

Nonlinear Time Series Analysis of Pathogenesis of COVID-19 Pandemic Spread in Saudi Arabia

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Abstract: This article discusses short-term forecasting of the novel Corona Virus (COVID-19) data for infected and recovered cases using the ARIMA method for Saudi Arabia. The COVID-19 data was obtained from the Worldometer and MOH (Ministry of Health, Saudi Arabia). The data was analyzed for the period from March 2, 2020 (the first case reported) to June 15, 2020. Using ARIMA (2, 1, 0), we obtained the short forecast up to July 02, 2020. Several statistical parameters were tested for the goodness of fit to evaluate the forecasting methods. The results show that ARIMA (2, 1, 0) gave a better forecast for the data system. COVID 19 data followed quadratic behavior, and in the long run, it spreads with a high peak. It is concluded that COVID-19 will follow secondary shock waves, and it is strongly advisable to maintain social distancing with all safety measures as the pandemic situation is not in control.

Keywords: COVID-19; short-term forecast; ARIMA; GIS

1 Introduction

Coronaviruses (CV) are RNA viruses that are respiratory pathogens. Coronavirus transmission is defined as zoonotic, i.e., between animals and people. They can cause benign seasonal illnesses like common cold as well as more severe public health emergencies like Middle East Respiratory Syndrome (MERS) and Severe Acute Respiratory Syndrome (SARS). However, the new strain of Coronavirus disease identified in 2019 has been reported for the first time in human beings [1]. The first case of COVID-19 was declared on December 31, 2019, in Wuhan, China, with several cases of ‘pneumonia due to unknown causes’ following in quick succession, marking the outbreak of the novel coronavirus disease. In a few weeks, the virus spread rapidly throughout China and worldwide. The Chinese authorities had to lock down Wuhan on January 23, 2020, to contain the viral transmission, but by that time, approximately 5 million persons had already left Wuhan [2,3] with an estimated reproduction number >1 (range 2.6–4.7), early reports predicted a potential Coronavirus outbreak [4]. This novel Coronavirus was named COVID-19 by WHO on February 11, 2020.



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Healthcare systems require an important prediction for disease to handle the corona pandemics and help others in finding recommendations in daily life to keep away from its spread. As per [5], the problem of two-layer nonlinearity coupled multiplex network problems with the application of Lyapunov stability theory has been proposed. The results verified by theoretical and numerical simulation are feasible and effective. The time-variant nonlinear equations have been solved to achieve faster convergence, which is independent of the initial states of the models [6]. The errors and nonlinearities in finite-time stability reduce by adopting the approximation ability of neural networks [7]. Recently, the paper [8] proposed an artificial intelligence to provide resource allocation and decision making the administrative authorities. The models also help to identify the critical cases based on the pathological reports but a limited size of 53 cases. The results have a high degree of accuracy.

1.1 Tracking the Numbers

Coronaviruses (CV) are RNA viruses that are respiratory pathogens. The first report of five hospitalized patients with pneumonia was on December 29, 2019. The numbers kept rising to 41 cases (January 2, 2020), 571 cases (January 22, 2020), 1975 cases (January 25, 2020) and 7734 cases (January, 30 2020), with a worldwide spread that included countries from Asian, European, North American and Australian continents. By February 7, 2020, a total of 31,161 peoples were reportedly infected, with more than 630 deaths in China alone [9]. The first 100,000 confirmed cases occurred in 3 months, but the next 100,000 happened only in the next 12 days [9]. On January 30, 2020, WHO declared COVID-19 as a public health emergency of international concern (PHEIC) [4]. As of June 04, 2020, WHO estimates 6,416,828 confirmed cases of COVID-19, including 382,867 deaths reported from 176 countries [10]. The total number of confirmed cases is rapidly rising, as reported by WHO (Fig. 1).

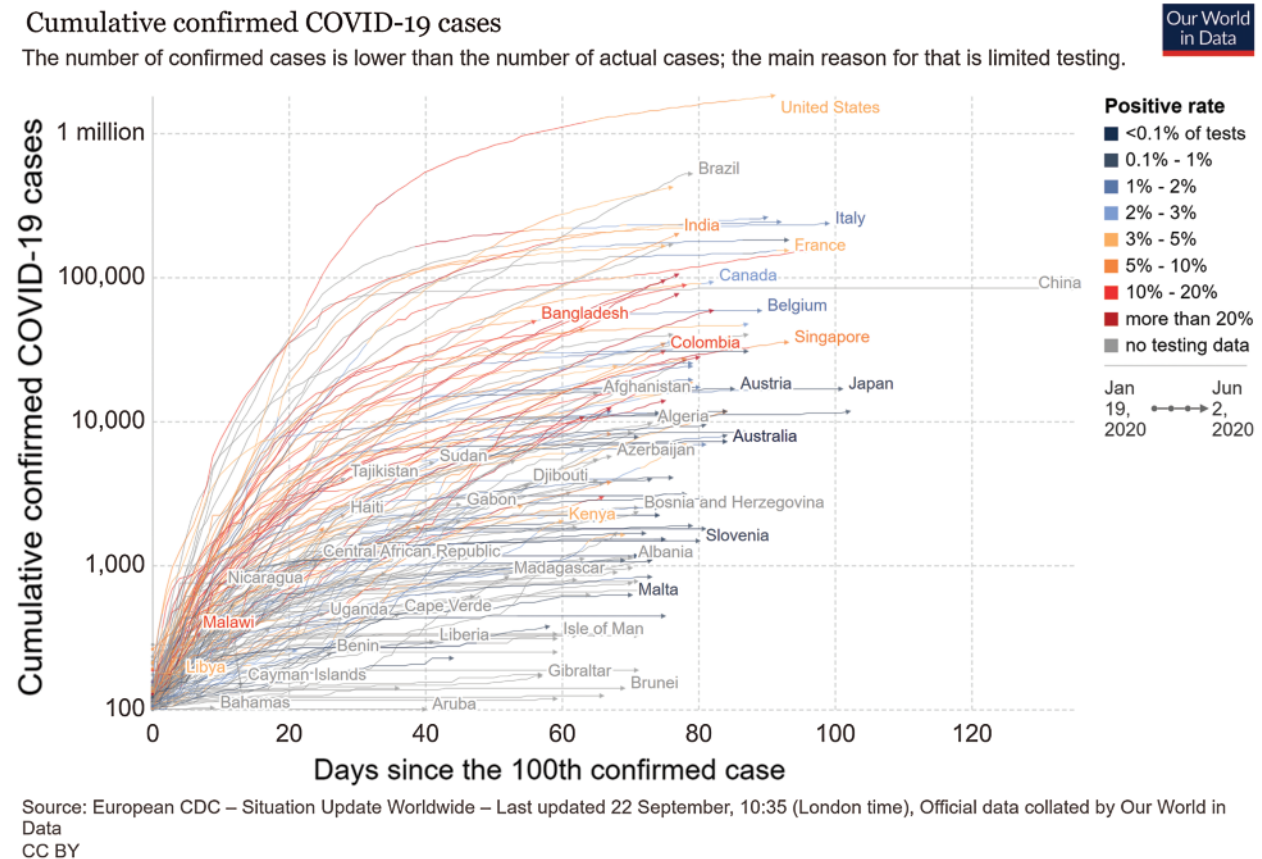


Figure 1: COVID-19 worldwide epidemic curve as reported by WHO

1.2 Modes of Spread

Coronavirus transmission is zoonotic, and once it enters human beings, person to person transmission takes over. Phylogenetic analysis implies that the COVID-19 is linked to the beta coronavirus genus, which attacks bats, human and certain wild mammal species [11]. Epidemiological investigations attributed SARS-CoV & MERS-CoV reservoirs to be civet cats and dromedary camels, respectively. However, possible animal sources of COVID-19 are under investigation. The first cases were found in a local wet market in Wuhan. Later, human-to-human spread occurred within families and among people with no history of contact to the wet animal market [12]. The transmission happens with direct contact or by droplets of coughing or sneezing from the infectious person. The human cellular receptor has been identified as angiotensin-converting enzyme 2 (ACE2) receptors, which bind to the SARS-CoV receptor-binding domain [13]. A study on nine pregnant women in their third trimesters found no evidence of vertical transmission to newborns [14]. Studies have estimated that the developing period of the virus lies within the range of one to fourteen days, with a median of five days. For 1,099 confirmed symptomatic patients, four days was the median incubation period with two to seven days as the interquartile range [15]. WHO's China fact-finding mission found that in Wuhan, the case-fatality rate was around 5.8%, as compared to 0.7% in the rest of China. One study calculated it to be at 2.2% [4]. Droplet transmission has been described as the primary mode of person to person transmission. These droplets are generated when an infected person coughs or exhales, which can either be inhaled by a nearby person or lands on nearby objects and surfaces. Others can then get infected by touching these surfaces and later touching their eyes, nose, or mouth. WHO & other health organizations' ongoing research on COVID-19 transmission is underway and will divulge information on other environmental factors that contribute to it [10,15].

