



Original Article

Forecasting the spread of the COVID-19 pandemic in Saudi Arabia using ARIMA prediction model under current public health interventions

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ABSTRACT

The substantial increase in the number of daily new cases infected with coronavirus around the world is alarming, and several researchers are currently using various mathematical and machine learning-based prediction models to estimate the future trend of this pandemic. In this work, we employed the Autoregressive Integrated Moving Average (ARIMA) model to forecast the expected daily number of COVID-19 cases in Saudi Arabia in the next four weeks. We first performed four different prediction models; Autoregressive Model, Moving Average, a combination of both (ARMA), and integrated ARMA (ARIMA), to determine the best model fit, and we found out that the ARIMA model outperformed the other models. The forecasting results showed that the trend in Saudi Arabia will continue growing and may reach up to 7668 new cases per day and over 127,129 cumulative daily cases in a matter of four weeks if stringent precautionary and control measures are not implemented to limit the spread of COVID-19. This indicates that the Umrah and Hajj Pilgrimages to the two holy cities of Mecca and Medina in Saudi Arabia that are supposedly scheduled to be performed by nearly 2 million Muslims in mid-July may be suspended. A set of extreme preventive and control measures are proposed in an effort to avoid such a situation.

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Introduction

The number of novel coronavirus cases continues to escalate at an alarming rate across the world. This virus is the seventh of coronaviruses that infected humans; the first four caused mild symptoms and were identified in the mid-1960s, but the fifth and sixth, which are SARS-CoV and MERS-CoV that appeared in 2003 and 2012 respectively, developed severe symptoms [1]. In December 2019, the seventh virus which was named SARS-CoV-2 (previously known as 2019-nCoV) emerged in Wuhan, China [2], and develops COVID-19 disease as named in February 2020 by the World Health Organization (WHO), by which the disease was later declared as a pandemic in March 2020 [3]. COVID-19 disease can

be asymptomatic, or cause mild, moderate, or severe symptoms [4]. The latter leads to developing acute respiratory distress syndrome (ARDS) and thus the patient will need mechanical ventilation, and some others may get admitted to the ICU [2].

Despite a multitude of preventive and control measures that have been implemented in many countries, this novel coronavirus proved to be very contagious and has been quickly surging worldwide [12]. As of April 20, 2020, the total number of infected people is over 2.5 million in over 212 countries, of which about 30% and 40% are in the United States [5] and Europe [6], respectively, and these numbers are substantially increasing, which continue to adversely impact people's lives, healthcare facilities, and countries' economies. Therefore, it is evident that forecasting the future surge of this pandemic utilizing the available data is of high importance in order to understand the current situation, evaluate the severity of the pandemic, and help the authorities put well-tailored strategies and productive decisions to contain the disease and limit new infections in the near future.

Recently, several research studies have proposed different mathematical and machine-learning based forecasting models to estimate the spread of the disease, and determine its impact [7],

Abbreviations: AR, autoregressive; MA, moving average; ARMA, autoregressive moving average; ARIMA, autoregressive integrated moving average; COVID-19, Coronavirus disease 2019; ADF, augmented Dickey–Fuller; RMSE, root mean square error; MAE, mean absolute error; MAPE, mean absolute percentage error; RMSRE, root mean squared relative error.

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globally [8] and for specific countries such as the USA [9], China [10], Italy [11], Spain [12], France [13], India [14], Japan [15], among others. To the best of our knowledge, no previous studies have been conducted to predict the extent of the spread of COVID-19 in Saudi Arabia, where the number of cumulative daily cases is continuing to grow substantially, rising to 11,631 cases in total [16].

