

## Impact of lockdowns on the spread of COVID-19 in Saudi Arabia

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### ABSTRACT

Epidemiological models have been used extensively to predict disease spread in large populations. Among these models, Susceptible Infectious Exposed Recovered (SEIR) is considered to be a suitable model for COVID-19 spread predictions. However, SEIR in its classical form is unable to quantify the impact of lockdowns. In this work, we introduce a variable in the SEIR system of equations to study the impact of various degrees of social distancing on the spread of the disease. As a case study, we apply our modified SEIR model on the initial spread data available (till April 9, 2020) for the Kingdom of Saudi Arabia (KSA). Our analysis shows that with no lockdown around 2.1 million people might get infected during the peak of spread around 2 months from the date the lockdown was first enforced in KSA (March 25th). On the other hand, with the Kingdom's current strategy of partial lockdowns, the predicted number of infections can be lowered to 0.4 million by September 2020. We further demonstrate that with a stricter level of lockdowns, the COVID-19 curve can be effectively flattened in KSA.

### 1. Introduction

In December 2019, a novel coronavirus, named SARS-CoV-2, has emerged in Wuhan, Hubei Province, China, and has spread globally within a relatively short period of time [1]. The World Health Organization (WHO) named the infection with the virus officially as coronavirus disease 2019 (COVID-19) [2]. SARS-CoV-2 is unique because of high transmissibility, and by virtue of this trait, it has infected over 20 million individuals worldwide causing more than 790,000 death cases as of August 21, 2020 [3].

Considering to the need to develop effective vaccines and antibody-based therapeutic agents against SARS-CoV-2, over 90 vaccine and 50 antibody approaches are being tested in different parts of the world [4–6]. However, we are still far from the success and uncertainly looms over as we learn more about the virus [7,8].

Currently, due to the lack of effective vaccines and or other therapeutic agents and because of high spread rate of COVID-19, attempts are being made to slow down the spread of the COVID-19 [9,10,11,12].

Today, lockdowns have been implemented in many countries across the globe and other strict measures such as curfews have been imposed in many cities to ensure social distancing [10]. The existing health system of many countries, including advanced ones as well, is unable to accommodate the growing number of confirmed COVID-19 patients [11, 13]. In the absence of vaccination and proper cure, countries are making efforts to flatten the curve of the pandemic for necessary preparation to cope with the disease.

To predict the spread of COVID-19, several techniques ranging from soft-computing approaches to data-driven analysis to mathematical models have been explored recently [14–19]. Among various relevant models, authors in Refs. [14] found Autoregressive Integrated Moving Average (ARIMA) model to be more appropriate for forecasting number of daily COVID-19 cases for KSA [14]. Similarly, SIR and SEIR models were used extensively in the literature [20,21,11,12,16]. While using COVID-19 time series data, Ensemble Empirical Mode Decomposition (EEMD) and Artificial Neural Network (ANN) based strategy was employed in Ref. [17]. Similarly, the work done in Ref. [18] predicted

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infected individuals and mortality rate for Hungary using machine learning. In Refs. [19], using hybrid soft-computing techniques, COVID-19 transmission risks were estimated.

The classical SEIR epidemiological model overlooks the impact of lockdowns in COVID-19 spread which is an effective strategy to slow the spread. The work provides an insight into how the levels of lockdowns can delay the spread in KSA. It is shown that with no lockdowns at all, around 2.1 million people can get infected during the peak of spread around 2 months from the date lockdown first began in KSA (March 25th). However, with the Kingdom's current strategy of lockdowns ( $\rho = 0.6$ ), the projected peak infections can be around 400,000 after 176 days, starting from March 25, 2020. In this work, we study the impact of lockdown on COVID-19 spread by extending the classical SEIR model. In this work, we modify the SEIR system of equations by integrating the impact of various degrees of lockdowns on disease spread. After this brief introduction, the rest of the paper is divided into the following sections; Section 2 reports the current data of COVID-19 from the perspective of KSA while methods and material section highlights the sketch of the model used for predictions. We discuss our results in Section 4 for predicting COVID-19 spread in the Kingdom using modified SEIR models. The paper is concluded in Section 5.