1.3 Symptomatology and Diagnoses

Asymptomatic infection is a possibility; however, its incidence is unknown. The risk of getting infected from an asymptomatic person is very low but possible. Many infected people experience mild symptoms, which include fever, fatigue, dry cough, anorexia, and myalgia. Fever is the most common symptom and can be present from the beginning or in later stages. Severe disease can present with dyspnea and pneumonia and may require hospital admission. Acute respiratory distress syndrome (ARDS) is a significant complication and can develop in a variable proportion of hospitalized patients, which may require mechanical ventilation. WHO reported that for the severely infected, the recovery time was three to six weeks whereas it was about two weeks for those with mild infections [15]. The criterion for suspicion of COVID-19 is prominent in patients suffering from fever and/or breathing problems (e.g., cough, dyspnea) with the following history in the last 14 days: either coming in close association with a confirmed or suspected COVID-19 case, including healthcare workers; residence in or travel to hotspot areas (e.g., China, South Korea, most of Europe [including Italy, Iran, Japan]) and potential exposure by attending events where COVID-19 cases have been reported. Centers for Disease Control and Prevention [CDC] endorses the collection of a nasopharyngeal swab specimen or sputum specimen (in patients with productive cough) to test for SARS-CoV-2. Diagnostic RNA sequence is detected by reverse-transcription polymerase chain reaction (RT-PCR) [16].

1.4 Prescribed Precautions & Containment Measures

The current coronavirus has higher transmissibility between people as compared to SARS-CoV-1, which is less adapted to humans. Thus, while it caused severe infection, it was not very easily transmissible from one person to another. COVID-19 is mostly transmitted in hospitals and common places. Given the ease of transmission, this new coronavirus is transmitted mostly in the community and hence, requires stringent measures including social isolation. Measures taken for public welfare can delay the spread and dissemination of the virus. Actions such as sociable distancing, and travel-related interventions can forge an individual's protection. As of now, we have no cure or proper treatment for

COVID-19. WHO recommends a whole set of preventive measures to be taken at the individual and global level, which include [17].

1. Maintenance of personal & hand hygiene: Regularly washing with soap and water or with a hand rub (alcohol-based). Avoid touching nose, eyes, and mouth. Following good respiratory hygiene (covering face while coughing & sneezing)
2. Avoiding crowds & close contact with ill individuals (a minimum distance of 1–2 meters).
3. Mask to be worn only if you are symptomatic (especially coughing) or are looking after a confirmed case of COVID-19.
4. Surface disinfection: Regular cleaning with disinfectant to kill the virus
5. Screening: At international checkpoints; people with symptoms suspicious of COVID-19 to be forbidden travel
6. Stay home in case you feel ill. If having a cough, difficulty breathing, or fever, seek medical attention.
7. Preventive measures, especially for those who have recently visited or are in a hotspot zone areas in the last 14 days. Home isolation for even in mild symptoms, until recovery.

The first case in Saudi Arabia was reported on March 2, 2020. The data up to June 18, 2020 were taken into consideration and based on short-term forecasting techniques the intensity of the pandemic was estimated up to July 02, 2020.

2 Methodology

The different techniques and methodologies used for forecasting given in the flow chart as Fig. 2.

2.1 Case Fatality Rate (CFR)

CFR is a ratio of cumulative deaths to cumulative confirmed cases of a specified disease over a period. It gives us a measure of the severity of the disease. It is used to study the impact of disease and effect of treatment in medicine; it is not constant and varies between population, time, treatment and patient care. $CFR = (\text{total deaths}/\text{total confirmed cases}) * 100$

2.2 Time Series

A set of observations x_t is defined as a time series if it possesses observations at a time t . It is a discrete-time series when it is observed at a fixed time interval. Time series analysis is utilized:

- To identify the characteristics showcased by a sequence of observations
- To predict future trends of a variable taken (Forecasting).

2.3 Autoregressive Integrated Moving Average (ARIMA)

$ARIMA(p, d, q)$ is defined for a non-negative integer d if $Y_t(1 - B)^d X_t$ which is derived from $ARMA(p, q)$ process. The observations set $\{X_t\}$ satisfies the varying equation: $\phi^*(B) \equiv \phi(B)(1 - B)^d X_t = \theta(B)Z_t$, $\{Z_t\} \sim WN(0, \sigma^2)$, where, $\phi(z)$ and $\theta(z)$ are the polynomials of degrees p and q in powers of z , respectively, and $\phi(z)$ does not have a zero in the unit interval $|z| \leq 1$. $\phi^*(z) = 0$, at $z = 1$ for the order of d . The process is non-stationary if $d \neq 0$, in this case, it reduces to a $ARMA(p, q)$ process. For the other case when d is nonzero, the polynomial trend of degree $(d - 1)$ to $\{X_t\}$. $\{X_t\}$ is an $ARIMA(1, 1, 0)$ process if for some $\phi \in (-1, 1)$, $(1 - \phi B)(1 - B)X_t = Z_t$, $\{Z_t\} \sim WN(0, \sigma^2)$. In this case, $X_t = X_0 + \sum_{j=1}^t Y_j$, $t \geq 1$ where, $Y_t = (1 - B)X_t = \sum_{j=1}^{\infty} \phi^j Y_j$ [18–30]. For long term behavior or random walk, the slanting approximation of AR [1] and AR [2] coefficients along with constant terms are approximated using the iterated equation: $\hat{Y}_t = \mu + Y_{t-1} + \phi_1(Y_{t-1} - Y_{t-2}) + \phi_2(Y_{t-2} - Y_{t-3})$