In this work, we employed the autoregressive integrated moving average (ARIMA) model to forecast the daily number of new COVID-19 cases in Saudi Arabia in the next four weeks. The ARIMA model has been recently used to predict the dynamics of COVID-19 disease in the most affected 15 countries [17] and showed a realistic numbers that are almost identical to the current situation in those countries. Another study that used this model focused on Italy and Spain and the prediction results exhibited an acceptable accuracy for the daily number of cases in these two countries [12]. It is worth noting that the reason for focusing on Saudi Arabia in this research work is because it is regarded as the heart of the Muslim-populated countries, from which about 2 million people are planning to land in Saudi Arabia in the mid-July 2020 in order to visit the two holy cities, Mecca and Medina, for performing Umrah and Hajj pilgrimages. Therefore, it is important to forecast the future trend, and accordingly, present a set of useful recommendations for the authorities as to how to lessen the spread of the disease and implement new rigorous measures to avoid a potential suspension of these pilgrimages.

Materials and methods

Models description

This research focuses on the use of linear parametric model structure prediction approach. The simplest and very widely applied model structure is called Autoregressive (AR) model. In AR model, the current output $z(t)$ is expressed by previous values and parameters α_{t-p} , as formulated in (1), where t is the time and p is the parameters order.

$$z_t = -\alpha_1 z_{t-1} - \alpha_2 z_{t-2} - \dots - \alpha_k z_{t-p} + \varepsilon \tag{1}$$

where $\alpha(z^{-1})$ is given by

$$\alpha(z^{-1}) = 1 - \alpha_1 z^{-1} + \dots + \alpha_k z^{-p} \tag{2}$$

A less common model structure compared to AR is called moving average (MA). In MA model, the output $z(t)$ is expressed in term of innovation input including filtered with the weights β_q as formulated in (3) and (4).

$$z_t = \varepsilon + \beta_1 \varepsilon_{t-1} + \beta_2 \varepsilon_{t-2} + \dots + \beta_t \varepsilon_{t-q} \tag{3}$$

$$\beta(z^{-1}) = 1 - \beta_1 z^{-1} + \dots + \beta_k z^{-q} \tag{4}$$

By combining both AR and MA we get a more augmented structure called ARMA model that is defined in (5).

$$z_t = -\alpha_1 z_{t-1} - \dots - \alpha_k z_{t-p} + \varepsilon + \beta_1 \varepsilon_{t-1} + \dots + \beta_t \varepsilon_{t-q} \tag{5}$$

A more augmented model is called Autoregressive Integrated Moving Average (ARIMA), where differences at least once are included. The formula ARIMA model is expressed in (6). This model has many successful prediction practical examples in literatures in different fields such as the mentioned [16].

$$z_t = (1 - z_{t-d}) - \alpha_1 z_{t-1} - \dots - \alpha_p z_{t-p} + \varepsilon + \beta_1 \varepsilon_{t-1} + \dots + \beta_t \varepsilon_{t-q} \tag{6}$$

ARIMA model is identified by assigning the order for the three terms: p for AR, q for MA and the number of difference steps d

Parameters estimation

Before estimating the parameters for the ARIMA model, the data were tested for stationarity using Augmented Dickey–Fuller (ADF) test, for which the null hypothesis H_0 is that the time series is said to be non-stationary. The result of the ADF test suggested that the time-series data were non-stationary ($p > 0.05$). After applying the first difference, i.e., $d(0)$, the p -value obtained was less than the significance level ($p < 0.05$) and the statistical ADF is lower than any of the critical values, so null hypothesis was rejected.

The parameters of ARIMA model were chosen based on the value of Akaike information criterion (AIC) which is given by (7).

$$AIC_{p,q} = \frac{-2 \ln(\text{maximized likelihood}) + 2r}{n} \approx \ln(\hat{\sigma}_a^2) + r \frac{2}{n} + \text{constant} \tag{7}$$

where n is the number of data observations, $r = p + q + 1$ and $\hat{\sigma}_a^2$ is the maximum likelihood prediction.

Table 1 shows the AIC values for different p and q parameters.