## 2. The COVID-19 spread in KSA

The human history shows that pandemics have reached their peak points before and then vanished over time with few exceptions. However comparison of COVID-19 with previous pandemics might be misleading as human population has almost doubled in the last 5 decades and hence the chances of human to human spreads is now higher and can result in early peak hit for which the countries are not ready with existing health infrastructure [22,3,13,23–26]. Worse, today more than three-quarters of the world's population lives in high density urban areas which makes the citizen even more susceptible to pandemics [23, 27]. Considering disease spreads, future infrastructure developments are expected to be smarter with the provision of detecting, reporting, and analyzing various disease symptoms to avoid any spread on premises [28,29].

Many factors play a critical role in the spread of COVID-19 such as population density, local evolution of COVID-19, the lifestyle of a society, and other factors. For instance, the population of KSA is around 38.8 million with the urban population being 84% of the total, while Japan has a population of 126.4 million where the urban population is 92%. Intuitively, based on population size, the spread should be faster in Japan as compared to KSA. Similarly, Iran's population is 83.9 million and 76% is urban population while Turkey has a total population of 84.3 m and 76% of them are urban [3,30]. COVID-19 spreads at various rates at different geographical locations and the accurate number is hard to determine [11,12]. However, it is reported that on average COVID-19 spreads on human to human level by a factor of 1.5–3.5 [12,31] Assuming the number of cases continues to climb at its current pace (April 2020), hospitals at KSA can come under massive pressure for per peak cases.

The first COVID-19 confirmed case was reported on March 2, 2020, in KSA [10]. The disease took only 34 days before infecting 2400 individuals by April 5, 2020. Noticeably, the spread was much slower in Japan and the country managed to delay it for 71 days before reaching 2400 confirmed cases (the first case in Japan tested positive on January 16, 2020) [3]. Contrarily, the disease spread was much faster in Iran and Turkey where the same number of people were infected in 14 days [30]. It took only 34 days before infecting 2400 individuals by April 5, 2020 [3]. Interestingly, the spread was much slower in Japan and the country managed to delay it for 71 days before reaching 2400 confirmed cases as the first case in Japan was tested positive on January 16, 2020. By April 5, 2020, a total of 36 countries have confirmed cases of 2400 and above with an average of around 39.1 days. Based on available data, reported cases might not reflect the actual cases as many countries have different

policies for testing and reporting.

KSA has enforced strict containment policies to control the spread of COVID-19 in the country. Based on the dataset released by John Hopkins University [30], we report the predictions for COVID-19. Though no existing model can accurately predict the spread of COVID-19, based on our simulations we show that even partial lockdowns can significantly delay the spread in KSA by 5–6 months from anticipated 2.5 months when there is no lockdown at all. In addition, the number of infected cases can be lowered down to less than 0.4 million with effective lockdowns. As a limitation of the work, actual cases may deviate from projected ones as the government is imposing social distancing to slow the spread. The existing health system of many countries, including fairly advanced ones as well, is unable to accommodate the growing number of confirmed COVID-19 patients. Without vaccination and proper cure, cities are making various efforts to flatten the curve of the pandemic for necessary preparation to cope with the disease.

The number of confirmed cases is increasing day by day in KSA and at present (April 10, 2020), the number of deaths caused due to COVID-19 are in 2 digits, however, there are fears that with increased number of cases, deaths are likely to increase. With this unprecedented worldwide spread and non-availability of vaccine or precise treatment, countries are trying to slow the spread and KSA is no exception by imposing lockdowns and other precautionary measures. Our study predicts that under a pessimistic assumption of no-social distancing in place, COVID-19 can infect individuals in the range of thousands to 2 million on completion of 2 months' time from the date of the first victim in the Kingdom. However, these numbers are very unlikely as the cases are based on historical data and shows pessimistic growth while KSA has devised an effective policy of lockdowns and curfew in major cities to control the spread.

## 3. Methods and materials

The Susceptible Infectious Exposed Recovered (SEIR) which is a mathematical model for analyzing the spread of infectious diseases has been used. The SEIR model is based on four compartments where S denotes the number of susceptible population, E for people exposed to the disease but show no symptoms (latent carriers), I for the number of infectious individuals having COVID-19 infection, and R for the number of recovered or eliminated individuals. This model has been used to make predictions for HIV/AIDS spread with reasonable accuracy [32]. There exist many derivatives such as SIR, SIS, SIRS, and others [21,33, 34,35,36]. Recently authors in Ref. [11,12,37] tried SEIR for COVID-19 spread as infected persons can pass on the infections displaying no symptoms [38]. The previous works done in [9,20,11,12,38–41,14,42] enable us to modify and apply SEIR model for predicting disease spread in KSA.

