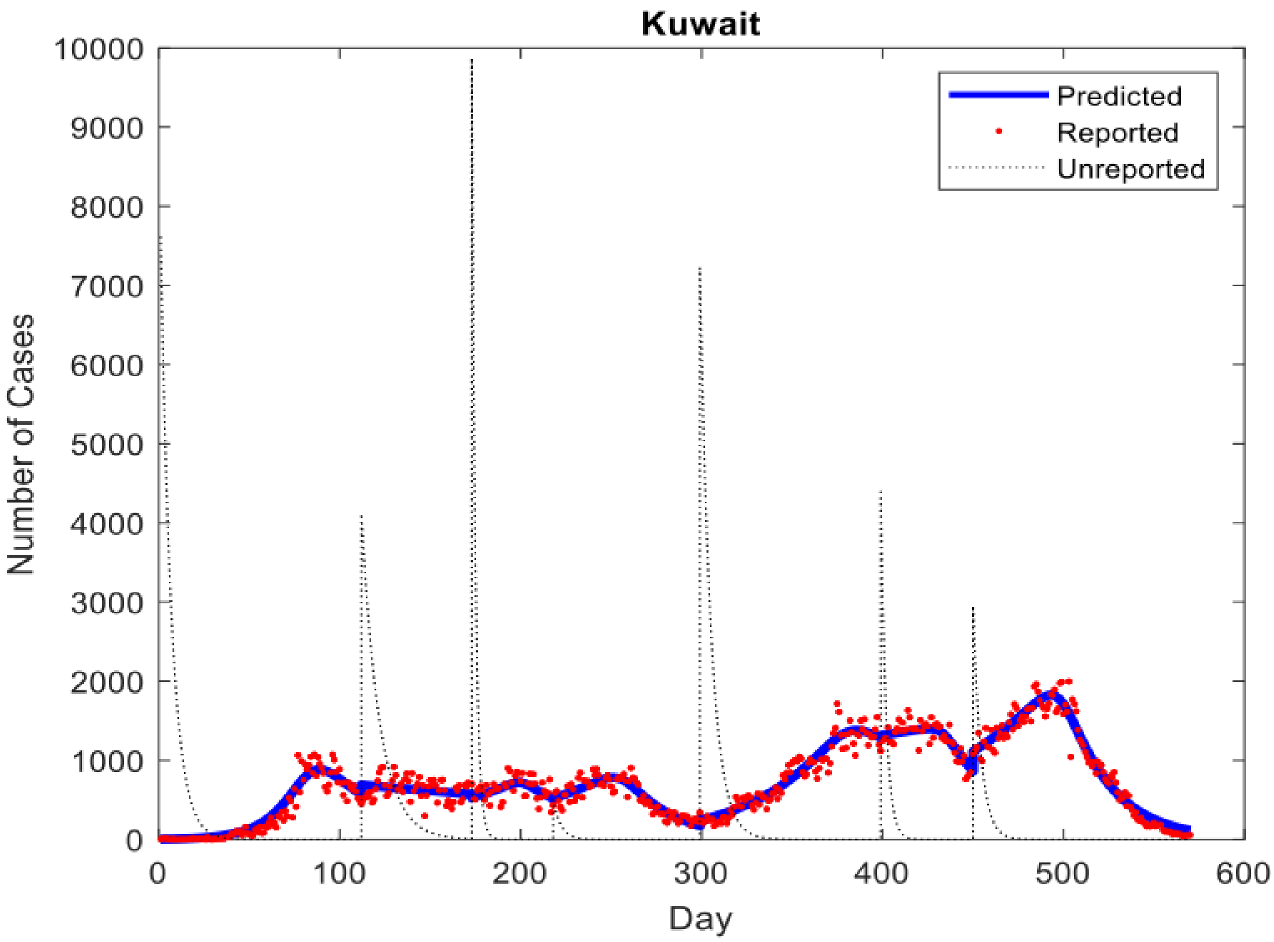

Figure 9. *Simulation results of the seven COVID-19 waves that occurred in Kuwait, using unsmoothed data used.*