We have tested different values of p and q parameters ranging from 0 to 5, while d was chosen to be 1 based on ADF test. We found that the best ARIMA model that gives the lowest AIC values is ARIMA(2,1,1).

Models performance measures

A very common accuracy measurement functions are used to assess the performance of each model described above. These performance functions are:

- Root mean square error (RMSE):

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (z_i - \tilde{z}_i)^2}$$

where z_i and \tilde{z}_i are actual and predicted values, respectively.

- Mean absolute error (MAE):

$$MAE = \frac{1}{N} \sum_{i=1}^N |z_i - \tilde{z}_i|$$

- Coefficient of determination (R^2):

$$R^2 = 1 - \frac{\frac{1}{N} \sum_{i=1}^N (z_i - \tilde{z}_i)^2}{\frac{1}{N} \sum_{i=1}^N (z_i - \bar{z}_i)^2}$$

where \bar{z}_i is defined as $\bar{z}_i = \frac{1}{N} \sum_{i=1}^N z_i$

- Mean absolute percentage error (MAPE):

$$MAPE = \frac{1}{N} \sum_{i=1}^N \left| \frac{\tilde{z}_i - z_i}{\tilde{z}_i} \right|$$

- Root mean squared relative error (RMSRE):

$$RMSRE = \sqrt{\frac{1}{N} \sum_{i=1}^N \left(\frac{\tilde{z}_i - z_i}{\tilde{z}_i} \right)^2}$$

Table 1
ARIMA order selection based on AIC approach.

q in MA(q)	p in AR(p)					
	0	1	2	3	4	5
0	246.273	246.409	238.148	240.046	236.383	239.350
1	222.589	220.098	210.423	241.333	237.323	223.239
2	220.125	213.321	214.084	228.322	212.937	215.669
3	257.311	230.384	245.298	252.156	259.344	228.294
4	243.833	241.455	239.998	245.431	243.221	238.334
5	236.772	236.386	242.226	239.999	241.029	244.204

Table 2
Performances of the proposed models to predict the total number of confirmed cases.

Model	RMSE	MAE	R^2	MAPE	RMSRE
ARIMA	21.17	14.93	0.99	2.16	0.024
ARMA	117.22	73.33	0.87	8.34	0.12
AR	180.29	160.4	0.69	32.32	0.25
MA	241.05	190.87	0.46	32.80	0.26

In this work, four statistical models are used to predict the spread of COVID-19 in Saudi Arabia. This includes AR, MA, ARMA, and ARIMA models. The performance of each model was evaluated using the above set of performance metrics, which provide the information for a good model fit. By analyzing the results in Table 2, it is clear that ARIMA model achieves the smallest RMSE, MAPE, RMSRE values, and highest R^2 value. Therefore, ARIMA model outperforms the other models, whereas the ARMA model is ranked second, followed by AR then MA models.

Data description

The data used in this work refer the daily and cumulative number of confirmed COVID-19 cases in Saudi Arabia, and are collected from the official website of Saudi Ministry of Health (<https://covid19.moh.gov.sa>). They contain information about the daily and cumulative number of infected cases in Saudi Arabia from March 2, 2020 to April 20, 2020. In addition, the data included the total number of confirmed cases across 31 affected cities.

Fig. 1 depicts the total number of the reported cumulative (in black) and daily (in blue) confirmed cases of COVID-19 in Saudi Arabia from March 2, 2020 to April 20, 2020.

The figure shows that the first confirmed case was reported on March 2, 2020, in the eastern province of Saudi Arabia. Two weeks following the first case report, the total number of confirmed cases reached 113 cases. The highest daily number of confirmed cases is 1147 cases, and it was reported on April 20, 2020.

If we analyze the trend of the number of the daily confirmed cases in Saudi Arabia, as it is shown in Fig. 1, we can clearly see that it took 20 days after the first confirmed case to exceed 100 infected patients. The number of infected patients went down the next day to 52 cases and then increased with 3.94 growth rate. In the next 10 days, there was a fluctuation in the number of reported cases ranging from 92 to 203. Suddenly, the number of infected patients went from 203 to 327 in the next 6 days with a growth rate of 2.33.