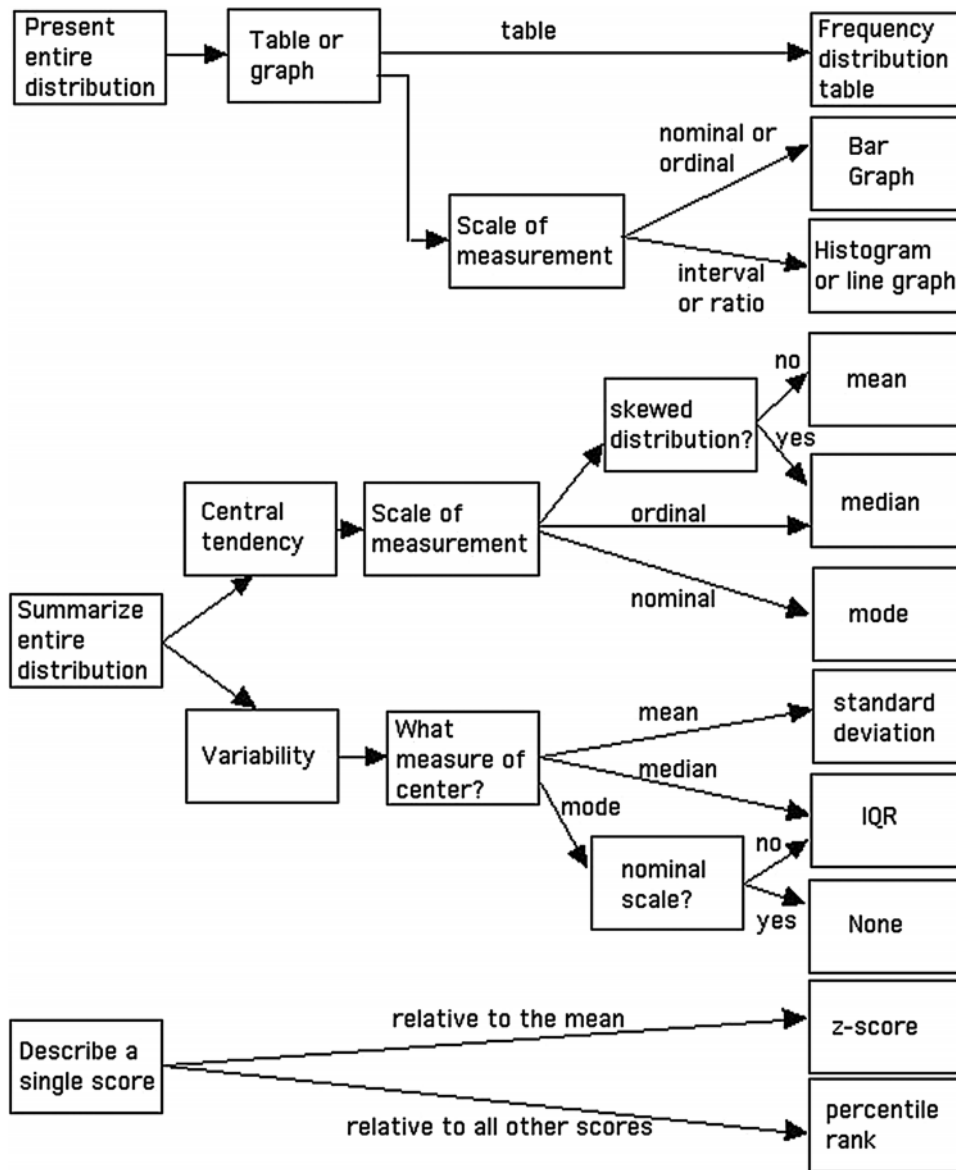


Figure 2: Descriptive analysis flow diagram

3 Results and Discussions for Model Selection

For long-term behavior, datasets of Saudi Arabia from March 2, 2020, to June 15, 2020 were analyzed. COVID-19 description of confirmed cases, active cases, recovered cases and death in different states of Saudi Arabia is shown in Fig. 3. Descriptive statistics are given in Tab. 1. Fig. 4 describes the trends of COVID-19 using a Q–Q plot with the details of correlation and the coefficient of determination. Time series of daily confirmed cases, the total confirmed cases, daily deaths, total deaths, daily recovered, and total recovered cases are shown in Fig. 5. Time series and trend analysis for CFR is shown in Fig. 6. Tab. 2 gives the details of the goodness of fit, whereas details of the AR (1) and AR (2) for the ARIMA (2,1,0) model are given in Tab. 3. Long-term forecasting using ARIMA (2,1,0) with residuals, ACF and PACF for daily confirmed cases, daily recovered cases, daily deaths, total confirmed cases, total deaths and total recovered cases are shown in Figs. 7–12, respectively. Fitting of the curve for forecast and trend analysis

for total confirmed cases, total recovered cases, total deaths and CFR has been plotted in Fig. 13 with forecasting values in Tab. 4. The results show that the Saudi Arabian health authorities can take effective decisions to cater to the needs of the new cases and old cases needing immediate healthcare for the COVID-19 pandemic. The Riyadh and Jeddah regions are especially affected, showing exponential growth since May 28. The incidence of new cases is increasing, and the government should take immediate actions such as lock down and media awareness programs. The daily confirmed cases have increased to 3500–4000 over the last ten days. Meanwhile, the deaths have also increased to 900, which is the highest in the gulf countries. This pattern forces a thorough review of the strategies to control the pandemic in Saudi Arabia. The intensive care and prevention unit should work on full capacity. The criticality of the situation is immense and will remain so till curative and preventive measures are adequately in place.

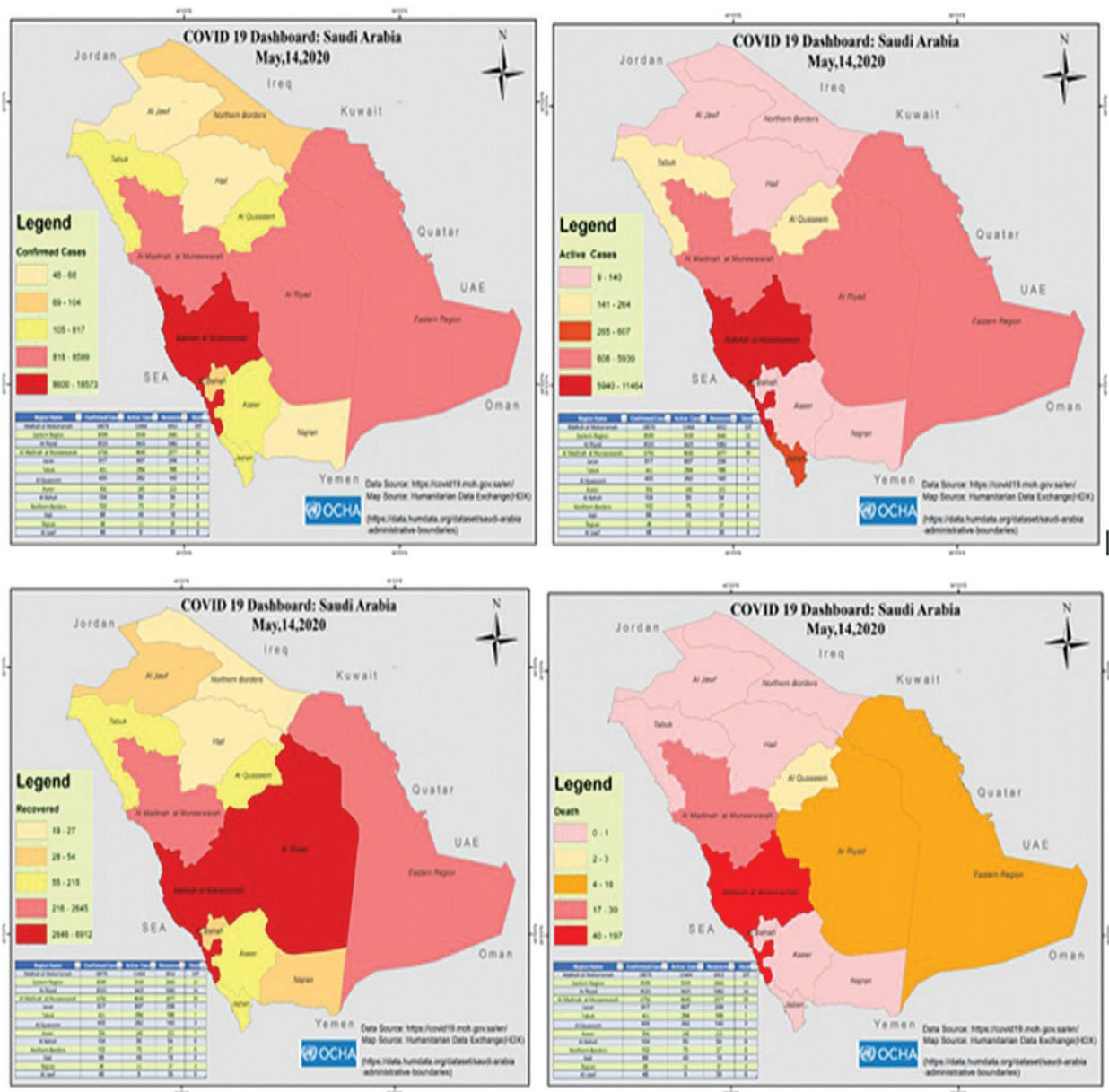


Figure 3: COVID-19 details for States of Saudi Arabia: Confirmed, active, recovered and death cases

Table 1: Descriptive statistics of COVID–19 pandemic in Saudi Arabia

Statistic	Daily Confirmed	Daily Recovered	Daily Death	Total Death	Total Confirmed	Total Recovered	CFR
Range	2840.00	6665.00	17.00	458.00	81765.00	60013.00	1.506
1st Quartile	92.00	4.00	0.00	1.00	767.00	29.00	0.130
Median	493.00	68.00	5.00	79.00	5862.00	990.00	0.609
3rd Quartile	1645.00	955.00	9.00	219.00	33731.00	9120.00	0.869
Mean	918.719	687.438	5.146	125.517	19837.798	8652.787	0.604
Variance	816936.091	1639557.8	20.217	18727.93	624806662.	229542917.	0.209
Standard Deviation	903.845	1280.452	4.496	136.850	24996.133	15150.674	0.457
C.V.	98.381	186.264	87.374	109.029	126.003	175.096	75.581
Variation Coefficient	0.978	1.852	0.869	1.084	1.253	1.741	0.752
Skewness (Pearson)	0.551	2.502	0.439	0.858	1.144	1.982	0.190
Skewness (Fisher)	0.561	2.545	0.447	0.873	1.164	2.016	0.194
Skewness (Bowley)	0.484	0.865	-0.111	0.284	0.691	0.789	-0.297
Kurtosis (Pearson)	-1.069	6.880	-0.625	-0.514	-0.011	2.923	-0.901
Kurtosis (Fisher)	-1.062	7.353	-0.591	-0.473	0.059	3.165	-0.883
CI (95.0%)	190.397	269.7302	0.947164	28.82777	5265.493	3191.52435	0.0961
S.E. Mean	95.807	135.728	0.477	14.506	2649.585	1605.968	0.048

From the figures and tables, it is observed that total confirmed, total death and total recovered cases are highly correlated. For ARIMA (2,1,0), it is observed that the value of constant is zero for all cases. Total confirmed cases, total deaths; total recovered cases and CFR are precisely fit to forecast using ARIMA (2,1,0) model, but daily deaths show a perturbed or random pattern, which is not perfectly fitted using ARIMA (2,1,0) model.

It may be observed that the actual and forecasted values using model ARIMA (2, 1, 0) for May 28, 2020, to May 30, 2020 are providing better results. It may be concluded that the ARIMA (2, 1, 0) model gives the best fit for long-term and short-term behavior. Hence, as the number of cases is increasing, proper cautionary measures and adherence to health guidelines are strongly recommended.

