BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-044102
Article Type:	Original research
Date Submitted by the Author:	22-Aug-2020
Complete List of Authors:	Al-Aamri, Amira; Ministry of Higher Education, Sultanate of Oman, Statistics Al-Harrasi, Ayaman; Ministry of Health Oman Al-Abdusalam, Abdurahman; Ministry of Higher Education, Sultanate of Oman Al-Maniri, Abdullah; Oman Medical Speciality Board, Strategy and Planning Department Padmadas, sabu; University of Southampton, Social Statistics and Demography
Keywords:	COVID-19, EPIDEMIOLOGY, PUBLIC HEALTH

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Forecasting SARS Covid-19 pandemic evolution and critical care resources threshold in the Gulf Cooperation Council (GCC) countries

Amira K Al-Aamri., M.Sc., Ph.D., Ayaman A Al-Harrasi., M.D., Abdurahman K Al-Abdusalam., Ph.D., Abdullah Al-Maniri., M.P.H., Ph.D., Sabu S. Padmadas, M.Sc., Ph.D.

Ministry of Higher Education, Sultanate of Oman, amira.alaamri@mohe.gov.om (AKA); Centre of Studies and Research, Ministry of Health, Sultanate of Oman, ayaman.alharasi@moh.gov.om (AAH),; College of Applied Sciences, Sultanate of Oman, abdulrhman.niz@cas.edu.om (AAA); Strategy and Planning Department, Oman Medical Specialty Board, Sultanate of Oman, abdullah.a@omsb.org (AAM); Social Statistics and Demography and Global Health Research Institute, University Of Southampton, S.Padmadas@soton.ac.uk (SSP)

Original article submitted for possible publication in BMJ Global Health
15 August 2020

Correspondence
Sabu S. Padmadas, M.Sc., Ph.D.
Professor of Demography and Global Health
University of Southampton, Highfield Campus
Southampton SO17 1BJ, United Kingdom
Email: S.Padmadas@soton.ac.uk

Word count abstract (298); main text (3011)

Contributors

All authors contributed substantially to the preparation of the manuscript including design, analysis and interpretation, and revising the article for important intellectual content. AKA, SSP and AAM conceived the idea and wrote the first draft of the paper. AAH and AKA conducted the literature review. Both AKA and AAH contributed equally to preparing the database and conducting the statistical analysis with technical support from AAA and SSP. AKA, AAH and SSP interpreted the findings. SSP and AAM revised the draft for intellectual content.

Funding

None

Competing interests

None declared

Patient and public involvement

No patients or public were not involved in the design, or conduct, or reporting, or dissemination of this research.

Patient consent for publication

Not applicable

Ethics approval

No formal ethical approval was required for this study.

Data sharing statement

Data used for the analysis are available in the public domain in anonymous aggregate format for research use. The list of data sources is available in the bibliography.

ABSTRACT

Objective

To generate cross-national forecasts of Covid-19 trajectories and their impact on essential critical care resources for disease management in GCC countries.

Design

Population-level aggregate analysis

Setting

Bahrain, Kuwait, Oman, Qatar, United Arab Emirates and Saudi Arabia

Methods

We applied an extended time-dependent SEICRD compartmental model to predict the flow of people between six states: Susceptible- Exposed-Infected-Critical-Recovery-Death, accounting for community mitigation strategies and the latent period between exposure, and infected and contagious states. Then, we used the WHO Adaptt Surge Planning Tool to predict ICU and human resources capacity based on predicted daily active and cumulative infected cases from SEICRD model. We assumed a stable population, asymptomatic population exposed are infectious, no re-infection rates and no changes in ICU resources during Covid-19.

Results

Covid-19 infections vary from 260 per million in Bahrain to 47 in Saudi Arabia and the number of deaths vary from 1.76 per million in Oman to 0.23 in Kuwait. Our predictions confirmed that UAE attained a peak towards the end of April 2020, and Oman and Bahrain by 2 August and 5 July respectively. In absolute terms, Saudi Arabia is predicted to have the highest Covid-19 mortality burden (3,972 deaths) by 31 October followed by Oman (987 deaths). The predicted maximum number of Covid-19 infected patients in need of oxygen therapy during the peak of emergency admissions vary between 690 in Bahrain, 1440 in Oman and over 10,000 in Saudi Arabia.

Conclusion

Our study demonstrates evidence of considerable variations in Covid-19 trajectory across GCC countries, and GCC countries have managed to flatten the epidemiological curve. The pandemic is predicted to recede over the next two months in the region. Current health infrastructure including the provision of ICUs and nursing staff seem adequate, but health systems should keep ICUs ready for managing critically ill patients.

Keywords: Covid-19; Gulf Cooperation Council (GCC); Forecasting; SEICRD model; Intensive Care Resources Capacity

Strengths and limitations of this study

- The analysis is the first of its kind in GCC countries to generate robust cross-national forecasts of Covid-19 and its impact on essential critical care resources for disease management.
- Overall, barring a few fluctuations, the difference between the observed and predicted number of deaths in the SEICRD model is generally marginal across GCC countries.
- The predictions are based on the assumptions that the populations under investigation are stable, asymptomatic population exposed are infectious, those confirmed Covid-19 positive will have no reinfections and no changes in ICU resources during Covid-19. Adaptt Surge Planning tool predictions of ICU resources apply to only inpatient care.
- Lack of availability of demographic and socioeconomic data restrict our understanding of the infection dynamics. Given the high representation of expatriate population across GCC countries, further investigation disaggregated by nationality is pertinent to understand the differential impact of Covid-19 on population sub-groups.

