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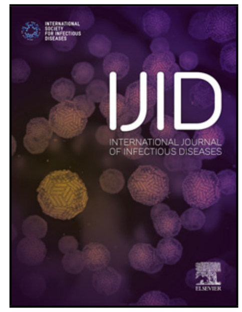

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Estimation of the probable outbreak size of novel coronavirus (COVID-19) in social gathering events and industrial activities

Motasem N. Saidan[1,*], Mohammad A. Shbool[2], Omar Suleiman Arabeyyat[3], Sameh T Al-Shihabi[2], Yousef Al Abdallat[2], Mahmoud A. Barghash[2] and Hakam Saidan[4]

[1] Chemical Engineering Department, School of Engineering, The University of Jordan, 11942, Amman, Jordan; m.saidan@gmail.com, m.saidan@ju.edu.jo
[2] Industrial Engineering Department, School of Engineering, The University of Jordan, 11942, Amman, Jordan; m.shboul@ju.edu.jo; s.shihabi@ju.edu.jo; abdallat@ju.edu.jo; mbargha@ju.edu.jo
[3] Computer Engineering Department, Faculty of Engineering, Al-Balqa Applied University,19117, Al-Salt, Jordan; arabiat@bau.edu.jo
[4] Jordan Food and Drug Administration, 11181, Amman, Jordan; hakam.rph@gmail.com

*****Correspondence: m.saidan@gmail.com, m.saidan@ju.edu.jo

Highlights

- R0 values varies depending on social activity and type that induce infection spread
- We proposed mathematical model to estimate the R0 of COVID-19 outbreak in clusters
- High R0=5 value is in wedding events, followed by religious gathering events (2.5)
- The lowest R0 value was found in the industrial cluster (R0=2)
- Our model is a vital tool for epidemiology investigations by knowing when to stop

Abstract

Background: The reproduction number (R0) is vital in epidemiology to estimate the number infected people and trace the close contacts. The R0 values varies depending on social activity and type of gathering events that induce infection transmissibility, in addition to its pathophysiology dependence.

Objectives: In this study, we estimated the probable outbreak size of COVID-19 at clusters mathematically using a simple model that can predict the number of COVID-19 cases, as a function of time.

Methods: We proposed mathematical model to estimate the R0 of COVID-19 in the outbreak occurring in both of local and international clusters in light of published data. Different types of clusters (religious, wedding, and industrial activity) were selected based on reported events in different countries between February and April 2020.

Results: The highest R0 values were found in wedding party events (5), followed by religious gathering events (2.5), while the lowest value was found in the industrial cluster (2). This in return, shall enable us to assess the trend coronavirus spread by comparing the model results and observed patterns..

Conclusions: This study provides a predictive COVID-19 transmission patterns in different clusters types based on different R0 values. This model offers the decision makers in the contact-tracing task the predicted number of cases, which would help them in epidemiology investigations by knowing when to stop.

Keywords: Coronavirus; COVID-19; pandemic; mathematical model; reproductive number.

Introduction

The outbreak of COVID-19 has currently spread to more than 217 territories (Hui et al., 2020) since December 2019 (Chang et al., 2020; Li et al., 2020; Roda et al., 2020; Wu et al., 2020). According to the latest statistics, until May 1, 2020, there have been more than 3,389,933 confirmed cases found in more than 187 countries covering six continents (Johns Hopkins Coronavirus Resource Center; 2020). COVID-19 was officially declared by the World Health Organization (WHO) as a pandemic on March 29, 2020 (WHO, 2020). COVID-19 causes Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) (Guliyev, 2020; Vega, 2020; Ceylan, 2020); moreover, COVID-19 can be considered as the greatest public health threat caused by a respiratory virus since 1918 (Sen-Crowe et al., 2020). In addition to its consequences for public well-being, COVID-19 has a profound impact on the economic well-being of affected nations

Several researchers have reviewed the impacts of COVID-19 on public health (Liu, Manzoor, Wang, Zhang, & Manzoor, 2020). (Di Gennaro, et al., 2020), pathophysiology and clinical manifestations diagnosis, case management, emergency response, and preparedness.

The primary reason for the long-distance transmission of COVID-19 is migration. Wu et al. (2020) analysed the relationship between the migration network and the spread of the virus. Setti el al. (2020) have studied the impact of the two-meter interpersonal distance, which was recommended by the WHO, on virus transmission. A work done by (Yasir, Hu, Ahmad, Abdul Rauf, Shi, & Nasir, 2020), investigated the effect of e-Government and COVID-19 word of mouth on the social presence while (Qeadan, et al., 2020) used data from South Korea and Italy, who disparately implemented public health actions to contain the spread of COVID-19, to build a naïve forecast for the outbreak of COVID-19 in the state of Utah in the USA.