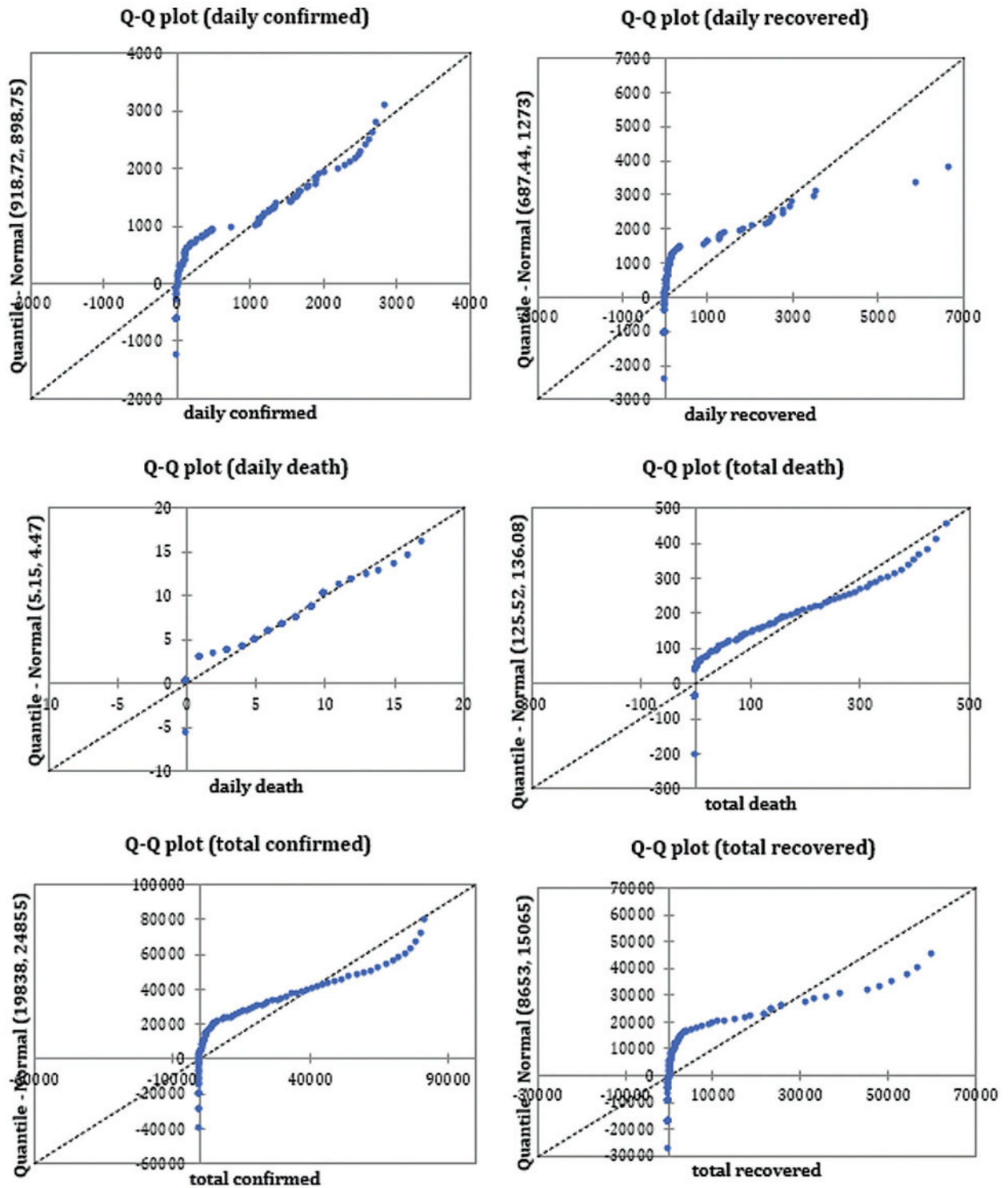
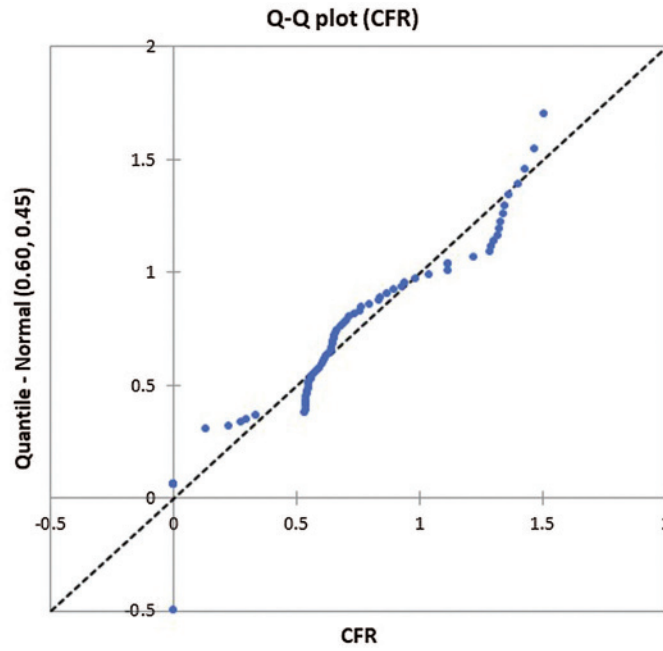