There are 50 cities in Saudi Arabia affected by COVID-19. The top four cities with highest number of COVID-2019 confirmed cases are Mecca (2857 cases), Riyadh (2356 cases), Medina (2008 cases), and Jeddah (1935 cases). The north region of Saudi Arabia has less percentage of the number of confirmed cases (about 2.08%). Overall, there have been 11,631 confirmed cases in Saudi Arabia, up to the date of writing this manuscript, among which 14.12% have recovered and 0.94% have died.

Results

As discussed previously, four different models were used to predict the expected number of confirmed cases over the coming four weeks in Saudi Arabia. To evaluate the performance of the models, the data were split up into two subsets, with each subset used for testing once while the other subset was used for training the models. The data were partitioned into training and testing sets in the ratio of 70:30. After training the models, they were then used to predict the number of daily confirmed cases in the testing set. By comparing the results shown in Fig. 2 and Table 3, we can see that ARIMA(2,1,1) model is in good agreement with the actual values ($p > 0.05$), and therefore it should be able to predict the number of confirmed cases of COVID-19 in Saudi Arabia in the next coming weeks better than the other models.

Fig. 3 and Table 4 show the predicted confirmed cases from April 21, 2020 to May 21, 2020. The forecasted curve based on ARIMA(2,1,1) model (in red) of daily confirmed cases of COVID-19 for the next month and the current number of confirmed cases officially registered by the Saudi Ministry of Health from March 2, 2020 to April 20, 2020 (in black) are shown in Fig. 3. Additionally, the results also show that the cumulative infected patients of COVID-19 in Saudi Arabia can reach 127,129 after one month. Using the ARIMA model forecasting, the estimated average increase in number of confirmed cases every day is about 213 cases with a growth rate ranging from 0.2 to 10.8 every day. The forecasting results also shows that Saudi Arabia will not reach the plateau in COVID-19 cases in the next month. We can see clearly that both the confirmed cases rate and the cumulative cases rate of COVID-19 continue to increase.

Discussion

The number of novel coronavirus (SARS-Cov-2) cases continues to escalate at an alarming rate across the globe. The total number of infected people is now over 2.5 million in over 212 countries, about 0.46% of whom are in the Kingdom of Saudi Arabia. The main purpose of this work is to monitor and forecast the epidemiology of the new COVID-2019 in Saudi Arabia by applying a commonly used statistical analysis model, known as an ARIMA model, based on the data of confirmed daily cases officially announced by the Saudi Ministry of Health. We believe that theoretical studies based on statistics modeling play a vital role in understanding the pandemic characteristics of the outbreak and hence we can predict the potential tendency of the COVID-19 pandemic. The findings of such statistics modelings give a full picture of the current pandemic situation and assist the authorities in being proactive by making strategies and productive decisions to combat the pandemic and thus limit its impact on society, healthcare systems, and economy.

Based on our results, the prediction methods of ARIMA model performed better than other models discussed above. As such, the daily number of confirmed cases of COVID-19 pneumonia in Saudi Arabia were predicted using ARIMA(2,1,1) model after first-