The reproduction number (R0) is a measure used in epidemiology to estimate the number of cases, infected people, that are caused by contacting one infected person in the population (Zhao et al., 2020; Liu, 2020). If R0 is more than one, infections will continue to spread; while, if R0 is less or equal one the infection will eventually diminish; however, COVID-19 virus is still new, many assumptions are needed to calculate Covide-19 R0, and researchers do not have a consensus about this value. According to the published literature, R0 of COVID-19 ranges between 1.4 to 6.49 (Liu et al., 2020a; Wu *et al*., 2020; Shen *et al., 2020*; Liu *et al.*, 2019; Read *et al*., 2020; Majumder *et al*., 2020; Cao *et al*., 2020; Zhao *et al*., 2020; Imai, 2020; Julien and Althaus, 2020; Tang *et al*., 2020; Li *et al*., 2020).

The variations in the estimated values of R0 for COVID-19 indicates that it is situation-dependent. Furthermore, R0 for COVID-19 varies based on the time of the outbreak and the measures that are imposed by the countries to combat the virus spread. To date, most of the virus outbreaks in several countries can be attributed to events that had several people present, such as wedding parties, religious events, scientific conferences, national festivals, etc. Henceforth, we use the word cluster to describe any event that involved the presence of an infected person with a group of susceptible people.

The main objective of this study is to estimate (R0) of COVID-19 at clusters mathematically. We rely on published data from several events and countries to estimate R0. Using the estimated R0, we develop a simple model that can predict the number of COVID-19 cases, as a function of time, where these cases emerge from such clusters.

We validate our prediction model by applying it to religious, socials, and industrial clusters. Results show that decision-makers can rely on our model in estimating possible cases related to such cluster, which would help them in epidemiology investigations by knowing when to stop.

Mathematical Model

We use dynamical modelling to capture and predict the number of cases with time. Unlike previous research that relies on the classical SIR (susceptible-infectious-recovered) model and its extension (Calafiore et al., 2020), we have a new definition for the different compartments into which people in the cluster are divided (Fanelli et al., 2020). Moreover, we present a new set of transition equations among the compartments. We assume that our mathematical model is only valid when the COVID-19 infection is transmitted in a cluster event of homogeneous population and with the same social contact pattern. For instance, infected individuals are infected with the same transmission probability from the susceptible group of individuals. This can help in the contact tracing while undertaking epidemiological investigation.

However, to track the COVID-19 spread in heterogeneous populations with no-contact social pattern, our model cannot model and perform this situation with reasonable accuracy. Other mathematical models were proposed to do so. For example, Liu et al. (2020b) developed the contact network and no-contact models to keep track of the disease spread in and contact patterns, such as unprotected and protected contact and airborne spread. This in fact not our objective. Our mathematical model is only predicting the spread in a homogenous population (event attendees) based on contact model to mainly offer the decision maker in the contact-tracing task the predicted number of cases, which would help them in epidemiology investigations by knowing when to stop.

The population that we target in our model is only the people attending an event, those in the cluster. The different compartments in which we divide the targeted population are:

1) suspected individuals (S) who is exposed to positive infected individuals with symptoms of COVID-19 infection,

2) infected individuals (I) who have confirmed COVID-19 infection with a positive result for Polymerase Chain Reaction (PCR) testing of respiratory specimens,

quarantined infected individuals (Q) who are either quarantined or in hospitals.

An infected person in a cluster exposes S_0 individuals with the virus, who were present in the event, to the disease. Out of the S population, $\boldsymbol{I}(\boldsymbol{t})$ individuals are identified by PCR testing to have the virus at the time $\boldsymbol{t}$.

The Infection Rate (r_i) depends on R_0 and incubation period (N), as shown in equation (1):

$$r_i = \theta R_0/N \quad (1)$$

where, θ is empirically estimated as 0.035 for COVID-19 in the present study to best fit the actual cases (i.e. with accuracy more than 80% given as a constraint to the model), which represents the average transmissibility. Liu et al. estimated θ to equal 0.026 under no quarantine measure. The R0 range given to the model was between 2 to 5.; and N is 14 days for COVID-19 (range, 2 to 14 days) (Lauer et al., 2020; Linton et al., 2020).

At the time of the event, we divided attendees into S_0 and I_0 to show the starting numbers of susceptible and infected individuals. I_0 is either a given number or is a percentage of S_0, 2% to 4% of the S_0, depending on the infection source country. For example, for the religious event that took place in South Korea and caused thousands of infections, the source of infection was a single individual; consequently, $I_0=1$ and S_0 is equal to all the event attendees, except the infected individual.

The number of suspected and infected cases in the first day (n=1) can be calculated using Equations 2 and 3, respectively. Two to 14 days after the event, the number of suspected and infected cases are found using Equations 4 and 5, respectively.

$$S_{i=1} = S_0 - I_0 \tag{2}$$

$$I_{i=1} = I_0 \tag{3}$$

$$S_{i=n} = S_{i=n-1} + I_{i=n-1} - I_{i=n} \tag{4}$$

$$I_{i=n} = I_{i=n-1} + (S_{i=n-1} * r_i) \tag{5}$$

In order to calculate the suspected cases per day after identification of infected cases and removing them (the infected cases) from the susceptible population for treatment, then equation (5) is substituted in Equation (4), as shown in Equation (6)

$$S_{i=n} = S_{i=n-1} - (S_{i=n-1} * r_i) \tag{6}$$

Study clusters

The clusters types are selected in the present study because they are considered as a homogenous sample with running contact-based model in specific time and location. The cluster event is bounded and well identified. Accordingly, the social pattern and communication intensity is relatively varied, hence, it is expected that the R0 is varied too. Most importantly, these clusters events were in the initial beginning of the virus spread worldwide and played a role in causing outbreaks in each of the considered countries in the present study.