Figure 4: Q-Q plots for COVID 19 trends of Saudi Arabia



Trend of Coronavirus CFR

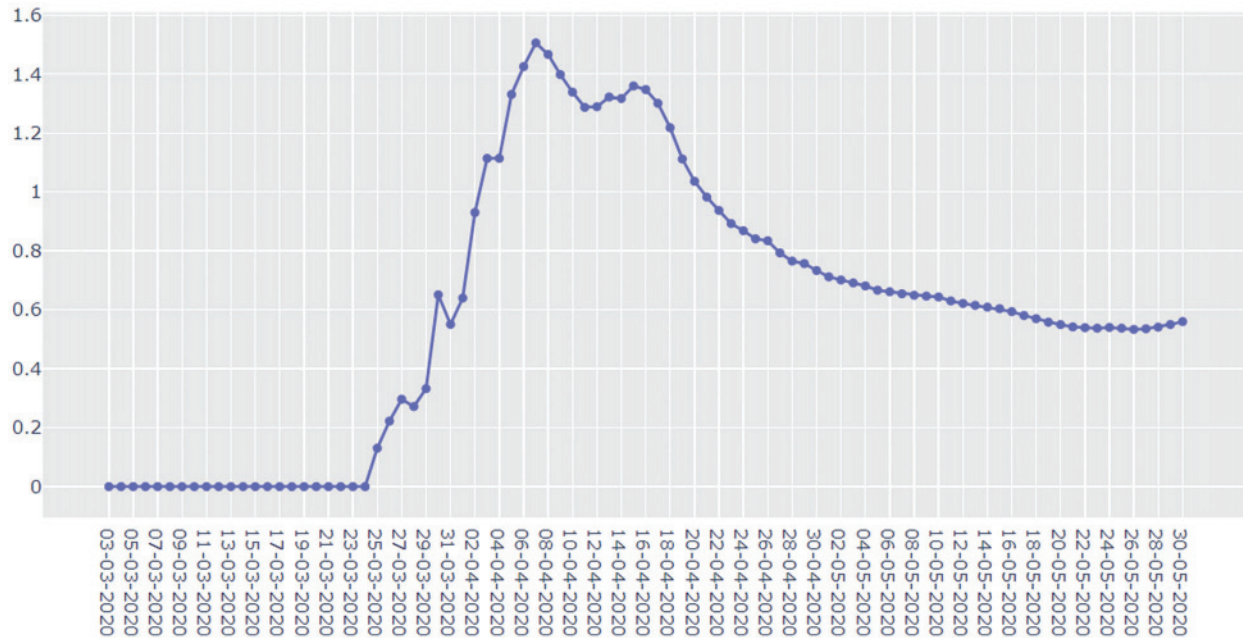


Figure 5: Time series and trend analysis for CFR in Saudi Arabia

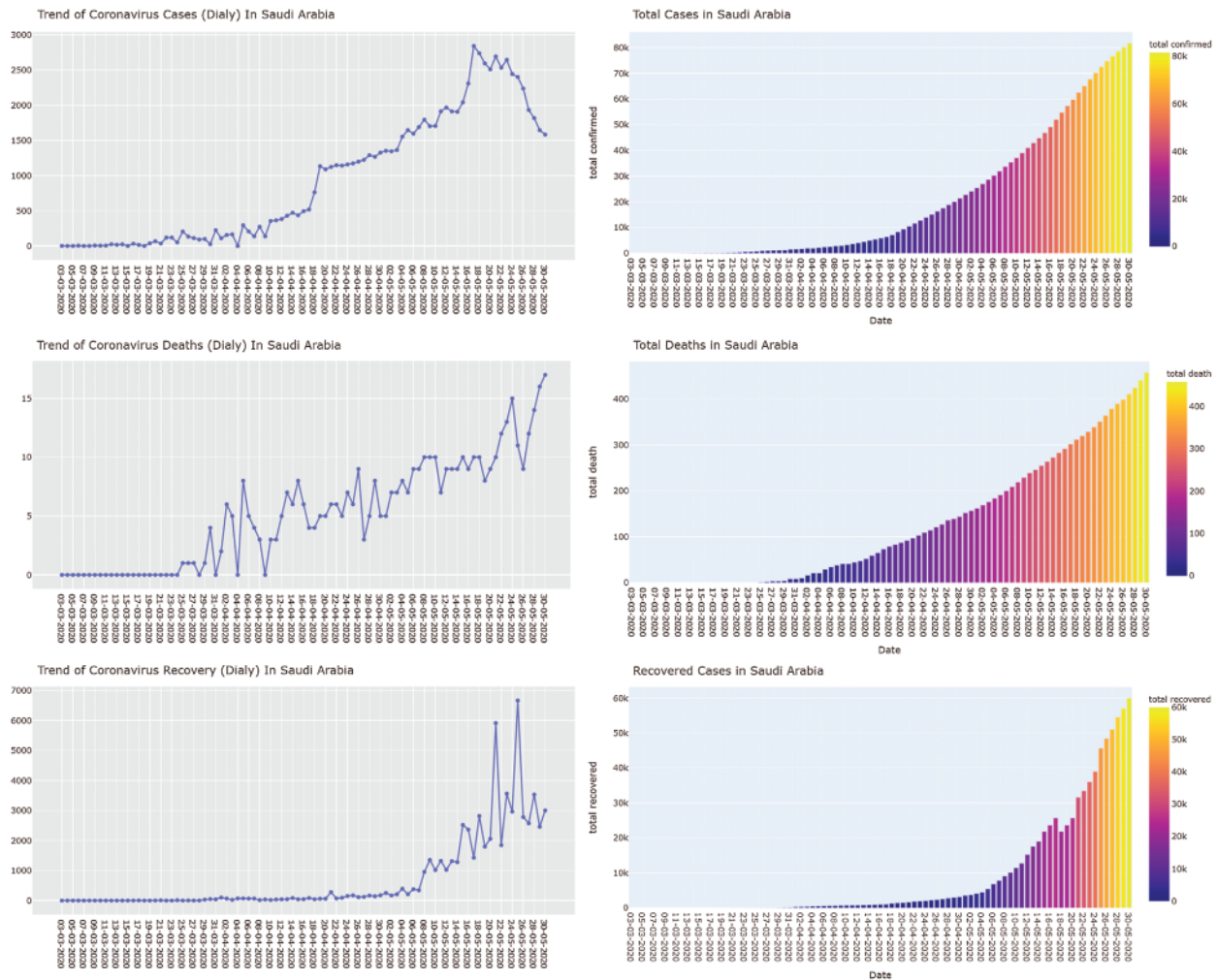


Figure 6: Time series for confirmed, and recovered cases and deaths

Table 2: Goodness of fit statistics at 95% confidence interval

ARIMA (2,1,0)	Daily confirmed	Daily recovered	Daily death	Total confirmed	Total death	Total recovered
Observations	78	78	78	78	78	78
DF	75	75	75	75	75	75
SSE	1071083	4548665	201.9451	1386006	238.8917	48833583
MSE	14281.1	60648.87	2.692602	18480.08	3.185222	651114.4
RMSE	119.5036	246.2699	1.640915	135.9415	1.784719	806.9166
WN Variance	14281.1	60648.87	2.692602	18480.08	3.185222	651114.4
MAPE(Diff)	107.2695	134.0415	84.07516	28.09379	28.74866	60.41713
MAPE	34.61708	49.83621	28.22668	6.603886	6.929255	11.92799
-2Log(Like.)	967.56	1080.822	299.1665	1006.569	315.2194	1265.88
FPE	15032.74	63840.92	2.834318	19452.72	3.352866	685383.6

Table 2 (continued).

ARIMA (2,1,0)	Daily confirmed	Daily recovered	Daily death	Total confirmed	Total death	Total recovered
AIC	973.56	1086.822	305.1665	1012.569	321.2194	1271.88
AICC	973.8843	1087.146	305.4908	1012.893	321.5437	1272.205
SBC	980.6301	1093.892	312.2366	1019.639	328.2896	1278.95
Iterations	49	75	77	1	185	129
Minimum	0.000	0.000	0.000	1.000	0.000	0.000
Maximum	2840.000	6665.000	17.000	81766.000	458.000	60013.000
Mean	918.719	687.438	5.146	19837.798	125.517	8652.787
St. Deviation	903.845	1280.452	4.496	24996.133	136.850	15150.674

Table 3: ARIMA (2, 1, 0) fitness with AR (1) and AR (2) data for COVID-19 parameters

AR (1)							
Type	Value	Hessian standard error	Lower bound (95%)	Upper bound (95%)	Asymptote. standard error	Lower bound (95%)	Upper bound (95%)
Total Confirmed	0.514				0.099	0.320	0.708
Daily Confirmed	0.057	0.113	-0.164	0.278	0.113	-0.165	0.279
Total Recovered	0.306	0.109	0.092	0.520	0.108	0.094	0.518
Daily Recovered	-0.653	0.110	-0.868	-0.438	0.109	-0.866	-0.440
Total death	0.560	0.101	0.361	0.758	0.102	0.359	0.760
Daily death	-0.606	0.103	-0.809	-0.403	0.104	-0.809	-0.402
AR (2)							
Total Confirmed	0.486				0.099	0.292	0.680
Daily Confirmed	-0.013	0.113	-0.235	0.208	0.113	-0.235	0.209
Total Recovered	0.291	0.112	0.072	0.511	0.108	0.079	0.504
Daily Recovered	-0.280	0.118	-0.511	-0.048	0.109	-0.493	-0.066
Total death	0.427	0.101	0.228	0.626	0.102	0.227	0.628
Daily death	-0.398	0.103	-0.599	-0.196	0.104	-0.601	-0.194