INTRODUCTION

The pace and magnitude of the novel, highly contagious Severe Acute Respiratory Syndrome (SARS) Coronavirus disease 2019 (Covid-19) pandemic outbreak vary substantially across world regions. Covid-19 first reported in Wuhan region of China[1,2] spread rapidly to European countries of Italy, Spain and the United Kingdom, and in North and Latin America including United States, Canada and Brazil.[3,4]

Within the Gulf Cooperation Council (GCC) countries, UAE reported the first four cases as early as 29 January 2020, and other GCC countries including Saudi Arabia, Oman, Bahrain, Qatar and Kuwait reported their first few cases towards the end of February 2020.[4,5] Since, then the new Covid-19 infections and deaths have more than doubled within the GCC region. For example, the weekly total number of new infections in GCC countries has doubled from 25,965 for the week May 3-9 to 51,713 for the week June 21-27, whereas the number of deaths per week increased from 144 to 393 during the same period. Saudi Arabia, the most populous country within GCC, has been the worst affected in terms of the total number of positive cases and case fatalities.[6]

While most GCC countries responded early to disease control and prevention in terms of enforcing social distancing, lockdown, public health awareness and behavioral change campaigns, the implementation was transient and inconsistent due to economic and demographic challenges. As countries prepare to face another global economic recession post Covid-19, the situation is exacerbated in GCC countries severely affected by the recent oil crash.[7,8] Covid-19 has also extensively disrupted national economic diversification plans and functioning of small and medium industries and businesses in the GCC region. On average, two-thirds of GCC population represent young expatriate workers, working mostly in services and construction sectors, and they live in congested accommodation, often with low wages.[9] The share of expatriate population is the highest in UAE and Qatar (over 80%) and the lowest in Saudi Arabia (33%).[9]

Data from respective government ministries show a disproportionately higher incidence of Covid-19 infections and deaths among expatriate workers. However, these data are currently unavailable for research use in GCC countries. Older people aged 65 and above constitute between 3.3% in Saudi Arabia and 2% or less in the rest of GCC countries, which partly explain the anomaly between high incidences of Covid-19 infections and low case fatalities in the region.

On the other hand, GCC countries have high rates of non-communicable and chronic diseases including ischemic and coronary heart diseases, obesity, hypertension and diabetes mellitus.[10,11] GCC countries spend, on average, 4.3% of their GDP on healthcare, ranging

between 5.8% in Saudi Arabia to 3.1% in Qatar, mostly for treatment and management of non-communicable and chronic diseases.[9]

Except for a few review and clinical studies,[12,13] there is no clear understanding of the future trends of Covid-19 in GCC countries and their impact on critical care capacity for disease management. As of 31st July, GCC countries with a combined population of 58.5 million conducted a total of 10.6 million tests, identified 631,628 positive cases, of these 558,693 (88%) recovered and 4,400 (0.7%) died.[6] The number of new cases reported every day remains high in the GCC region, particularly in Saudi Arabia.

The current pandemic situation is rather uncertain in GCC countries, especially with no systematic data on emergency admissions, and adequate population-level testing. The potential peak of the pandemic is uncertain and there is little consensus on resource allocation for emergency care including ICU beds and ventilator support in the event of further increase and new wave of infections. The goal of this article is to apply forecasting techniques to investigate the evolution of Covid-19 pandemic and quantify the critical care resource threshold for infection control and management in GCC countries.

METHODS

We considered a systematic approach to find the best model to predict the future evolution of Covid-19 pandemic and hospital resources capacity threshold in GCC countries. The input data derived from various sources including the Johns Hopkins Coronavirus Centre[4], Our World in Data[5], World Health Organization[3], GCC Stat[6] and respective Ministries of individual countries were verified for consistency.

We extended the SIR compartment model[14] by including variants[15-17] to develop a SEICRD model taking into account of community mitigation strategies and the latent period between when a person is actually exposed and until infected and contagious. It incorporates the transition of individuals between six states (**Figure A1**, Appendix). The states include Susceptible (S): number of individuals susceptible to be exposed; Exposed (E): number of individuals exposed where the disease status is latent, and individuals are infected but not infectious yet; Infected (I): number of individuals actually infected and infectious; Critical (C): infected individuals who need intensive care; Recovered (R): numbers infected who recover with an assumed lifelong immunity and they do not return to the Susceptible (S) state and the absorbing state Death (D).

We assumed that the population is stable, no re-infection of people who already had the infection and there are no changes in the size and composition of ICU resources during Covid-19. The input data included the number of ICU beds per 100,000 population, proportion of population by age group, transition probabilities from infected to critical, critical to dead, and the number of confirmed cases and deaths per day by country. The analysis was conducted in

Python Jupyter version 3.7.6.[18] The mathematical equations to predict the outcomes of SEICRD model are described in detail elsewhere.[19]

The SEICRD model predicts the number of ICU beds needed to treat Covid-19 critical cases, taking into account the predicted number of patients with critical conditions and existing bed capacity. Suppose that a given country has B number of ICU beds to treat C_N Coronavirus cases with critical condition. If the number of critically ill patients (C_N) exceeds the *number of* ICU beds (B), then we will have ($C_N - B$) critical cases that cannot be treated, and hence the patient may die due to the shortage in the number of ICU beds. However, if B is greater than C_N, then all critical cases have the chance to be treated.[19]

The predicted number of cases in need of critical care, critical cases requiring oxygen and mechanical ventilation, Extra Corporeal Membrane Oxygenation (ECMO) and Renal Replacement Therapy (RRT), nursing resources and specialized medical practitioners were estimated using WHO Adaptt Surge Planning Tool.[20] The input parameters for the Adaptt tool were based on the outputs from SEICRD model: daily predicted active infected, daily predicted new infected and cumulative infected cases. In the Adaptt tool, we selected the option very low scenario[20] attack rate (5%) which represents the percentage contracting Covid-19 at the population level, and a universal social distancing mitigation measure. The infection transmission rates have been relatively slower across GCC countries.

The Adaptt model predicts the future ICU beds needed by date, for treating patients with moderate, severe and critical symptoms including ECMO and RRT and the human resources needed. Note Adaptt model only considers inpatient care. It takes into account the number of nurses required per shift and the shift configuration for treating Covid-19 patients. The tool enables users to input epidemiological data and generate mitigation scenarios for hospital resources planning and decision-making. It classifies patients into mild, moderate, severe and critical categories according to the level of resources needed.[20] Those classified mild can recover at home without inpatient care, moderate require inpatient care, severe require inpatient care with oxygen therapy, and critical patients require inpatient care with mechanical ventilation.

Patient and Public Involvement

None

RESULTS

The mode of Covid-19 transmission is confirmed at the community level in Oman, UAE and Qatar whereas the infection is contained in different clusters in Bahrain, Kuwait and Saudi Arabia. **Table 1** shows the testing, confirmed cases and deaths attributed to Covid-19. The number of cases per day vary from 260 and 145 per million population in Bahrain and Kuwait to only 47 in Saudi Arabia.