We searched for data reported in the news and public health reports, official website (WHO), and governmental reports that reported the situation of COVID-19 infection in the selected study cases. For each case, we extracted from the news and other sources the number of the positive cases recorded each day after the event.

In most cases, the interval of possible COVID-19 virus exposure was selected at the time between the time of the event held, and the latest reported positive cases related to the event. We assumed that the transmission is proceeding until the epidemiological teams are reaching all cases (generations) of the infection chains.

Religious events

Two religious events are analysed in our work. The first event took place in the Malaysian mosque while the second event took place in South Korean church.

Malaysia

A four-day Tablighi Jamaat event was held at Jamek Mosque in Sri Petaling, Kuala Lumpur, from February 27 to March 1, where 16000 attendees (including about 1,500 from outside Malaysia (Barker, 2020)) were invited and at least 10,500 guests have attended this event. The event was socially active (including sharing of foods, sitting close to each other's, and holding hands, while no COVID-19 precautions were officially declared), but most attendees washed their hands during the event (The New York Times, 2020).

The Tabligh assembly is considered the largest cluster that kicked off the second wave of COVID-19 infections in Malaysia. On March 16, 553 positive cases were reported and linked to this Tabligh assembly in Malaysia, in addition to 620 people, including those from other countries, who attended the event have tested positive, making it the largest-known center of COVID-19 transmission in Southeast Asia (Beech, 2020).

South Korea

Shincheonji was connected to the coronavirus outbreak on February 18 in South Korea. A 61-year-old South Korean woman, had no prior overseas travel history or contact with other confirmed cases, attended two services in the Shincheonji religious group before testing positive for the virus, and she is believed to have spread the virus (Martin, 2020). A cluster of infections followed. By February 20, the national tally had increased from 31 to 156 and the first death was reported. The religious group became involved in controversy during the COVID-19 infections, reaching 4,000 cases of COVID-19 within two weeks, and roughly 60% of the total infections nationwide having stemmed from the church (KCDCP, 2020).

Social events

Two weddings, one in Jordan and the other in Uruguay, have witnessed several COVID-19 cases due to the presence of infected individuals.

Jordan

79 coronavirus cases were officially reported in Jordan (https://corona.moh.gov.jo/ar), from March 14 to March 27 which had been guests at the wedding party attended by 400 to 450 guests, which was held on March 13 despite a ban on large gatherings. This coronavirus cluster virus put Jordan at a crossroads in dealing with the pandemic and enforced the government to seal off the City of Irbid, which is Jordan's second-biggest city, and the surrounding province after dozens of guests, who attended the wedding, tested positive for the coronavirus. Accordingly, the government announced a lockdown on March 17 and subsequently turned into a strictly-enforced curfew that was described as one of the world's strictest measures. However, the four-day lasted curfew was later relaxed as government plans to deliver food to neighborhoods had failed, and people were allowed to walk to buy groceries from local stores from 10 am till 6 pm when civil defense sirens were used to announce the end when people can go out (CNN, March 26 2020).

Uruguay

500-guest wedding party was held on March 7 and was reported then to be causing the explosive growth of COVID-19 positive cases. It was traced back to a traveller who decided to attend the wedding event just hours after arriving from Spain, who later tested positive (The Guardian, 2020). Accordingly, the confirmed cases had a leap from four on

March 12 to 79 on March 20, where 44 cases were traced back to a 500-guest wedding party.

Hence, various containment measures were introduced in mid-March, and major restrictions on movement followed in late March.

Industrial event

After suppressing the infection rate to below 1%, parts of Australia started easing restrictions (i.e. social distancing); consequently, a relatively small COVID-19 cluster has emerged on April 2 2020 at a meat factory in Victoria (Kelly, 2020). After that, 49 positive cases were reported in a meat processing plant, with 350 employees, on April 29 2020. The physical layout of meat factories is relatively challenging the physical distancing since the workers have to be in relative proximity.

Results

Reported cases

Table (1) shows the confirmed case of COVID-19 infection for wedding party events in Jordan and Uruguay; religious gathering events in both Malaysia and South Korea; and in industrial activity cluster in Australia.

R0 Estimation

To evaluate the transmissibility of COVID-19 in the selected clusters and events, as stated before, we applied the mathematical model to estimate the R0 in such types of clusters and accordingly fitted the expected infected cases while comparing its accuracy with the actual reported cases in these aforementioned events.

We assumed the interval values of the corresponding parameter (R0) of this mathematical model, by which COVID-19 at the early stage of spread in each country, without intervention scenarios (curfew, lockdown, restricted social distancing, etc) are modeled.

The R0 values were selected in the interval between 2 to 5.5, and then the best fit R0 value was determined for each event.