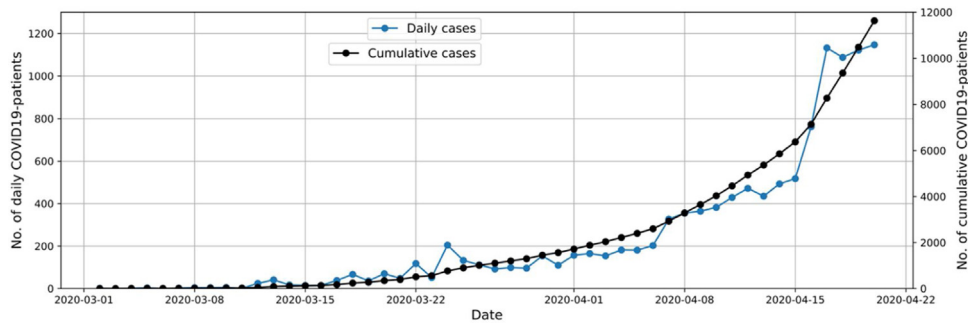


Fig. 1. The cumulative (in black) and new daily confirmed (in blue) cases of Covid-19 in Saudi Arabia as a function of days from March 02, 2020 to April 20, 2020.

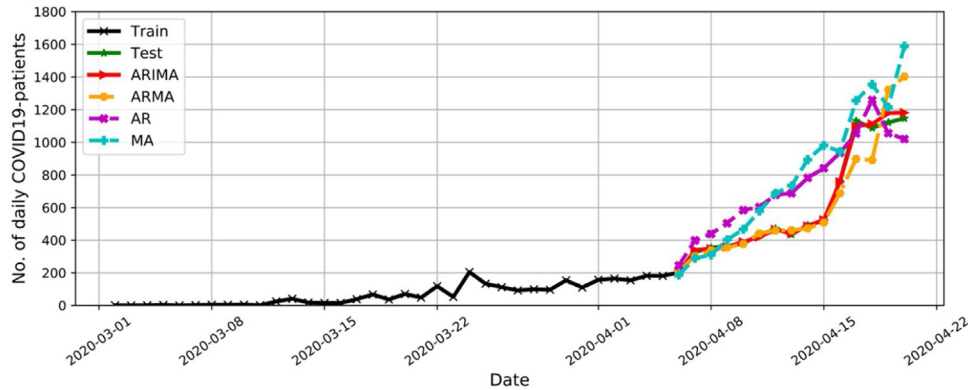


Fig. 2. Comparison of prediction results for the daily number of confirmed cases in Saudi Arabia. The comparison used the ARIMA, ARMA, AR, and MA models.

Table 3
Comparison of the predicted and actual values of the ARIMA, ARMA, AR, and MA models with 95% confidence interval.

Date	Actual	ARIMA	ARMA	AR	MA
04-06-2020	203	199 (98, 108)	210 (143, 277)	245 (170, 320)	187 (94, 280)
04-07-2020	327	340 (328, 352)	302 (235, 369)	399 (324, 474)	289 (196, 382)
04-08-2020	355	348 (336, 360)	338 (271, 405)	439 (364, 514)	310 (217, 403)
04-09-2020	364	360 (348, 372)	356 (289, 423)	505 (430, 580)	403 (310, 496)
04-10-2020	382	390 (378, 402)	377 (310, 444)	585 (510, 660)	467 (374, 560)
04-11-2020	429	420 (408, 432)	442 (375, 509)	604 (529, 679)	579 (486, 672)
04-12-2020	472	466 (454, 478)	460 (393, 527)	678 (603, 753)	688 (595, 781)
04-13-2020	435	442 (430, 454)	461 (394, 528)	689 (614, 764)	735 (642, 828)
04-14-2020	493	487 (475, 499)	473 (406, 540)	783 (708, 858)	895 (802, 988)
04-15-2020	518	525 (513, 537)	509 (406, 576)	842 (767, 917)	981 (888, 1074)
04-16-2020	762	758 (770, 746)	689 (756, 622)	936 (1011, 861)	944 (1037, 851)
04-17-2020	1132	1099 (1087, 1111)	899 (832, 966)	1054 (979, 1129)	1256 (1163, 1349)
04-18-2020	1088	1112 (1100, 1124)	892 (825, 959)	1259 (1184, 1334)	1355 (1262, 1448)
04-19-2020	1122	1179 (1167, 1191)	1322 (1255, 1389)	1056 (981, 1131)	1216 (1123, 1309)
04-20-2020	1147	1182 (1170, 1194)	1403 (1336, 1470)	1021 (946, 1096)	1589 (1496, 1682)