The SEIR model is ultimately a system of non-linear ODEs as discussed below. Here,  $\alpha$  is the rate of transmission (or contact rate),  $\mu$  shows incubation rate., i. e., rate with which an exposed individual gets infected, while  $\beta$  denotes the rate of an infected individual to move to the recovered/removed compartment.

$$\frac{dS}{dt} = -\alpha SI \quad (1)$$

$$\frac{dE}{dt} = \alpha SI - \mu E \quad (2)$$

$$\frac{dI}{dt} = \mu E - \beta I \quad (3)$$

$$\frac{dR}{dt} = \beta I \quad (4)$$

SEIR works under strong assumptions such as follows:

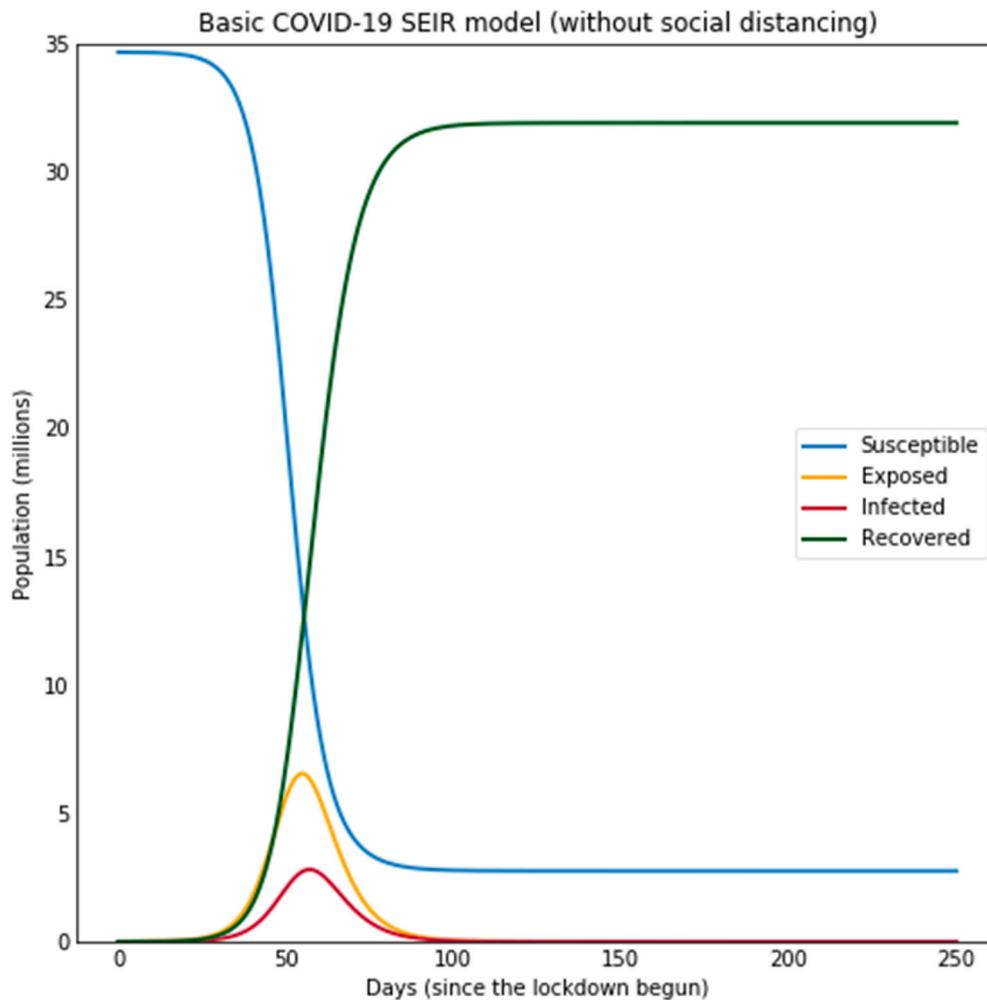


Fig. 1. SEIR predictions for KSA without implementing social distancing.