Wedding party events

Two wedding events, which were held in Jordan and Uruguay, as stated before, were selected to evaluate the transmissibility of COVID-19 in such types of clusters. There was insufficient information about these two cluster cases, so we relied on limited daily data which were published in official reports and daily news websites, and hence, this limited the capability to undertake sound statistical analysis.

Using the existing data of reported cases and the mathematical model incorporating these data, we provide an estimation of the R0 of COVID-19 in these wedding events. We estimated that R0 was about 5, as shown in Figures (1) and (2) while modeling different ranges of R0 (2.0–5.5) where the values of modeled cases are shown in the bars above the modeled cases of R0=5. Figure (3) compares the modeled (predicted) and actual cases at the wedding events in both Jordan and Uruguay, at R0=5. The correlation coefficient between the two is 0.7303. It is noteworthy that it is quite difficult to precisely calculate the R0 since it is challenging to determine the actual daily cases during any cluster due to the delay in epidemiological tasks, cases sampling, and PCR testing, as well as, other parameters that might delay cases reporting such as demographic variations, etc (Delamater et al., 2019; Zhang et al., 2020). Moreover, our model assumes that all suspected cases (exposed cases and cases who had close contact with confirmed cases) have been identified and PCR-tested, including those asymptomatic cases.

Religious gathering events

Two religious gathering events, which were held in Malaysia and South Korea, as stated before, were selected to evaluate the transmissibility of COVID-19 in such types of clusters. There was insufficient information about these two cluster cases, so we relied on limited daily data which were published in official reports and daily news websites, and hence, this limited the capability to undertake sound statistical analysis.

As shown in Figures (4) and (5), the R0 estimates based on the officially reported cases and after incorporating these data in our mathematical model, while modeling different ranges of R0 (2.0–5.5) as shown in the bars above the modeled cases. We estimated that R0 was about 2.5, which fits the actual data in good agreement. Figure (6) compares the modeled (predicted) and actual cases at the religious gathering events in both of Malaysia and South Korea, at R0=2.5. The correlation coefficient between the two is 0.8755.

Industrial activity cluster

The meat and poultry processing industry is considered among the medium to large industries worldwide, and an essential component of any country's food infrastructure. Hence, it is of great importance to predict the COVID-19 spread in such industrial sector.

Therefore, we incorporated the existing data of reported cases in Australia, as stated before, and accordingly, we provided an estimation of the R0 of COVID-19 in the meat processing case. We estimated that R0 was about 2, as shown in Figures (7), while modeling different ranges of R0 (2.0–5.5) where the values of modeled cases are shown in the bars above the modeled cases of R0=2.

Discussion

Since most of increasingly transmitted COVID-19 outbreaks started with clustering events as stated before, then the transmission trends analysis based on daily positive cases data using mathematical modeling is of crucial significance. Hence, it can be employed as early warning system for non-pharmaceutical interventions and needs for imposing restricted measures (i.e., lockdown, confinement or quarantine), to combat and weaken the outbreak chains. Our proposed model might be used as a conventional tool to track the COVID-19 by testing and reporting changes overtime, and benchmark the cases mainly within and after imposing of measures (i.e. restricted or intermittent). Despite of the limited data at the beginning of any cluster-causing-outbreak, however, the timely prediction of pattern variations might provide the responsible agencies with more information on the varied spread momentum, trend pattern, and outbreak size. Thus, this helps to make decisions of measures ahead of time that lead to flatten the COVID-19 epidemic curve.

The R0 estimates for different types of clusters events, accordingly, our model can be used for predictive purposes, and based on this the healthcare authorities can assess their capabilities and resilience to absorb such events outbreak wave.

Our findings indicated that the daily predicted infected cases and the size of the outbreak are drastically dependent on the R0 value. When no lockdown measures were imposed, the R0 value was relatively high at the early beginning of the COVID-19 spread, despite of the fact of awareness dissemination campaigns and directives that were unleashed by governments worldwide.

Based on different values of R0 (according to cluster type), we carried out a prediction of daily incidence and the probable size of the outbreak for 14 days at least for each selected case. Our mathematical modeling results show the values of R0 for the selected outbreaks clusters are 2 for industrial activity, 2.5 for religious events, and 5 for wedding events. All of these values are within the range of 2-5.5, and these values are acceptable when compared to other published literatures.

However, the estimated cases presented in Figures 2, 4, 5, 7 are also modeled for varied R0 values between 2-5.5 and this is shown in the bars, while the actual cases are within these bars values above the selected predicted value.

Study limitations

In cluster types of outbreak infection, normally the susceptible population is more and less the same as the exposed population, which is decreasing rapidly. Hence, the modeling period is relatively short (i.e. less than a month) depending on the contacts tracing, epidemiological activity and performance. Moreover, the prediction of new cases cannot be performed until some cases are identified as infected cases, and removed from the susceptible population for treatment, hence, this might affect the infection transmission within the modeling period, and R0 is expected to change but its variation cannot be though modelled.

Since our mathematical model is aimed to be used as a tool for the contacts-tracing team in the epidemiological investigation, then the target is to give the overall cumulative infected cases after 14 days (or the modeling period). Accordingly, the R0 was estimated by the model to give very good compatibility between the actual and predicted cases in the last days of the modeling period.