Population level infection control measures including social distancing, lockdown, curfew and movement restrictions appear to have had perceptible effects only in UAE and Qatar whereas similar measures in other countries seem ineffective or inconsistent (**Figure 1**). As illustrated in terms of weekly average trends, Oman, Bahrain and Saudi Arabia recorded a steady increase in new cases until mid-June. **Figure 1** clearly demonstrates evidence of flattening of the epidemiological curve in Qatar and UAE, while other GCC countries are on the descending trajectory.

On the other hand, the number of daily tests carried out is the lowest in Oman and Kuwait (<1 per 1000 population) and highest in Bahrain and UAE. Saudi Arabia has the lowest testing rates proportionate to population size (**Table 1**). Qatar recorded the highest recovery rate (97%) followed by Bahrain (91%) and UAE (89%) whereas Oman recorded the lowest recovery rate (80%).

The total number of deaths varies between 104 per million population in Kuwait and 35 in UAE. Saudi Arabia has the highest mortality burden in absolute terms at the population level. The doubling time for mortality varies between 24-31 days in Oman and Bahrain, and 78 days in UAE.

The predicted future trends in Covid-19 based on the SEICRD compartment model are plotted in **Figure 2**. The chart on the left panel shows the number of people who are susceptible (light blue, decreasing over time) and recovered (green, increasing cumulatively over time), those who are infected (red) and exposed (grey) in the mid-panel, and those who become critical (blue) and eventually die (red). The predicted values are based on the probabilities of transition across different states from infected to critical, critical to dead and so on. Note that the scale (y-axis) is different for each panel because of varying population size for each country: Bahrain (1.69 million); Qatar (2.80 million); Kuwait (4.27 million); Oman (5.01 million); UAE (9.88 million) and Saudi Arabia (34.79 million).

To illustrate, in Oman, on the peak date of the infection (2 August), of the 3.26 million people susceptible to Covid-19, 264,025 people were infected, 87,552 exposed (infected but not infectious yet) and 1432 cases manifested severe or critical symptoms (**Table 2**). By 31 October 2021, Oman will have a predicted cumulative number of 987 deaths and 257 cases needing critical care.

The model estimates indicate that there are variations between GCC countries in terms of the date of the infection peak, with UAE as the first country in GCC to achieve a peak towards the end of April 2020. On the other end, Oman and Bahrain attained the peak on 2 August and 5 July respectively. In absolute terms, Saudi Arabia is predicted to have the highest Covid-19 mortality burden (3,972 deaths) by 31 October followed by Oman (987 deaths). By October

2020, GCC countries together will have a predicted 6,463 deaths and an additional 84 deaths by the end of this calendar year.

The fitted models were robust and there was little difference between the observed and predicted outcomes (**Figure A2,** Appendix). Overall, barring a few fluctuations in Kuwait, the difference between the observed and predicted number of deaths in the SEICRD model is marginal across GCC countries. In Kuwait, the model slightly over predicted the deaths during the first phase of the pandemic (April and May) and post mid-July. In Qatar, the model over-predicted the deaths during May whereas in UAE the deaths were slightly under-predicted during August 2020.

The predicted ICU equipment capacity and human resources for Covid-19 management is graphically illustrated in **Figures 3a and 3b** respectively. The model assumes that all active cases are detected at the population level, and also takes into account the lag between date of infection and date when symptoms become critical or severe. Note GCC countries are relatively well equipped with intensive care systems and human resources, and the existing systems are currently able to manage Covid-19 pandemic without disruptions. However, the circumstances could change if the infections surge beyond the predicted levels.

The predicted number of infected persons requiring critical care during the peak of emergency admissions (area shaded in blue) is estimated to vary between 2000 and 22,000 depending on the population exposed and actually infected. Those in need of oxygen therapy is predicted to vary between 690 in Bahrain, 1441 in Oman and over 10,000 in Saudi Arabia (**Figure 3a**).

The demand for total nursing staff during the peak of emergency admissions is predicted to vary from 2000 in Bahrain, 4000 in Oman to as high as 40,000 in Saudi Arabia (**Figure 3b**). However, Saudi Arabia has over 190,000 nurses available within health systems. In comparison, Bahrain has 4254 nurses, UAE 56,375, Kuwait 31602, Qatar 21032 and Oman has 21448 nurses currently in employment.[5,6] The models predict a high demand for specialized ICU nurses during the peak of emergency admissions, which is expected over the period from August to October in most countries, except UAE.

Strengths and limitations of this study

The analysis is the first of its kind in GCC countries to generate robust cross-national forecasts of Covid-19 and its impact on essential critical care resources for disease management. Overall, barring a few fluctuations, the difference between the observed and predicted number of deaths in the SEICRD model is generally marginal across GCC countries. The predictions are based on the assumptions that the populations under investigation are stable, asymptomatic population exposed are infectious, those confirmed Covid-19 positive will have no reinfections and no changes in ICU resources during Covid-19. Adaptt Surge Planning tool predictions of ICU resources apply to only inpatient care.

Lack of availability of demographic and socioeconomic data restrict our understanding of the infection dynamics. Given the high representation of expatriate population across GCC countries, further investigation disaggregated by nationality is pertinent to understand the differential impact of Covid-19 on population sub-groups.

DISCUSSION

The scale and community level spread of Covid-19 pandemic has been relatively less severe in GCC countries when compared to other economically advanced nations.[3,4] The infection was initially confined in small clusters during the early phase of the pandemic, and increasingly amongst expatriate workers living in labor camps and boarding houses near construction sites and service stations.

Most countries in GCC are sparsely populated except in capital cities and adjacent small cities. Infection control measures including travel, international border control, quarantine, social and religious congregation restrictions, short curfews, social distancing and lockdown were initiated early but appear to be not fully effective in most countries, including in Saudi Arabia which had the Middle-East Respiratory Syndrome (MERS) Coronavirus outbreak in 2012.[21] The number of Covid-19 positive cases showed a steady increase towards the end of May 2020, as people returned to work and resumed economic activities after the religious Eid holidays.