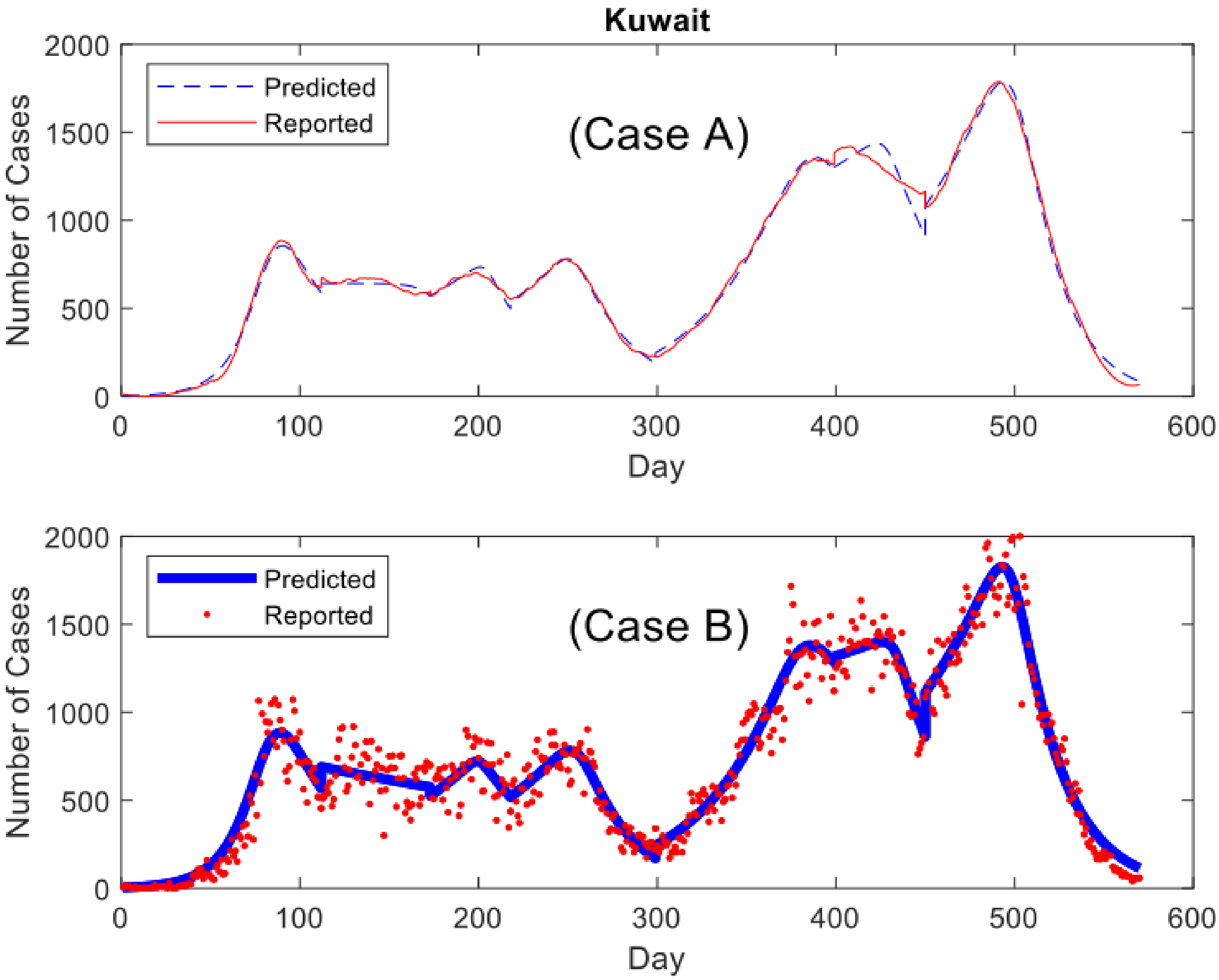

Figure 10. *Results of model fit to epidemic waves that occurred in Kuwait. Case A: fitting to smoothed data. Case B: fitting to unsmoothed data.*

According to the proposed model, the growth of an epidemic is directly related to the number of undiagnosed and thus unreported cases at the beginning of the epidemic, (s_0). As a result of this assumption, it has been possible to recognize and explain the different phases of the pandemic in GCC countries in a physically meaningful manner. This assumption, however, needs to be supported by more studies. It should be noted that the number of unreported persons (s_0) was found to represent only a small portion of the population of the GCC countries represents. During the seven epidemic waves in Kuwait, s0 ranged from 505 to 8281 people, which represents less than 0.2% of the population.

References

- Abusam A. Dynamics of COVID-19 in the Gulf Cooperation Council (GCC) countries. J Taibah Univ Med Sc 2022;17(3):461-466.
- Abusam, A., Abusam, R. and Al-Anzi, B. (2020). Adequacy of Logistic Models for Describing the Dynamics of COVID-19 Pandemic, Infectious Disease Modelling, 5:536-542.
- Li Q, Guan X, Wu P, Wang X, Zhou L, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. New Engl J Med. 2020. https://doi.org/10.1056/NEJMoa2001316
- Lin, X., Hewings, G., Zheng, S. and Li, X. (2020). Modeling the situation of COVID-19 and effects of different control strategies in China with dynamic differential equation and parameter estimation. https://www.researchgate.net/publication/340879118_Modeling_the_situation_of_COVID19_and_effects_of_different_containment_strategies_in_China_with_dynamic_differential_equations_and_pa
- Ma, J. (2020). Estimating epidemic exponential growth rate and basic reproduction number, Infectious Disease Modelling 5:129-141. Available at: https://www.researchgate.net/publication/338454727_Estimating_Epidemic_Exponential_Growth_Rate_And_Basic_Reproduction_Number
- Musa SS, Zhao S, Wang MH et al. Estimation of exponential growth rate and basic reproduction number of the coronavirus disease 2019 (COVID-19) in Africa. Infect Dis Poverty 2020; 9(96). https://doi.org/10.1186/s40249-020-00718-y
- Rasjid, Z. E., Setiawan, R., & Effendi, A. (2021). A comparison: Prediction of death and infected COVID-19 cases in Indonesia using time series smoothing and LSTM neural network. Paper presented at the Procedia Computer Science, 179 982-988. doi:10.1016/j.procs.2021.01.102
- Roda, W. C. Varughese, M. B. Han, D. & Li, M. Y. (2020). Why it is difficult to predict accurately the COVID-19 epidemic? Infectious Disease Modelling 5: 271-281. Available at:

https://www.researchgate.net/publication/339850601_Why_Is_It_Difficult_to_Accurately_Predict_the_COVID-19_Epidemic

- Worldometer. (2020). COVID-19 coronavirus outbreak. World meters, 2020. Available at: https://www.worldometers.info/coronavirus/#countries