To compare with the actual, reported cases cannot be done on a daily basis due to the delay in positive cases sampling, testing, and officially declared. This might influence the accuracy between the actual and predicted cases on a daily basis, as well as, the precision of R0 value estimation. However, the R0 was selected to reflect the overall and cumulative cases after 14 days or the modeling period.

Regarding the sensitivity analysis of our model, only one parameter is used in our model which is θ is empirically estimated as 0.035 for COVID-19 in the present study to best fit the actual cases (i.e. with accuracy more than 80% given as a constraint to the model). The value estimation of θ was based on the reported infection rate in the Lombardi city (Italy) and New York (USA), while comparing the number of infected bases to the total population of the aforementioned cities (Lombardi and New York), and after subtraction the infected cases from the total susceptible population of these cities. The transmissibility is believed to relatively have high value in the initial beginning of any outbreak because of the lack of public awareness of COVID-19 throughout Feb-March 2020 in the selected cases in the present study. It is noteworthy, that θ influences the infection rate (r_i) in our mathematical model. However, based on the actual data reported, θ = 0.035 was found to be the best fit (i.e. Liu et al. (2020) estimated θ to equal 0.026 under no quarantine measure).

Finally, to enhance the accuracy of our model, there is a need to show the testing capacities for each country corresponding to the outbreak timing in these countries and situations. Unfortunately, we could not find a reliable source of references or data to rely on while investigating these points (i.e. testing capacities at outbreak timing, bias reporting, etc) at that outbreak timing (Feb-March 2020).

Conclusions

The present study provides a predictive COVID-19 transmission patterns clusters with different types of activities (i.e. wedding party, religious events, industrial activity, etc.) based on different R0 values, respectively. Moreover, the proposed mathematical model offers a tool to benchmark the impacts of non-pharmaceutical interventions measures and operational responses, and their spread pattern towards flattening the epidemic curve for specific outbreaks induced by such types of clusters activity.

Our findings showed that the R0 is higher in wedding type of clusters, followed by religious gathering events, and the lowest value was found in the industry cluster. Accordingly, the present model can be used as a tool to predict the expected number of infected cases, based on the outbreaks cluster, so to enhance the plan for close contacts tracing of the positive PCR cases; hence, the epidemiological activities can be directed efficiently towards exposed cases with optimal logistics as expected.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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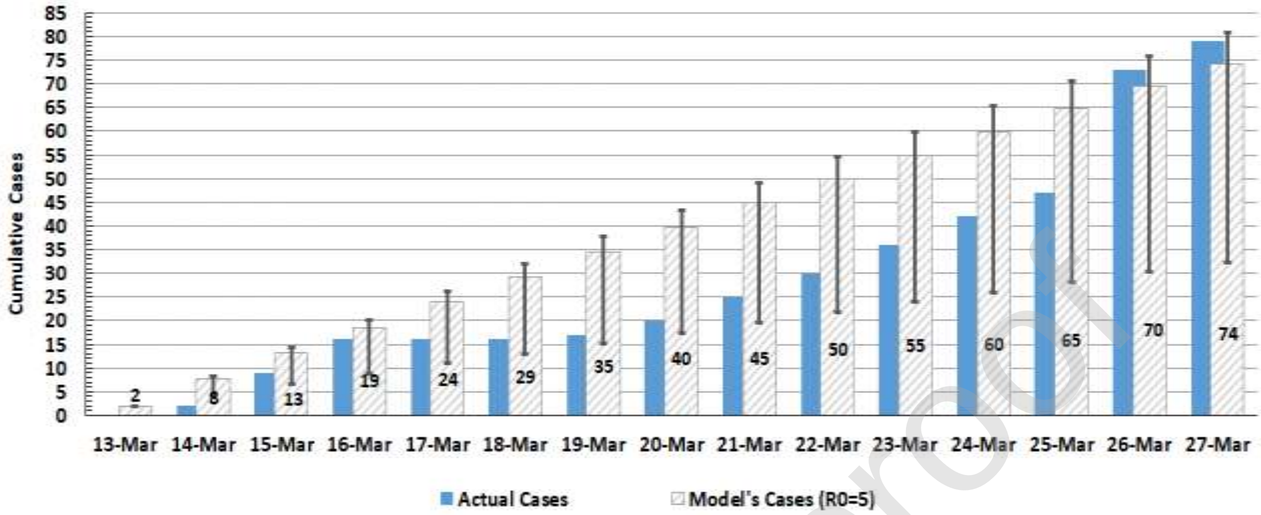

Figure 1. The cumulative cases for COVID-19 in Wedding event-Jordan (March 13, 2020, and March 27, 2020).