Our model-based predictions confirmed that UAE attained a peak towards the end of April 2020, and Oman and Bahrain by 2 August and 5 July respectively. In absolute terms, Saudi Arabia is likely to experience the highest burden of Covid-19 mortality followed by Bahrain, Oman and Kuwait.

These trends are predicted on the assumption that the current infection control measures prevail until the new infections are contained in small clusters, and with adequate testing and surveillance systems to trace, isolate and treat Covid-19 patients. Unless there is another wave or a newly mutated strain towards autumn and winter months, Covid-19 pandemic is likely to end in GCC countries by the end of the year. The variations in infection trends depend on population characteristics: size, composition, density and the readiness of hospitals to manage critical cases.

Our predictions show that the demand for specialized ICU nurses will continue until October 2020 and thus readiness plan need to be activated. There is also a need to make more nurses available to deal with the pandemic until early October 2020. These predictions are based on the assumption that the current public health interventions continue with adequate surveillance systems, and that the infection recedes without any further outbreak at the community level.

While the current health infrastructure including the provision of ICUs and nursing staff seem intact, health systems should prepare ICUs and be ready for managing patients with severe symptoms and complications at least until cases are brought under control in small clusters. The nursing population across GCC countries are predominantly expatriates from South and South East Asia and Africa. Media reports show trends of return migration of expat frontline health workers to their home countries since the pandemic started. Further investigation is needed reflecting on the demographic and socioeconomic data related to Covid-19. Unfortunately, we could not explore the population level characteristics such as age, sex, nationality and socioeconomic status due to lack of data.

International travel restrictions and quarantine measures can help reduce the infection rates as well enable systems to better coordinate appropriate public health response within countries.[22] Public health promotion should be intensified providing clear information, education and communication such as the need to maintain social distancing, infection prevention through sanitation and hygiene, proper understanding of the modes of infection spread and management of symptoms. The lack of proper risk communication and the ability to mitigate transmission in small populations highlight the need for strengthening public health expertise and leadership within the health system.

In the longer term, GCC countries need to address the major challenge of health inequity. There is evidence to suggest that expatriate workers, being the most vulnerable economically, die at younger age compared to native Arab population. It is essential to provide expatriate populations with appropriate health coverage, insurance and living standards to reduce the burden of future epidemic outbreaks. Equally important is the need to strengthen capacity and investment in pandemic research, and ensure monitoring systems to collect systematic data on infectious diseases. Alongside basic science research, we need to strengthen behavioral, social and cost-benefit economic analyses of government interventions to Covid-19 management and response.

CONCLUSION

Our study demonstrates evidence of considerable variations in Covid-19 trajectory across GCC countries and all countries have managed to flatten the epidemiological curve by early August. The pandemic is predicted to recede over the next two months in the region. Current health infrastructure including the provision of ICUs and nursing staff seem adequate, but health systems should keep ICUs ready for managing critically ill patients.

References

1. Zhu N, Zhang D, Wang W, et al. A novel coronavirus from patients with pneumonia in China, 2019. N Engl J Med 2020; 382: 727-33.
2. Zhou P, Yang X, Wang X. et al. A pneumonia outbreak associated with a new coronavirus of probable bat origin. Nature 2020; 579: 270–273.
3. Coronovirus disease 2019. Situation Report-72. Geneva: World Health Organization. https://apps.who.int/iris/bitstream/handle/10665/331685/nCoVsitrep01Apr2020-eng.pdf (accessed August 15, 2020).
4. Wuhan coronavirus (2019-nCoV) global cases: Operations dashboard. Johns Hopkins CSSE https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6 (accessed August 15, 2020)
5. Roser M, Ritchie H, Ortiz-Ospina E, Hasell J. Coronavirus pandemic (Covid-19). Our World In Data. https://ourworldindata.org/coronavirus (accessed August 18, 2020).
6. Coronavirus Pandemic Counts Map (COVID-19) for The Cooperation Council for The Arab Countries of The Gulf (GCC). GCC-Stat https://gccstat.org/en/covid-19-en (accessed August 20, 2020).
7. Nasir MA, Al-Emadi AA, Shahbaz M, Hammoudeh S. Importance of oil shocks and the GCC macroeconomy: A structural VAR analysis. Resource Policy 2019; 61: 166-179.
8. El-Saharty S, Kheyfets I, Herbst CH, Ajwad MI. The GCC countries response to Covid-19. Fostering Human Capital in the Gulf Cooperation Council Countries 2020; 39-57.
9. Gulf Cooperation Council Statistics, GCC-STAT 2020. https://www.gccstat.org/en (accessed July 26, 2020)
10. Rahim, HFA. Sibai A, Khader Y et al. Non-communicable diseases in the Arab world. The Lancet 2014; 383: 356-367.
11. Ng SW, Zaghloul S. Ali HI, Popkin BM. The prevalence and trends of overweight, obesity and nutrition-related non-communicable diseases in the Arabian Gulf States. Obesity Reviews 2010; 12: 1-13.
12. Uddin M, Mustafa F, Rizvi TA et al. SARS-CoV-2/Covid-19: Viral genomics, epidemiology, vaccines, and therapeutic interventions. Viruses 2020; 12:526.
13. Alandijany TA, Faizo AA, Azhar EI. Coronavirus disease of 2019 (Covid-19) in the Gulf Cooperation Council (GCC) countries: Current status and management practices. Journal of Infection and Public Health 2020; 13: 839-842.
14. Tolles J, Luong T. Modelling epidemics with compartment models. JAMA 2020: 323: 2515-2516.
15. Harko T, Lobo FSN, Mak MK. Exact analytical solutions of the Susceptible-Infected-Recovered (SIR) epidemic model and of the SIR model with equal death and birth rates. Applied Mathematics and Computation 2014; 236: 184–194.
16. Murray JD. Mathematical Biology: An introduction. USA: Springer 2002.
17. Harir A, Melliani S, El Harfi H, Chadli LS. Variational iteration method and differential transformation method for solving the SEIR epidemic model. International Journal of Differential Equations 2020; 1-7. doi: 10.1155/2020/3521936.
18. Pérez F, Granger BE. IPython. A system for interactive scientific computing, Computing in Science and Engineering 2007; 9: 21-29, May/June 2007, doi:10.1109/MCSE.2007.53.