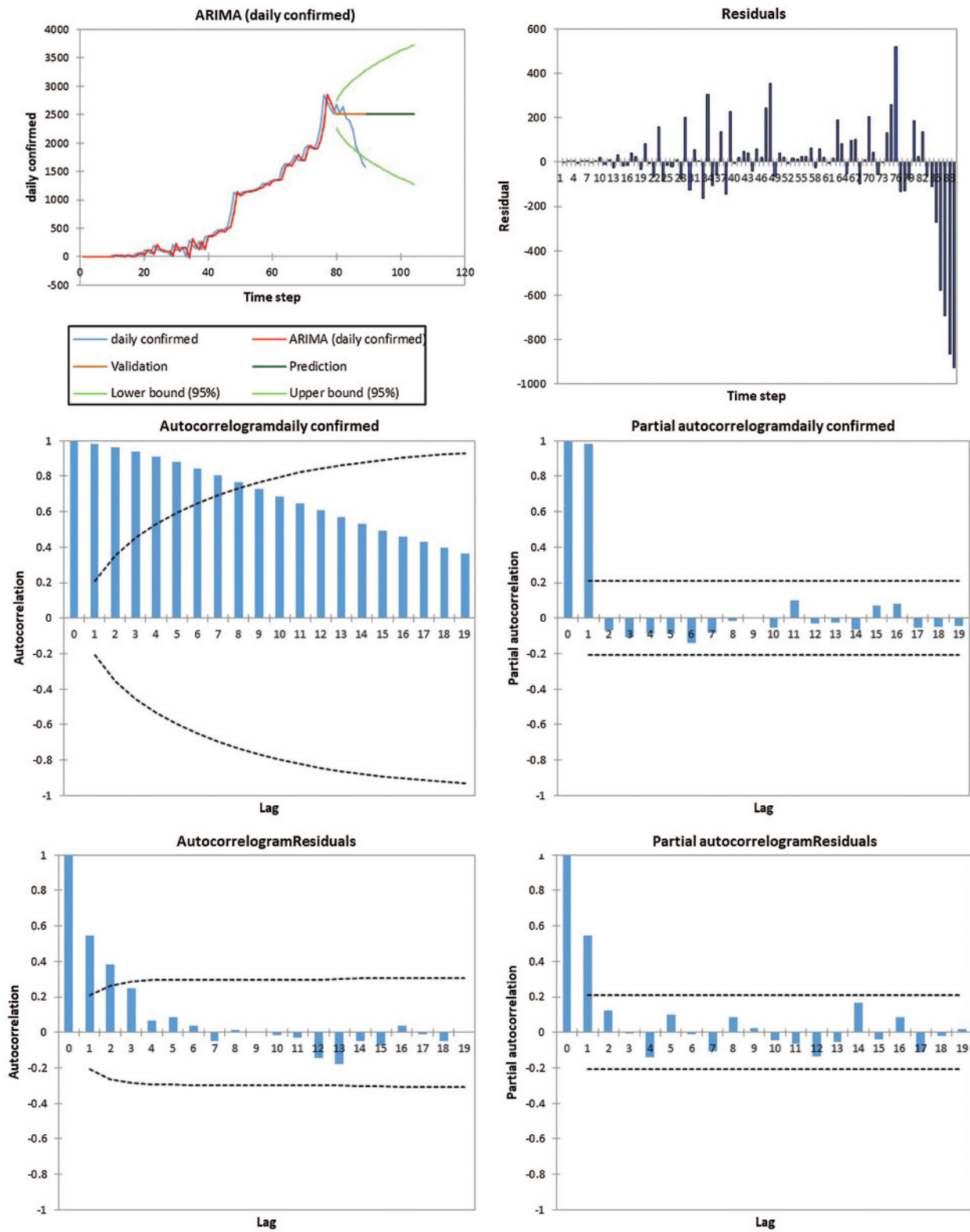


Figure 7: ARIMA (2,1,0) for daily confirmed cases

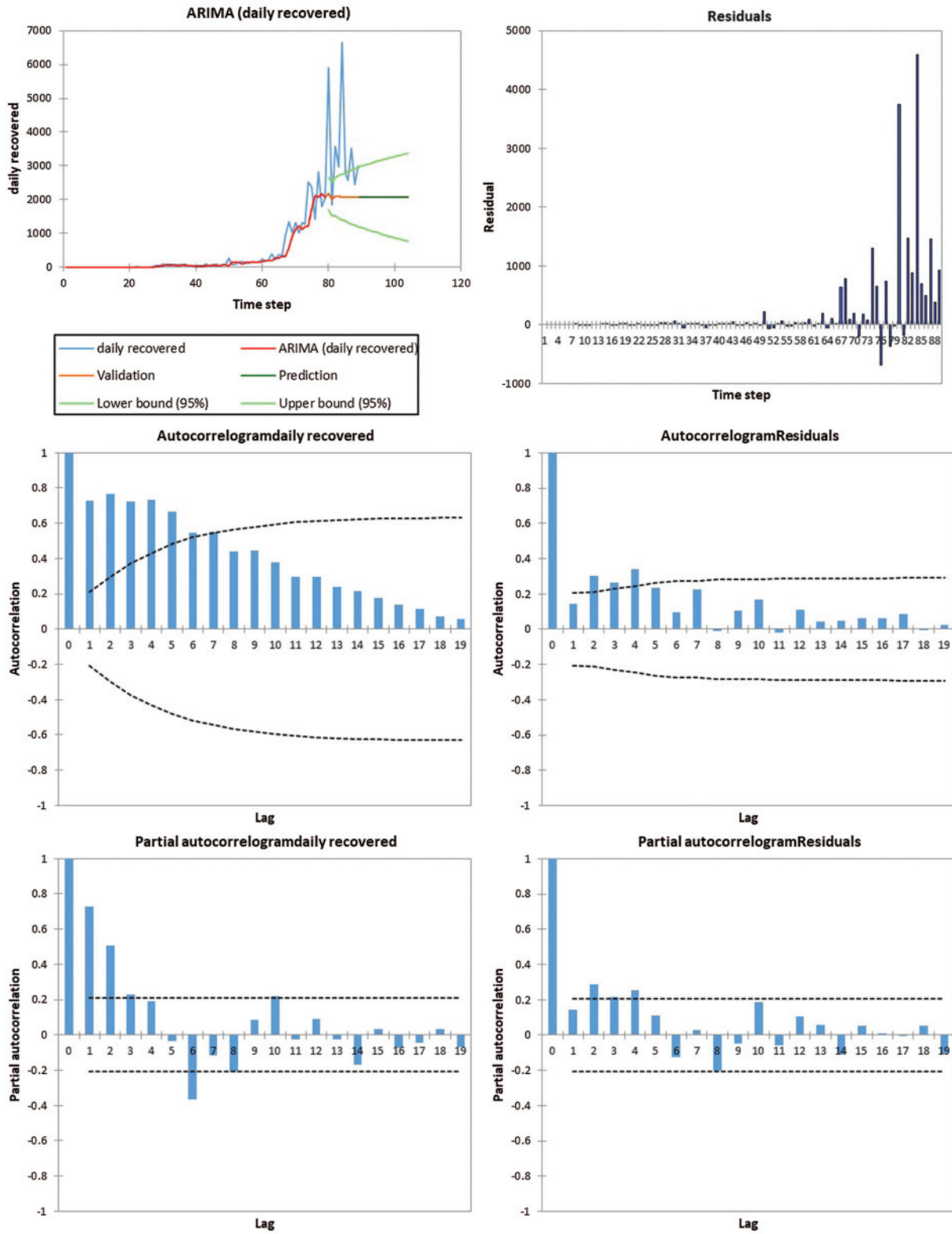


Figure 8: ARIMA (2,1,0) daily recovered cases

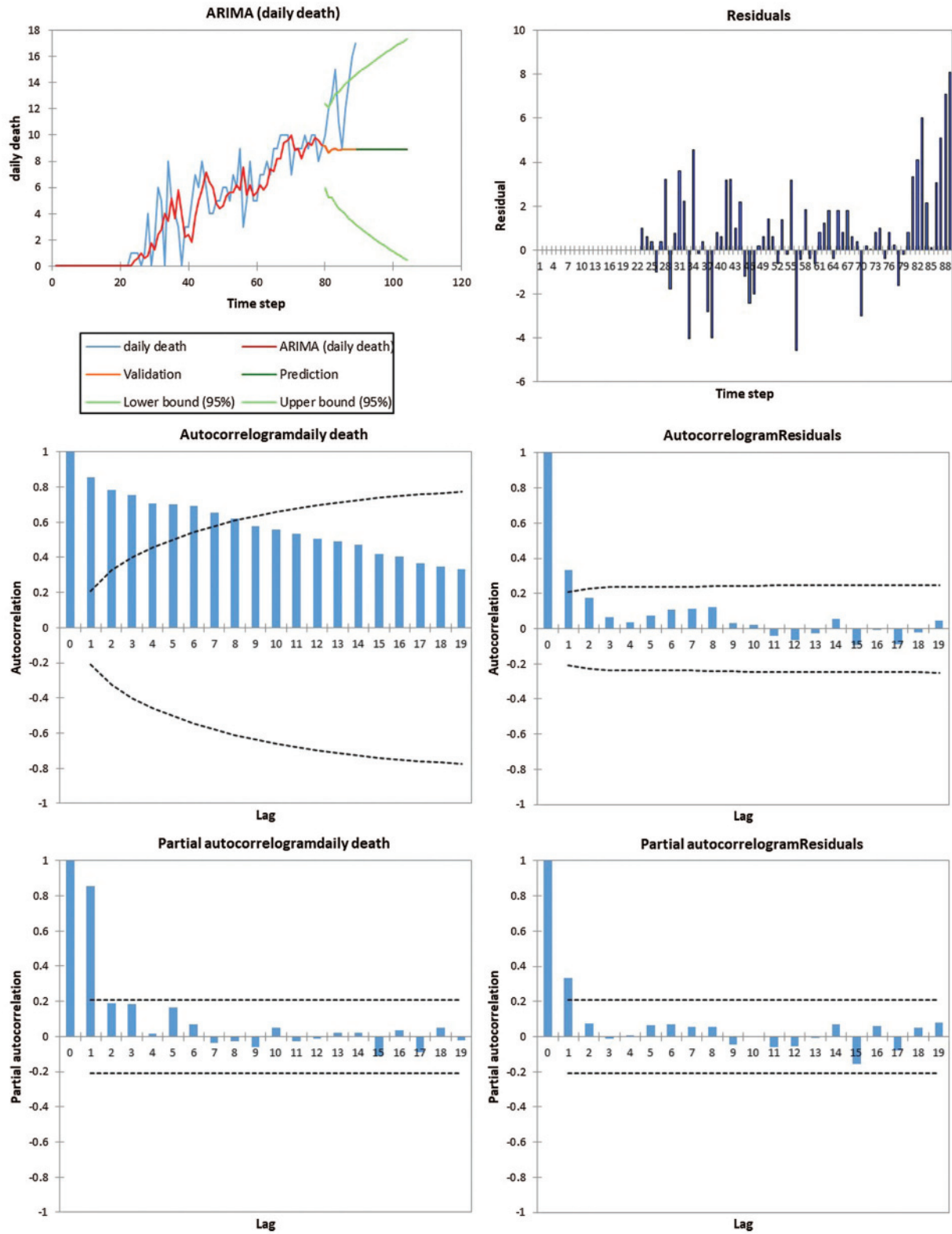


Figure 9: ARIMA (2,1,0) daily death cases

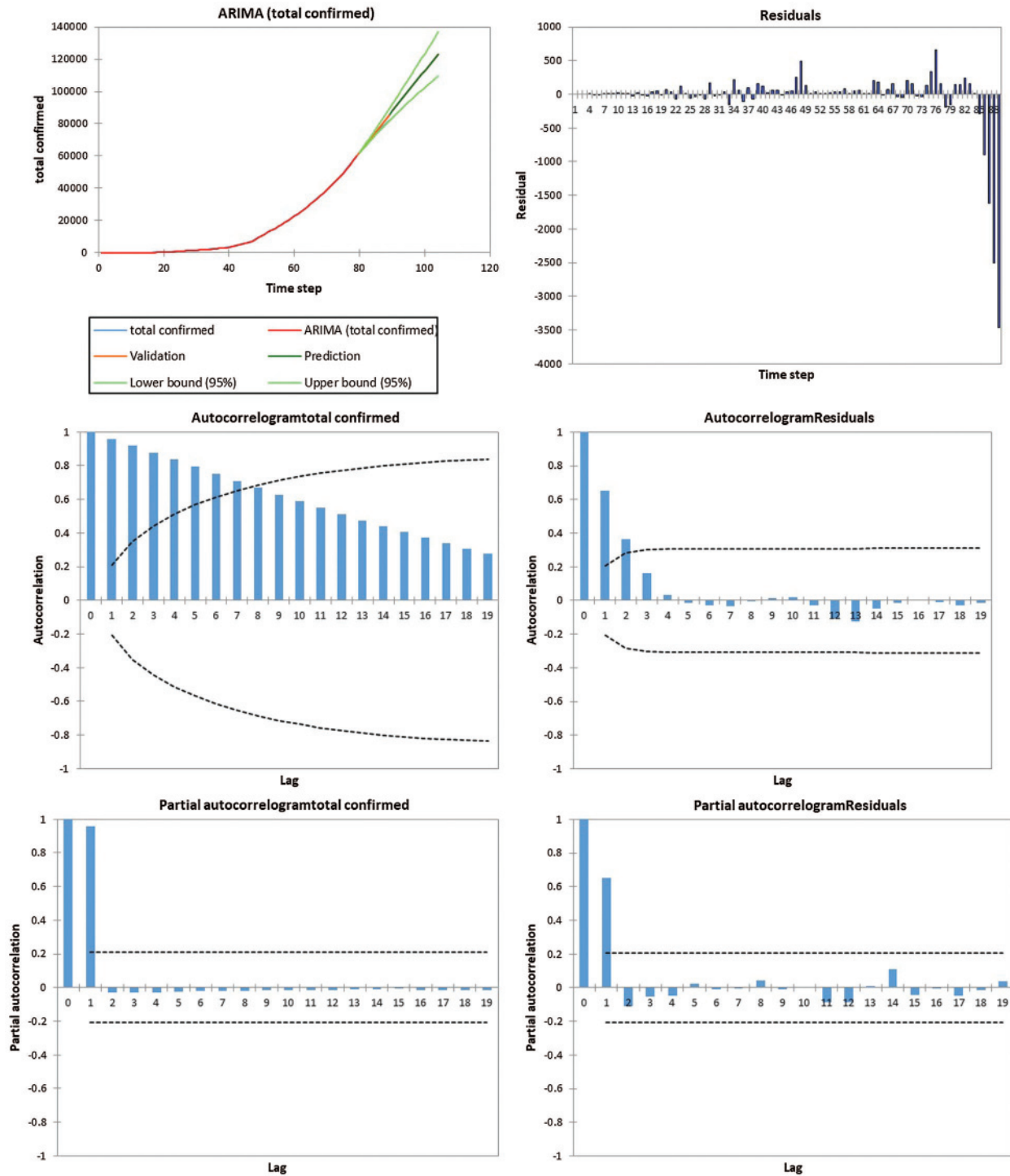


Figure 10: ARIMA (2,1,0) total confirmed cases

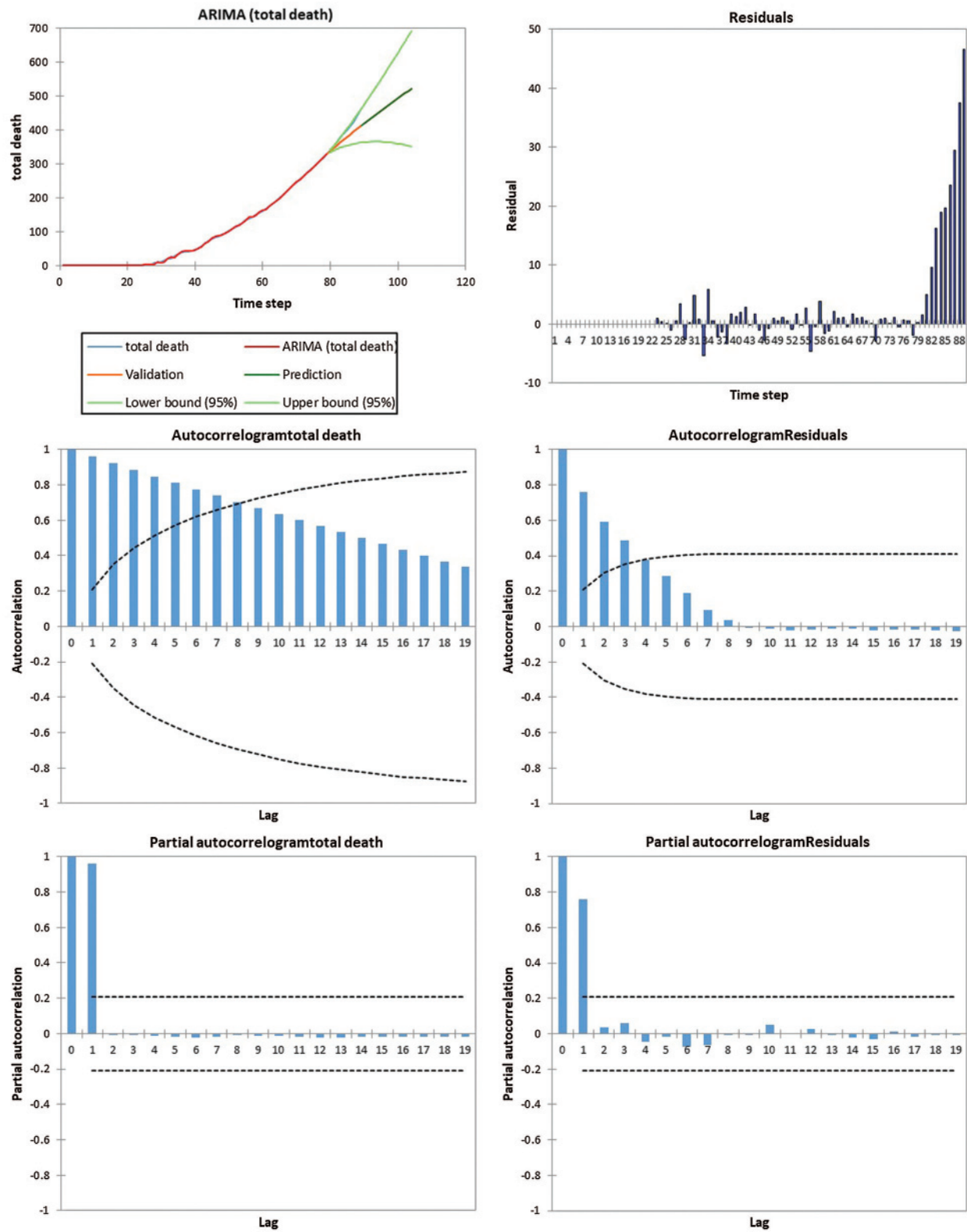


Figure 11: ARIMA (2,1,0) Total death cases

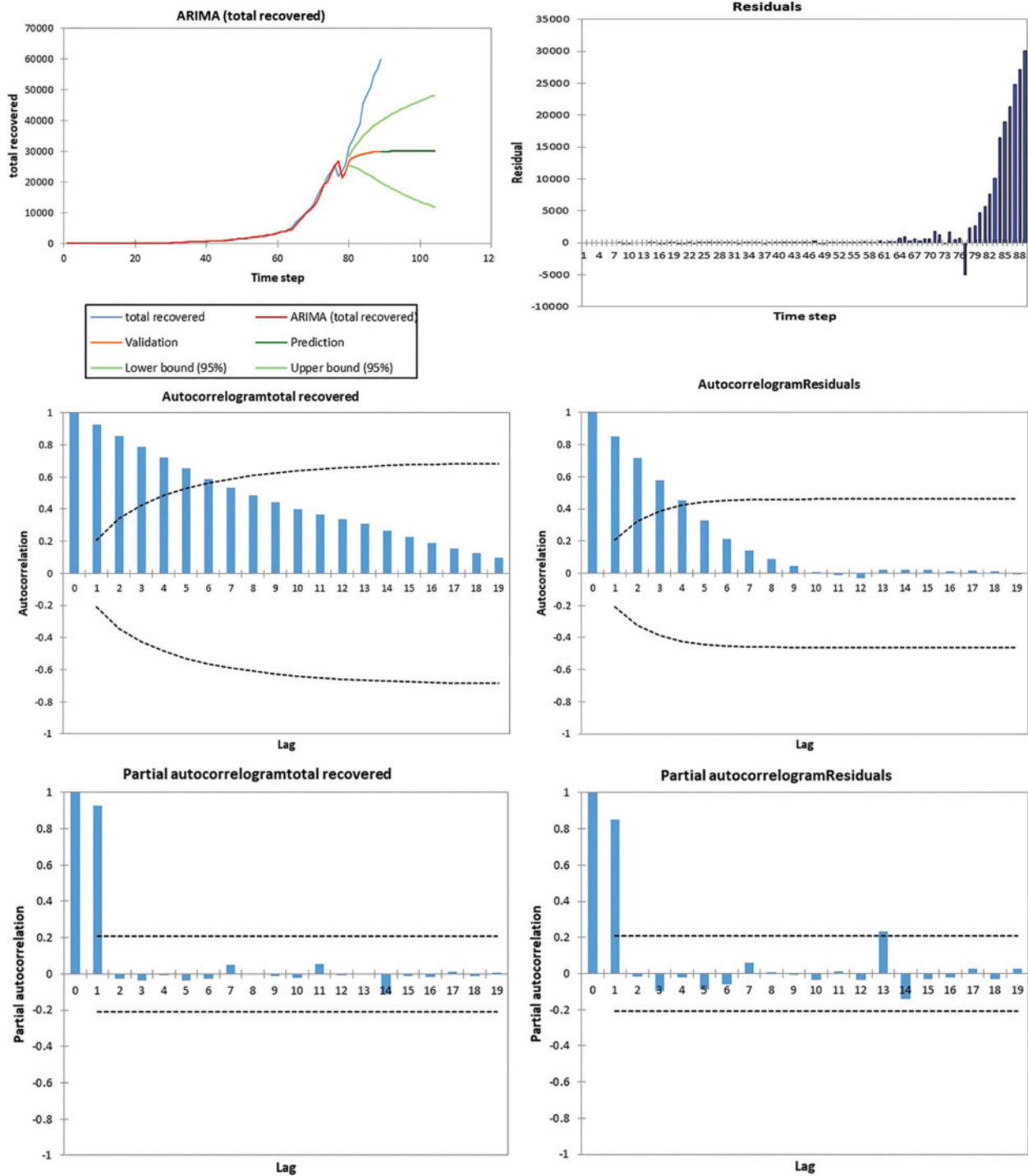


Figure 12: ARIMA (2,1,0) Total recovered cases

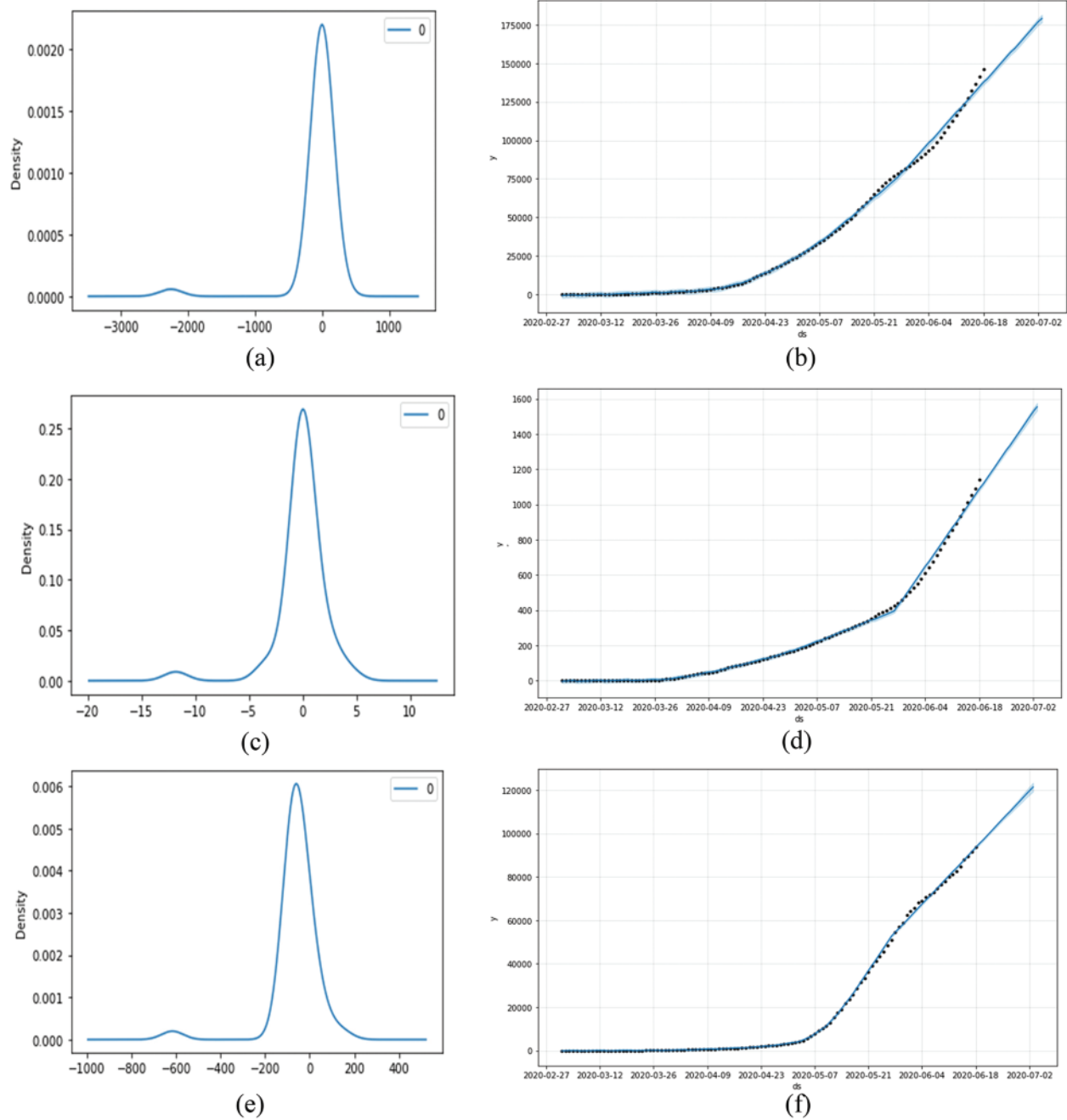


Figure 13: Forecast and trend analysis for total confirmed; total recovered; total death (a) Residual for total confirmed cases (b) Forecasting till July 02/2020 for total confirm (c) Residual for total death cases (d) Forecasting of total death cases (e) Residual for total recovered (f) Forecasting of total recovered cases

Table 4: Forecasting using ARIMA (2,1,0) model

Date	Total cases	Total deaths	Total recovered	Total active	CFR
19-06-2020	150755	1185	96023	53310	0.007868
20-06-2020	155509	1232	98116	55528	0.007938
21-06-2020	160256	1278	100139	57633	0.008008
22-06-2020	164995	1325	102120	59622	0.008079
23-06-2020	169725	1371	104050	61509	0.008150
24-06-2020	174448	1418	105936	63299	0.008221
25-06-2020	179164	1464	107777	65001	0.008292