order difference processing. The findings clearly show that the number of daily cases in Saudi Arabia could rise from 1147 to 7668 daily cases and 11,631 to 127,129 cumulative daily cases within one month. This alarming progression in the number of confirmed cases indicates that extreme preventive and control measures must be immediately implemented in Saudi Arabia, especially in those highly affected cities such as Riyadh, Jeddah, Mecca, and Medina. These cities are where the expected 2 million pilgrims will be landed in mid-July 2020. The latter two cities are where the rites of pilgrimages are performed. Therefore, the decision makers in Saudi Arabia only have either of these two options: suspension of pilgrimages, which have never been suspended for over 1400 years, or implementation of new extreme measures – including mass testing – to reduce the progression of COVID-19.

To mitigate the escalating impact of this pandemic, there must be a collaborate intensive work among different parties, including

individuals, communities, and government bodies led by the Ministry of Health. The first and utmost proactive measure is to actively engage the local community clinics in this battle so that nurses and medical workers establish regular visits to residential buildings in their district to weekly monitor the temperature of the residents and other symptoms of COVID-19; and if some have symptoms, they must be sent to the nearest hospital to do the necessary diagnostic tests for a potential pneumonia; and if tested positive, they put in a quarantine allocated buildings and receive the necessary treatment options. If the coronavirus is widely spread in specific districts, they must be isolated, and a full curfew in those districts must be implemented.

Despite Saudi Arabia has completely closed its borders, locked down regions so that individuals do not travel across the country, and implemented a partial curfew with limited traffic interval from 6 am to 3 pm, the spread of the virus is still growing and will continue to escalate as per the predictions made by this

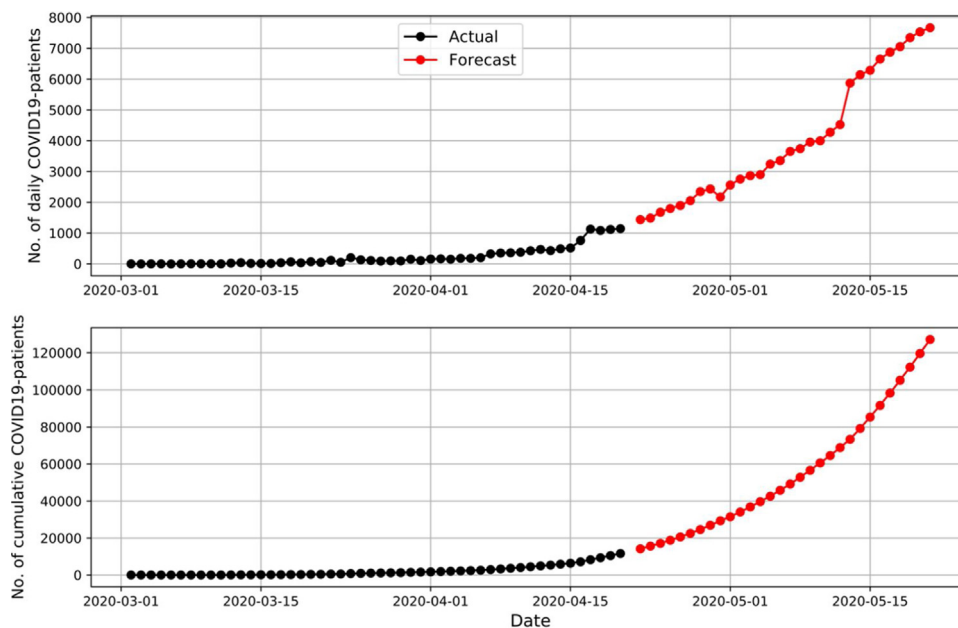


Fig. 3. The forecasting results of the total number of daily confirmed cases (above) and cumulative cases (below) in Saudi Arabia. The black curve is the actual confirmed cases from March 2, 2020 to April 8, 2020, and the red curve if the predicted cases from April 9, 2020 to May 8, 2020.