https://github.com/henrifroese/infectious_disease_modelling/blob/master/part_three.ipynb (accessed July 18, 2020)

19. Henri F. Infectious disease modelling: Fit your model to Coronavirus data. 2020 https://towardsdatascience.com/infectious-disease-modelling-fit-your-model-to-coronavirus-data-2568e672dbc7 (accessed July 10, 2020)

20. WHO Adaptt Surge Planning Support Tool. Regional Office for Europe. Geneva: World Health Organization 2020. https://www.euro.who.int/en/health-topics/Health-systems/pages/strengthening-the-health-system-response-to-covid-19/surge-planning-tools/adaptt-surge-planning-support-tool (accessed July 9, 2020)

21. Algaissi AA, Alharbi NK, Hassanain M, Hashem AM. Preparedness and response to Covid-19 in Saudi Arabia: Building on MERS experience. Journal of Infection and Public Health 2020; 13: 834-838.

22. Wells CR, Sah P, Moghadas SM, et al. Impact of international travel and border control measures on the global spread of the novel 2019 coronavirus outbreak. Proceedings of the National Academy of Sciences 2020; 117: 7504-7509.

Table 1. Covid-19 testing, confirmed cases, recovered cases and deaths, GCC Countries

Key indicators	**Bahrain**	**Sultanate of Oman**	**Kuwait**	**United Arab Emirates**	**Qatar**	**Saudi Arabia**	**GCC total**
Transmission classification	Cluster	Community	Cluster	Community	Community	Clusters	Na
Number of observations (24/07)							
Total tests	830,998	306,187	505,088	5,076,384	495,377	3,341,253	10,555,287
Total tests per 1000 population	488.37	50.50	118.27	513.26	171.94	95.98	241.30
Daily tests per 1000 population	5.09	0.51	0.86	5.09	1.52	1.66	2.46
Total confirmed cases	40,755	79,159	66,529	60,506	110,460	274,219	631,628
New cases	444	590	626	585	307	1,629	4,181
Daily cases per million	260.93	115.54	146.59	59.14	106.56	46.79	122.59
Total recovered	37,357	63,142	57,932	53,909	110,695	235,658	558,693
Total deaths	146	421	445	351	171	2,866	4,400
Total deaths per million	85.80	82.44	104.20	35.49	59.95	82.32	75.03
Daily deaths per million	1.18	1.76	0.23	0.40	0.69	1.44	0.95
Doubling time of deaths (in days)	31	24	54	78	37	32	43
Key dates in 2020 (day/month)							
First confirmed case	24-Feb	24-Feb	24-Feb	29-Jan	29-Feb	02-Mar	na
First death reported	16-Mar	31-Mar	04-Apr	20-Mar	28-Mar	24-Mar	na
Cases first exceeded 500 per day	31-May	24-May	05-May	23-Apr	20-Apr	16-Apr	na
Initiation of lockdown/restrictions	26-Mar	10-Apr	13-Apr	26-Mar	23-Mar	25-Mar	na

Source: compiled from World Health Organisation[3] Johns Hopkins CSSE,[4] Our World in Data,[5] GCC Stats,[6]
na: not applicable; last updated: 15 Aug 2020

Table 2. Predicted cumulative number of events by date based on SEICRD model

Country	Susceptible	Exposed	Infected	Critical	Dead
Peak date					
Bahrain (5 Jul)	1,303,738	20,803	62,543	337	90
Oman (2 Aug)	3,259,993	87,552	264,025	1432	440
Kuwait (20 Jun)	3,114,618	46,839	140,912	756	285
UAE (21 Apr)	9,567,170	40,563	122,986	477	56
Qatar (28 Jun)	2,801,559	3,649	11,076	325	104
Saudi Arabia (29 Jun)	31,725,801	169,891	513,416	6452	1,604
Predicted date (31 Oct)					
Bahrain	1,024,677	537	2572	19	224
Oman	2,101,761	8,497	36,427	257	987
Kuwait	2,223,249	3,424	13,442	88	662
UAE	9,258,422	71	298	2	360
Qatar	2,737,760	209	903	34	258
Saudi Arabia	29,733,965	911	5,891	121	3,972
Predicted date (31 Dec)					
Bahrain	1,021,398	34	175	1	226
Oman	2,036,987	1,011	4,452	32	1,031
Kuwait	2,191,572	669	2,659	18	680
UAE	9,257,851	10	42	0.30	361
Qatar	2,736,184	24	108	4	264
Saudi Arabia	29,730,270	15	119	3	3985

Figure 1. Number of Covid-19 confirmed cases from 21 February to 31 July 2020 in GCC countries