1. It is deterministic in nature, i. e., it assumes that everyone will eventually get infected,
2. Assumes that the spread continues only for short duration such that the population remains constant in that duration (no birth/death accounted)

Thus, based on the second assumption, we can further say that

$$S + I + E + R = \text{Total number of populations} = \text{Constant}$$

SEIR model is very much applicable to large populations such as the population of KSA which is 34,689,518 as on April 10, 2020 [3]. We use the same number in our simulations. Further, we take the Initial I (number of confirmed (infected) cases at the beginning of lockdown, March 25th, 2020) to be 900, Initial R (sum of number of recoveries (29) and deaths (2) at the beginning of lockdown) to be 31. We calculate initial E as suggested by Ref. [12] and use  $2.399 \times$  number of infected cases 6 days back as our estimated initial exposed population. Thus, initial  $E = 2.399 \times 274$ . Similarly, we assume  $Y = 5.2$  and  $D = 2.3$  as suggested in Ref. [12]. Our analysis ignores details such as the birth rate for S, death rates for S, E, I, R and other parameters and hence the predictions are just estimated values and not accurate numbers.

We have estimated other parameters as follows:

$\alpha$ : denotes the probability of transmitting the disease from an infected to a susceptible individual. We have calculated this value using an estimated reproductive number of 2.3 as various sources cite this number to be between 2 and 2.5. Thus, by using

$$R_o = \alpha/\beta$$

We get.  $\alpha = 1$

$\mu$ : is the rate of latent (exposed) individuals becoming infectious. It is equivalent to  $1/Y$  where Y is average incubation duration.  
 $\beta = 1/D$ , where D is the average duration of recovery D of the infection.

#### 4. Results and discussions

We extract KSA specific COVID-19 data points from John Hopkins University's dataset and analyze the trends from March 2, 2020 onwards (when the first confirmed positive case was reported in KSA). We then use a slightly modified SEIR model to incorporate the impact of social distancing in the spread of the disease and make projections for the same under varying degrees of such preventive measures. The infection rate varies and the number of confirmed cases also varies significantly. We understand these numbers fluctuate due to preemptive measures and psychological fear that stopped people from socializing. KSA is known for religious tourism which makes the Kingdom even more susceptible to infectious from visitors coming from other countries. The Kingdom has imposed strict lockdowns in many cities and has suspended many events and activities including sports, religious tourism, campuses, and so forth to minimize the probability of social interactions. Based on actual data until the April 9, 2020, we predict the spread and study the impact of these counter spread measures.