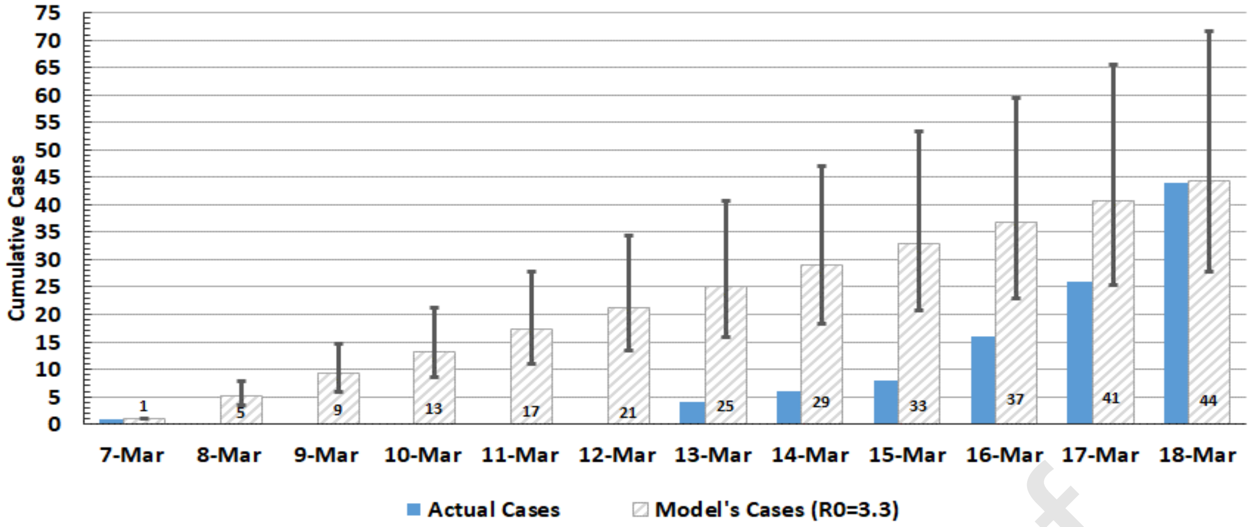

Figure 2. The cumulative cases for COVID-19 in Wedding event- Uruguay (March 7, 2020, and March 18, 2020).

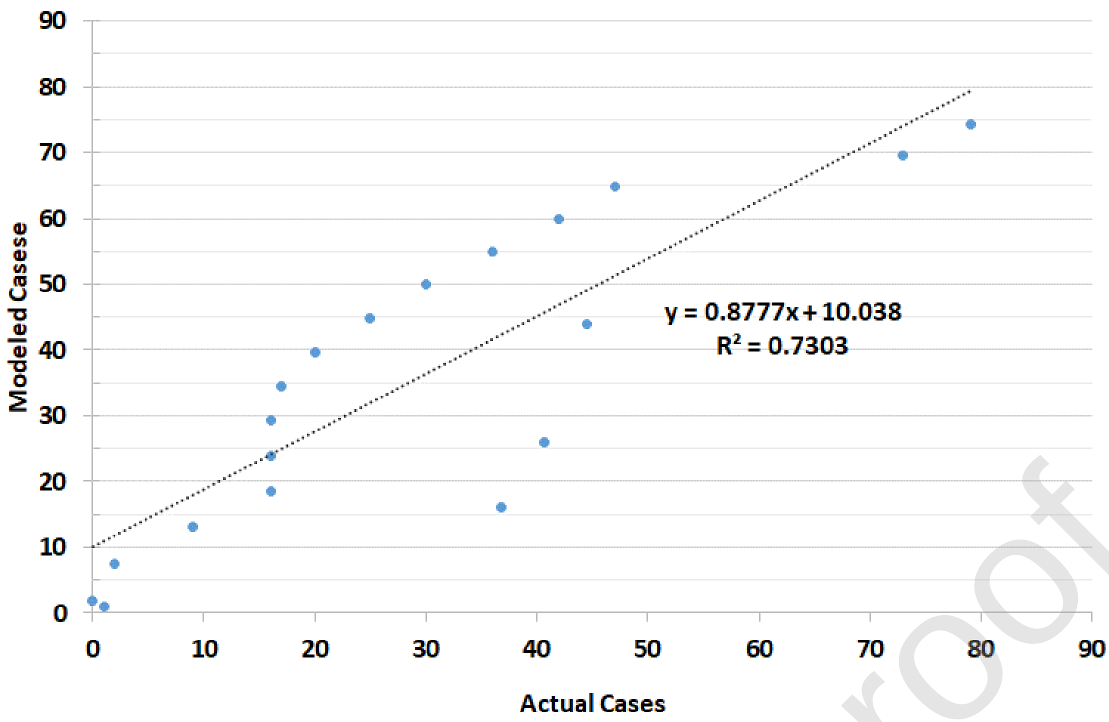

Figure 3. Modeled (predicted) and actual COVID-19 cases in the two wedding events.