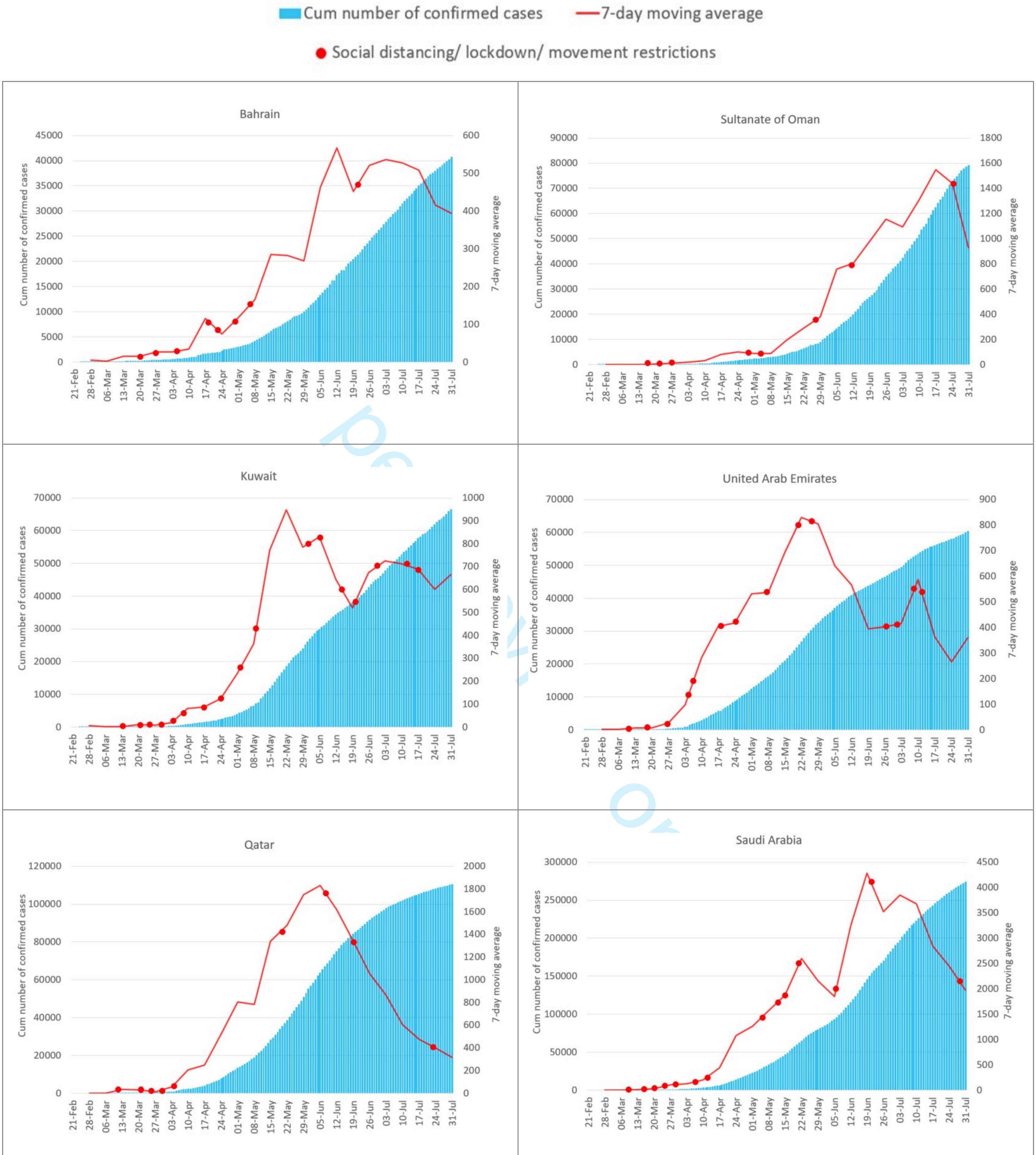

Figure 2. Predicted Covid-19 trends using SEICRD model, GCC Countries

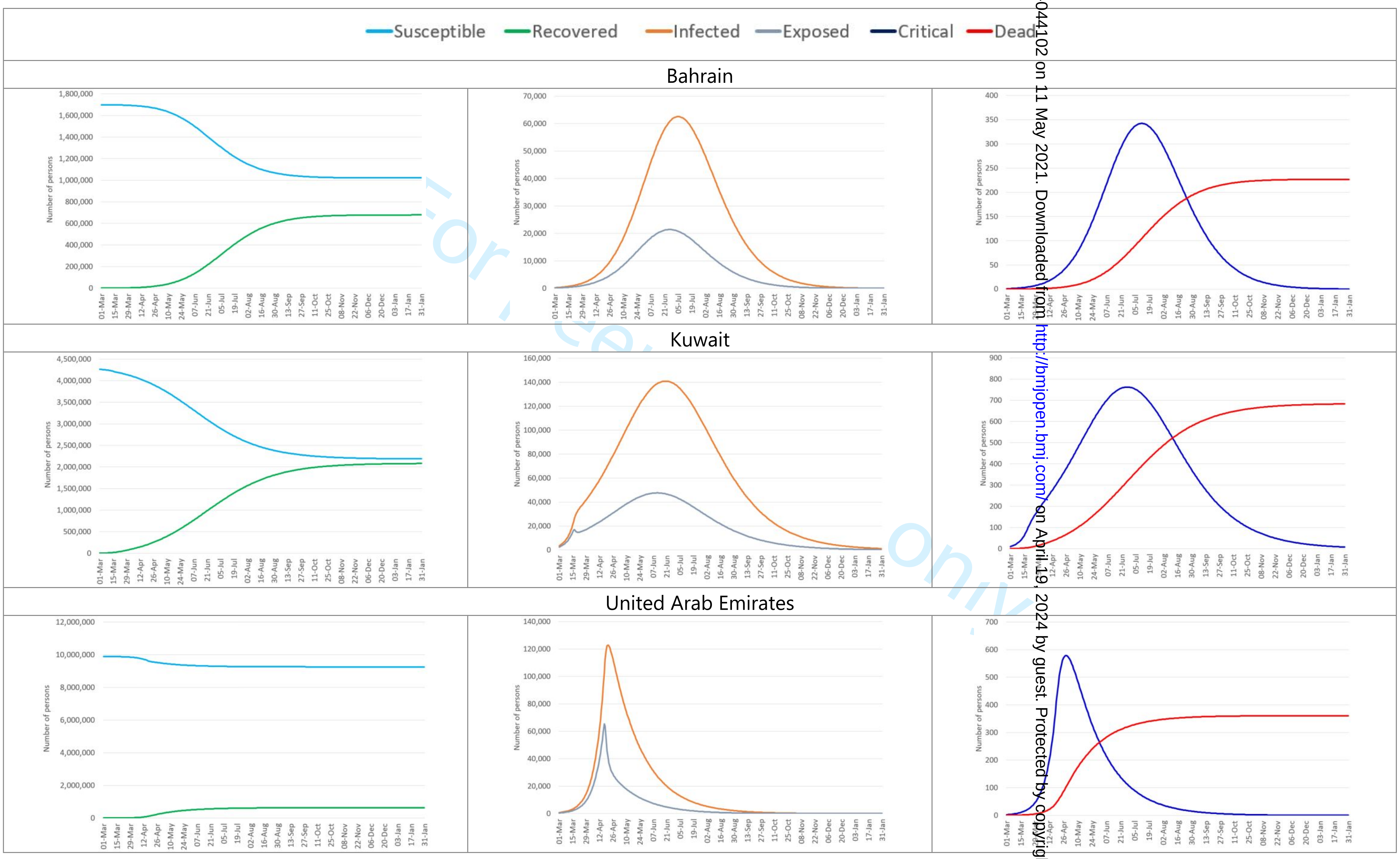

Figure 2 (contd). Predicted Covid-19 trends using SEIRCD model, GCC Countries