## COVID-19 SEIR model showcasing the impact of social distancing

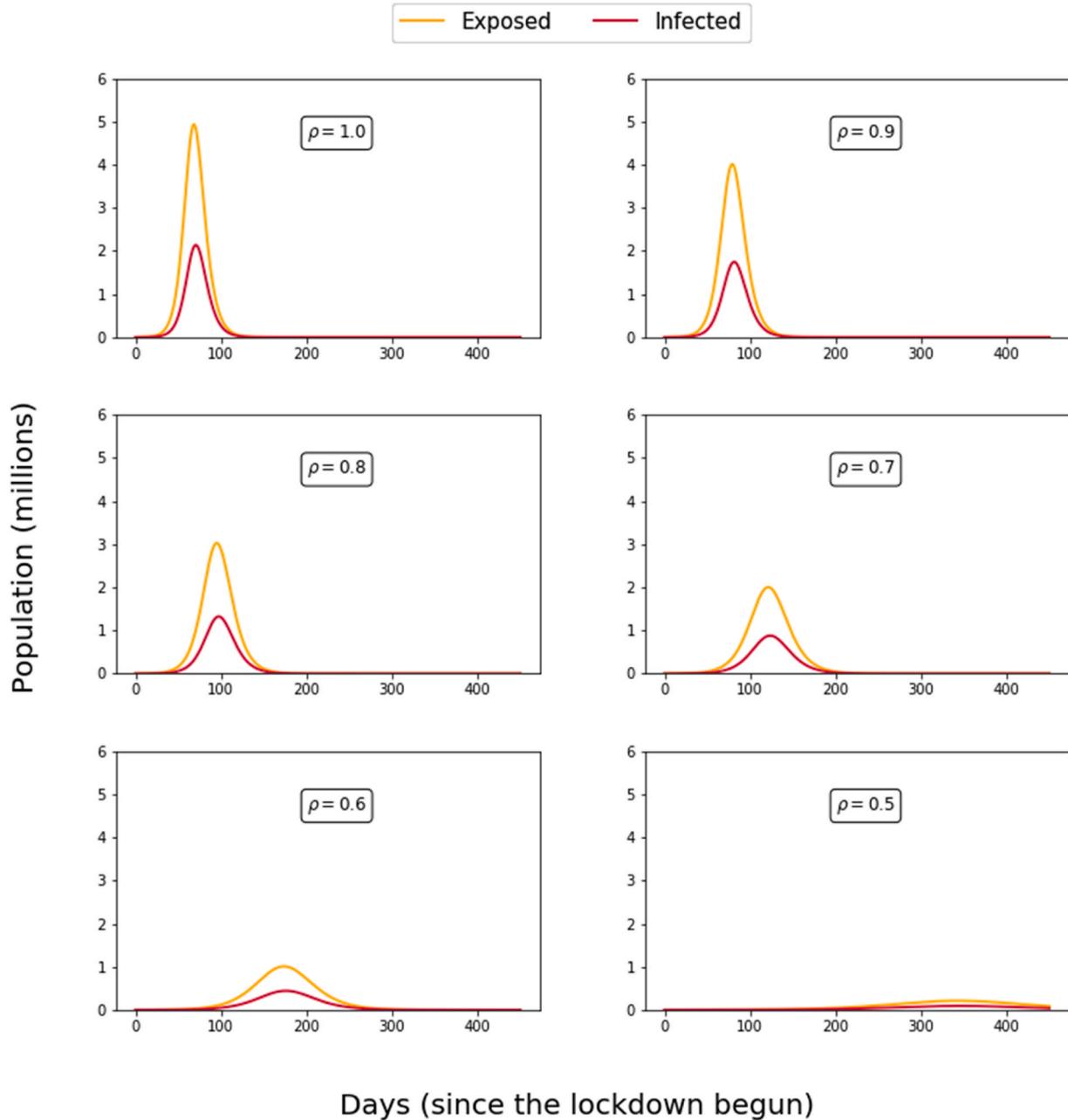


Fig. 2. COVID-19 projected spread in KSA

Assuming the number of cases continues to climb at its current pace, hospitals in KSA can come under massive pressure from per peak cases. It is suggested that a delay in the spread is better and probably the only option at present. Though the success story of the Chinese govt with strict social distancing imposed on January 23, 2020, helped in lowering infection from thousands to one infection within 2 months' time by March 15, 2020 [37], studies show that lockdown can only control the spread but there are fears that COVID-19 cannot be eliminated until a vaccine is found [39]. It is worth noting that as per KSA's ministry of health statistics for 2018, there were a total of 75,225 hospitals beds in the year 2018 [43]. We understand at present the number of beds has increased significantly but we could not access the latest data for 2020 from reliable sources. For KSA, using SEIR model without considering social distancing, the projected numbers have been plotted in Fig. 1 where peak infection is anticipated right after 2 months since the

lockdown was implemented. For plotting prediction, we assume that the population remains constant from the start of lockdowns (March 25, 2020). Again, this is the most pessimistic scenario possible. Based on the current actual and projected cases,  $\rho = 0.6$  can be a reasonable estimate to predict the disease spread in KSA.

In the Kingdom, the government is taking measures to reduce and eliminate the spread by closing schools, offices and even imposing day long curfews in major cities. Our analysis shows that without lockdown the peak would have come much earlier and there would be tremendous pressure on health infrastructure around the peak. In these models, the reproduction number plays an important role. When the rate is less than one, the disease gets vanished. However, when the rate is higher, the spread grows at tremendous speed. Similarly, the probability of getting infected can be lowered with simple actions like disposing of tissue papers immediately after sneezing or coughing, or sneezing into elbow,



Fig. 3. Projected infected population for various values of  $\rho$

frequent washing of hands and avoid touching nose or mouth. But the two most important strategies to deal with the virus are washing hands properly frequently and ensuring proper social distancing. Washing hands regularly reduces the probability of getting infected, while lockdown can help in containing the exposed population. With the SEIR model, it is shown that the number of infections can be brought to less than one million if a suitable degree of social distancing is imposed in KSA. It is important to note that the nature of COVID-19 disease is more complicated and existing prediction models need to be extended by considering factors such as population ages, birth/death rates, and herd immunity, and so on for more accurate predictions [37,38,44,45].