26-06-2020	183871	1511	109578	66620	0.008363
27-06-2020	188571	1557	111339	68163	0.008434
28-06-2020	193263	1604	113062	69636	0.008505
29-06-2020	197947	1650	114750	71045	0.008576
30-06-2020	202623	1697	116403	72393	0.008647
01-07-2020	207292	1743	118023	73686	0.008718
02-07-2020	211953	1790	119611	74928	0.008789

4 Conclusion and Future Work

The forecasting of COVID-19 in order to predict the outcome of the disease in Saudi Arabia is critical for the policymakers and for the health department to focus on strengthening the surveillance system and reallocating the resources. The time series model plays an essential role in the prediction and control of the disease. This study has used the Geographic Information System [GIS] analysis and the ARIMA model for Saudi Arabia, the worst affected country in the Arabian region, to help predict the prevalence of the COVID-19 pandemic. The results of the study can help the policymakers to reallocate the resources like hospitals, staff, and the facilities required for the critically infected peoples. The cases are rising increasing in the country, and there is a need to ensure utilization of the available resources. The analysis helps in understanding the complex nature of the spread of the disease. The accuracy of an epidemic and pandemic forecasting largely depends on the data availability and uncertainty estimation. Despite this fact, forecasting based on data simulation has its advantage to better understand the present circumstances and plan the future. If the situation remains stable and data collection methods do not change significantly, then the predicted total number of recovered cases from the pandemic, until July 02, 2020, will be about 119,611 out of 211,953 confirmed cases. These predictions provide us the bounds of deaths forecasted as per the usual trend and extreme case scenario. Also, the results show very significant rise in the number of recovered cases, and reduction in the CFR value. Uncertainty prevails in the future, regardless of model and data, which needs to be kept in mind while making or acting upon any prediction; COVID-19 is not an exception. It is commendable that Saudi Arabia managed to limit the outbreak with its timely intervention. Nevertheless, the present analysis would be very helpful in dealing with the unwanted future rising trend of the COVID-19 infections in Saudi Arabia and develop guidelines or strategies to contain the pandemic. For further research, this method may be compared with other models like Neural Networks and machine learning.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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