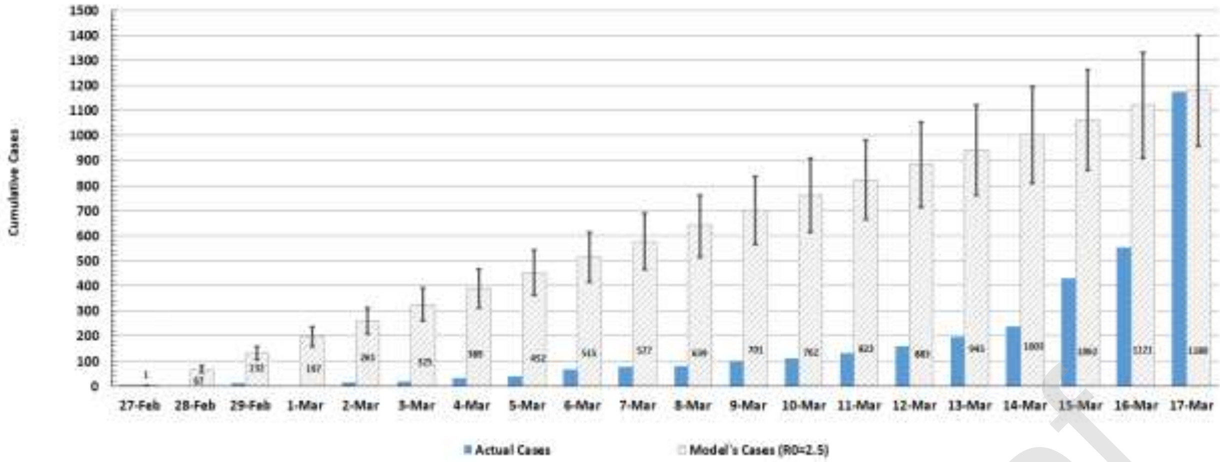

Figure 4. The cumulative cases for COVID-19 in religious gathering event- Malaysia (February 27, 2020, and March 17, 2020).

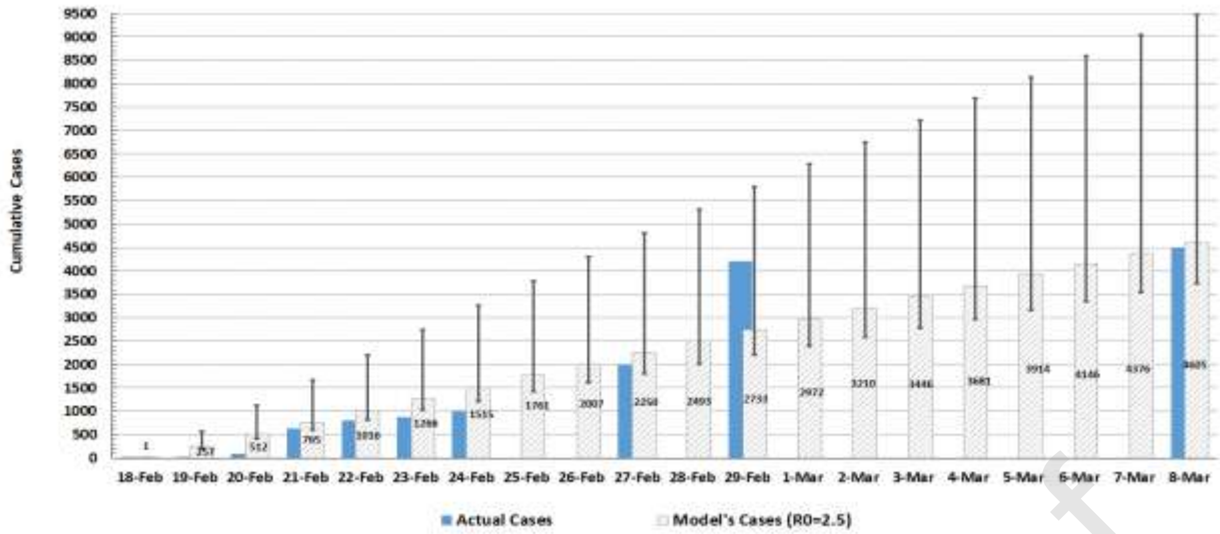

Figure 5. The cumulative cases for COVID-19 in religious gathering event- South Korea (February 18, 2020, and March 8, 2020).