As discussed previously, measures like social distancing and lockdowns directly impact the rate of transmission,  $\alpha$ . Hence, to quantify the impact of social distancing we introduce a variable,  $\rho$ , in the classical SEIR system of equations by replacing  $\alpha$  with  $\rho\alpha$ . It is to be noted that  $\rho = 0$  would denote complete lockdown whereas  $\rho = 1$  would indicate no social distancing being practiced at all. Fig. 1 demonstrates this effect graphically. The line plot denotes the number of COVID-19 infected and exposed population as a function of time. Note how the curve flattens and the peak delays as  $\rho$  decreases. The exposed population is an important factor in the spread as symptoms can take 2–14 days after exposure to appear that may include shortness of breath, fever, loss of appetite/smell, headache, body pain, and cough, etc. as symptoms vary from patient to patient [41,46]. Centre for disease control and prevention [40] and Ministry of Health-KSA [41] recommends immediate medical attention in case of trouble in breathing, confusion or inability to arise, persistent pain or pressure in the chest, and bluish lips or face, and so on.

For a better understanding of the impact of lockdown in KSA, we plot the infections versus the level of lockdown in Fig. 2, where under no lockdown, 2.1 million people can be potentially infected. Coding and figures have been plotted using Python. We have plotted figures using the modified SEIR model. We run the experiments under various lockdown levels starting from no lockdown to strict lockdown. One of the limitations of the methodology is that the level of lockdowns may change and hence results can vary significantly. With no lockdown around 2.1 million people in KSA might get infected during the peak of spread around 2 months from the date lockdown first began in KSA (March 25th). During our initial analysis on the data till mid-April 2020, it was anticipated that the value for  $\rho$  can be 0.7–0.8, however, KSA imposed strict lockdowns on time and lowered the spread. In June 2020,

we had an opportunity to revisit our analysis and as per trends in June 2020, a value of 0.6 for  $\rho$  was determined to be a good match. With implementing strict social distancing, the spread can be slowed accordingly. A stricter lockdown with say  $\rho = 0.5$  would mean that the number of infected at the peak could be less than even half a million and even this peak would arrive after 11 months. The SEIR model shows why quarantine of the infected is critical in curbing the spread of COVID-19. Even when an individual is exposed to such a situation, simple actions such as washing hands for 20–40 s and not touching face/eyes are believed to help. As per SEIR, under the current social distancing norms around 1.75 million KSA residents will be infected within the first three months since the lockdown was imposed. The infected population is plotted in Fig. 3 that points out that with no lockdown, around 2.1 million people in KSA might get infected during the peak of spread by day 71 from the date lockdown. Our higher-level prediction shows that with this rate, four hundred thousand people can get infected within 5 months' time, starting from March 25, 2020. Fig. 2 shows that for any smaller values ( $\rho \leq 0.5$ ) the COVID-19 curve can be effectively flattened but may need very strict lockdowns. Our analysis is based on studying the impact of lockdowns only using the SEIR model ignoring factors such as vaccination, herd immunity, washing hands, etc. that can help in lowering the spread and eventually fade away the virus. As shown in Figs. 3 and 0.6 is an estimated value for  $\rho$  that reflects the current COVID-19 spread trend in KSA and expected to provide reasonable spread predictions for KSA.

## 5. Conclusion

The mathematical disease spread model of SEIR has been modified to incorporate the impact of lockdowns on COVID-19 spread in KSA. It has been shown that initially the spread took only 34 days to infect 2400 persons in KSA. Based on the spread pattern till April 9, 2020, the impact of social distancing and lockdowns was studied, and predictions were made for the number of infected cases under various degrees of lockdowns. With no lockdowns at all, 2 million confirmed cases were expected by July 2020, however, the Kingdom has embraced various strategies to limit the spread. Consequently, with the current level of partial lockdown, the number of confirmed are projected to remain below 400,000 in KSA after 176 days, starting from March 25, 2020. It is shown that with a stricter level of lockdowns, the COVID-19 curve can be flattened effectively.

## Declaration of competing interest

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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