Table 4

The prediction epidemic results of COVID-19 in Saudi Arabia for the next month as predicted by ARIMA model.

Date	Confirmed cases (expected)	Date	Confirmed cases (expected)
04-21-2020	1289	05-07-2020	3654
04-22-2020	1440	05-08-2020	3742
04-23-2020	1489	05-09-2020	3958
04-24-2020	1679	05-10-2020	4002
04-25-2020	1799	05-11-2020	4276
04-26-2020	1896	05-12-2020	4523
04-27-2020	2056	05-13-2020	5873
04-28-2020	2349	05-14-2020	6145
04-29-2020	2433	05-15-2020	6288
04-30-2020	2175	05-16-2020	6653
05-01-2020	2563	05-17-2020	6875
05-02-2020	2755	05-18-2020	7056
05-03-2020	2867	05-19-2020	7345
05-04-2020	2899	05-20-2020	7531
05-05-2020	3243	05-21-2020	7668
05-06-2020	3356		

study. This might be attributed to the mass gatherings happening in the stores and local markets during the permitted traffic time without taking seriously the preventive measures such as social distancing and hand hygiene. Another reason for this continual spread is that many families are still gathering with their relatives in some places during the permitted traffic time, which put the family and their relatives at a tremendous risk of infection. Hence, the authorities need to involve the local police stations in such conditions by roaming in their districts and halting any potential gatherings as well as imposing fines on those disobedient to the movement restrictions. It would be more practical to impose a full curfew across the country so that the potential infections get confined indoors until they get monitored by the local community clinic nurse or through the ministry hotline for such cases.

Building an empirical model to predict COVID-19 daily cases has limitations starting from the uniqueness of the virus and the availability of the data. This work was done on the 20th of April, after almost one and a half month from the 1st recorded case in Saudi Arabia, where only increasing curve is recorded and

this might not enough to train the mathematical model properly. Second, the prediction model was based on current precautionary at a specific time of submitting the paper, which is expected to be changed and more restriction could be added to limit the sharp increase in the number of cases. Although the ARIMA model is usually a great option for such a forecast problem, there are few drawbacks on the method like, it does not have automatic updates, a new run has to be performed when new data added. Also, the prediction accuracy has a direct relation with the number of data. Moreover, ARIMA model is a linear model structure and our relief problem is nonlinear, as a result, if the model contains high nonlinearity the accuracy is expected to be reduced.

Conclusion

In this work, we studied the trend pattern of the COVID-19 outbreak in Saudi Arabia. We found out that the best prediction models for forecasting the trend of daily confirmed cases in Saudi Arabia is ARIMA (2,1,1). Using this model, we were able to estimate the daily reproduction number of confirmed cases for the next month. The predicted daily confirmed cases may reach up to 7668 cases on May 21, 2020 and the daily cumulative cases may be over 127,000 by the end of the month. These findings can potentially help in prompting policies to address COVID-19 pandemic and put viable strategies to contain it through introducing new movement restrictions as well as conducting proactive mass testing for potential COVID-19 cases across the country. Finally, we presented some containment recommendations ranging from the involvement of local community clinics in mass screening the residents within their neighborhoods, to imposing more extreme movement restrictions, to the importance of considering the full curfew in an effort to speed up the confinement of this disease and limit the outdoor person-to-person infections. This work has a lot of scope for improvement in the future in order to predict the spread of the pandemic of COVID-19 more accurately by including the statistics for predicting the daily deaths and recoveries. In addition, training the model on more data will lead to more precise forecasting.

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Conflict of interest

There is no conflict of interest for this work.

Ethical approval

Not required.

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