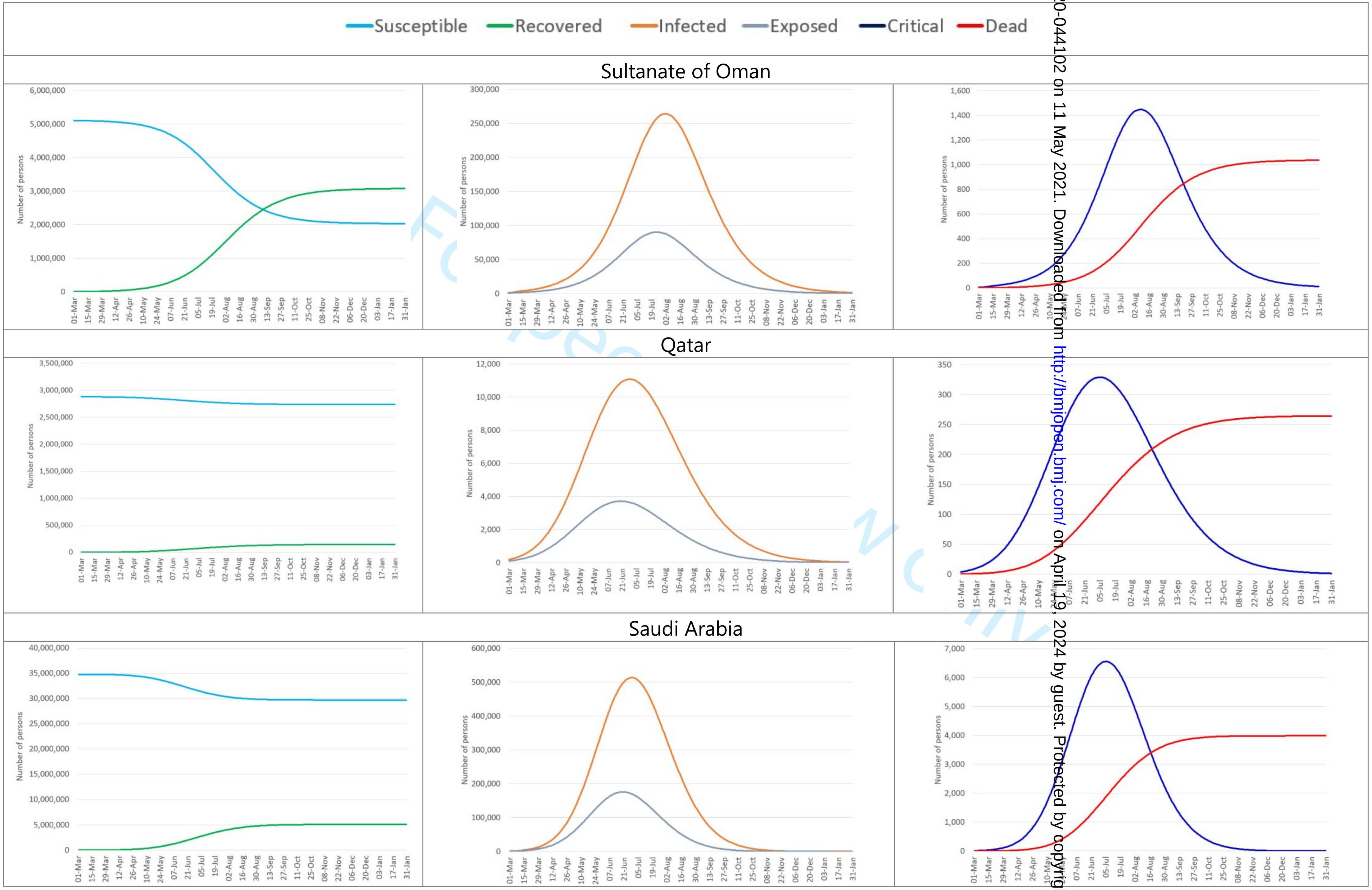

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Figure 3a. Predicted ICU equipment capacity for Covid-19 management applying SEICRD model estimates to WHO Surge Planning Tool, GCC Countries