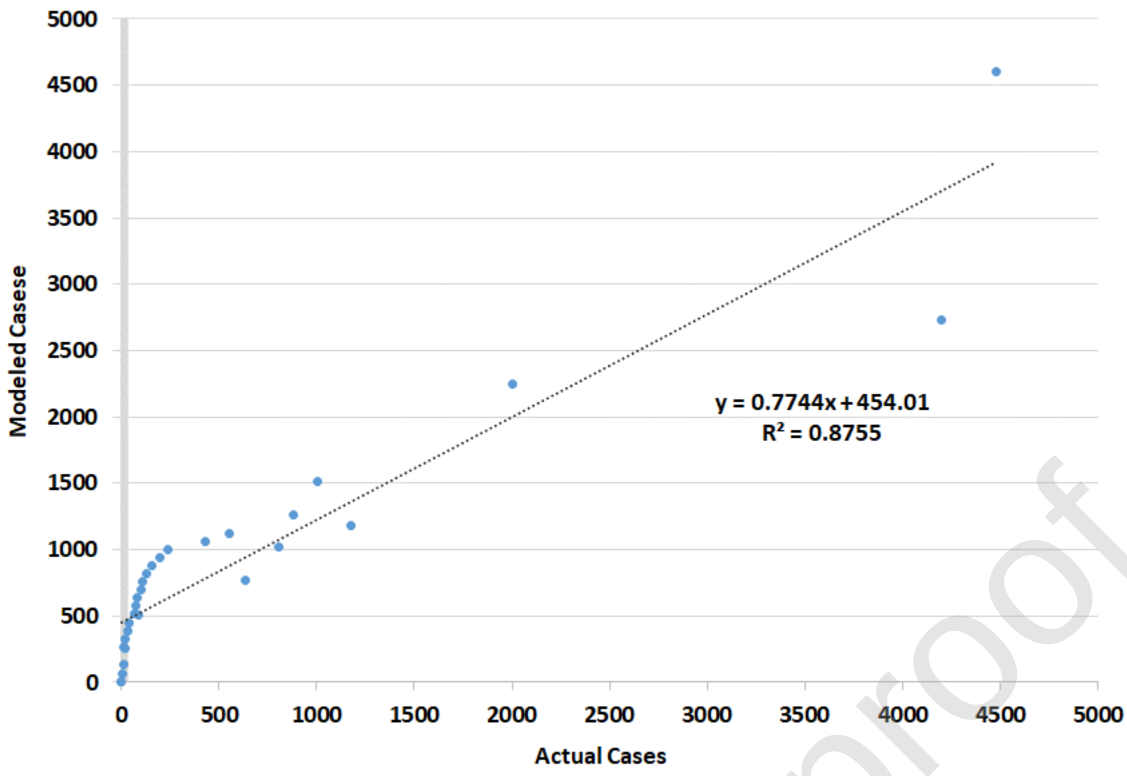

Figure 6. Modeled (predicted) and actual COVID-19 cases in the two religious gathering events.

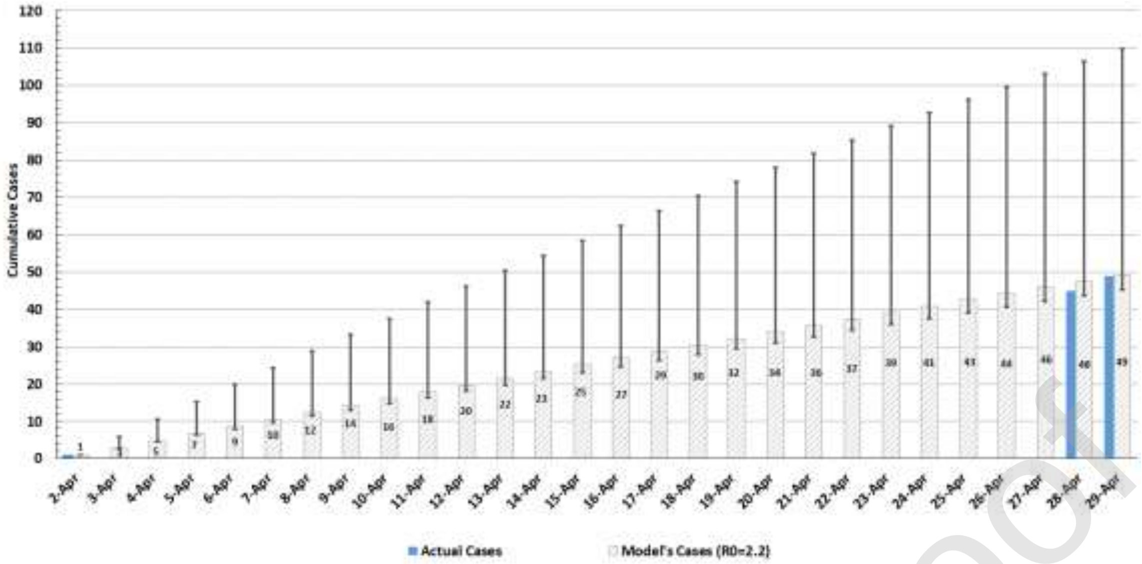

Figure 7. The cumulative cases for COVID-19 in the meat processing factory (industrial cluster) in Australia (April 2, 2020 and April 29, 2020).

Table 1. Reported actual cases of COVID-19 in the selected cases.

Days	Actual Cases				
	Jordan	Malaysia	Uruguay	South Korea	Australia
16-Feb		4		1	
17-Feb				21	
18-Feb		11		91	
19-Feb				635	
20-Feb		15		804	
21-Feb		18		879	
22-Feb		32		1008	
23-Feb		37			
24-Feb		65			
25-Feb		75	1	2000	
26-Feb		81			
27-Feb		100		4200	
28-Feb		112			
29-Feb		131			
1-Mar		158			
2-Mar		197	4		
3-Mar	2	238	6		
4-Mar	9	428	8		
5-Mar	16	553	16		
6-Mar	16	1173	26	4482	
7-Mar	16		44		
8-Mar	17				
9-Mar	20				
10-Mar	25				
11-Mar	30				
12-Mar	36				
13-Mar	42				
14-Mar	47				
15-Mar	73				
16-Mar	79				
2-Apr					1
28-Apr					45
29-Apr					49