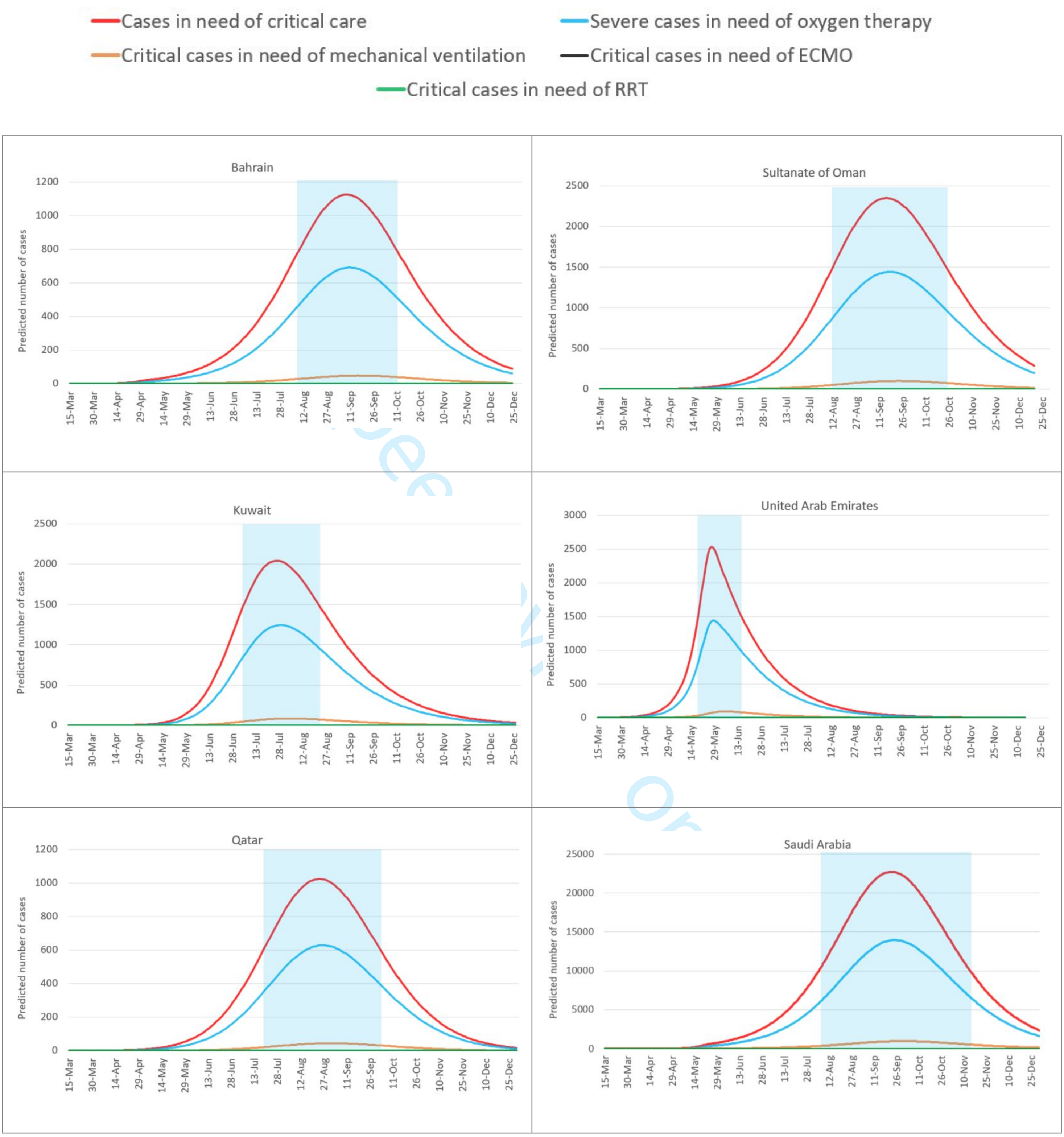
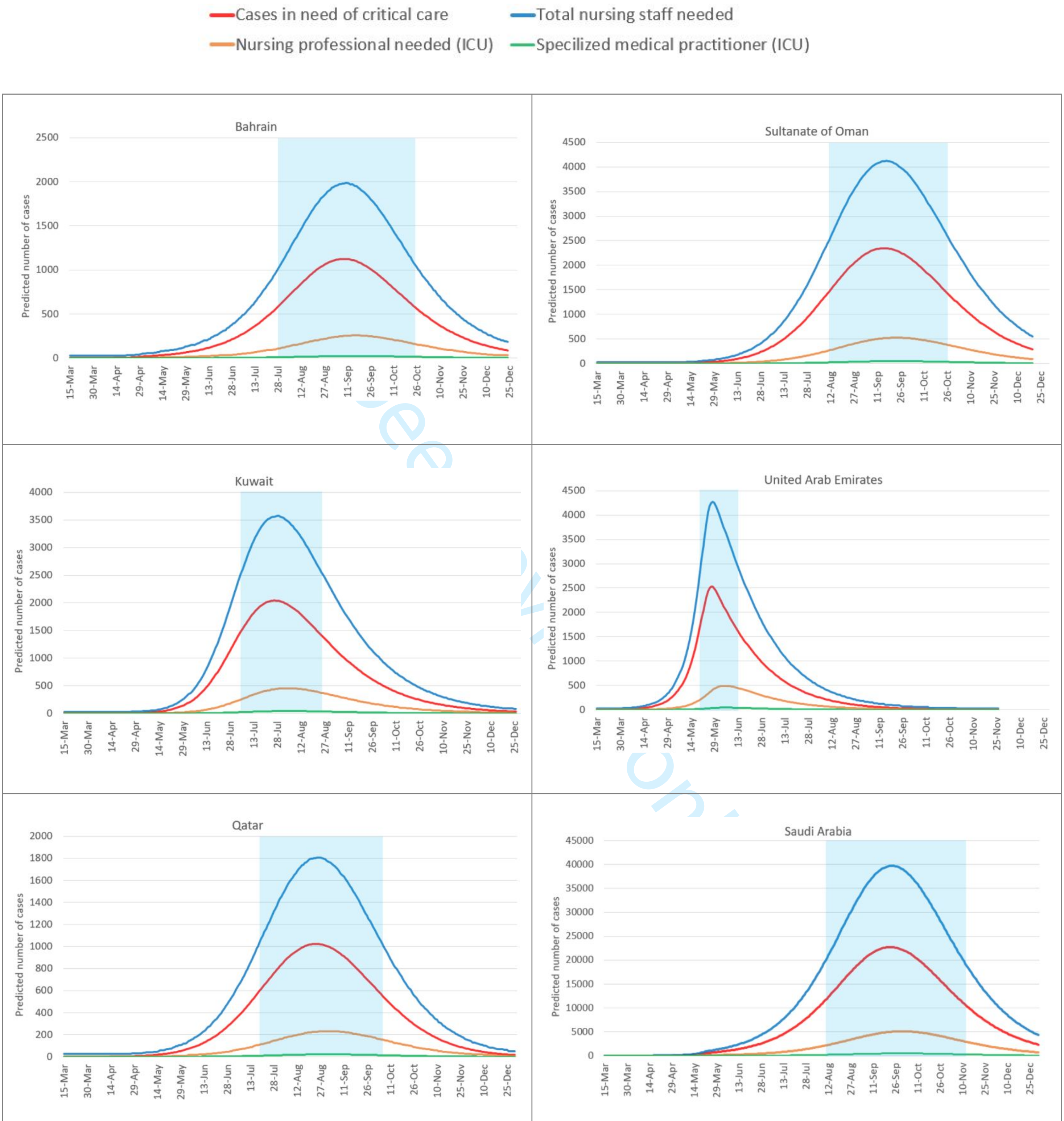


Figure 3b. Predicted ICU human resources capacity for Covid-19 management applying SEICRD model estimates to WHO Surge Planning Tool, GCC Countries



Appendix

Figure A1. Covid-19 infection transition states based on SEICRD model

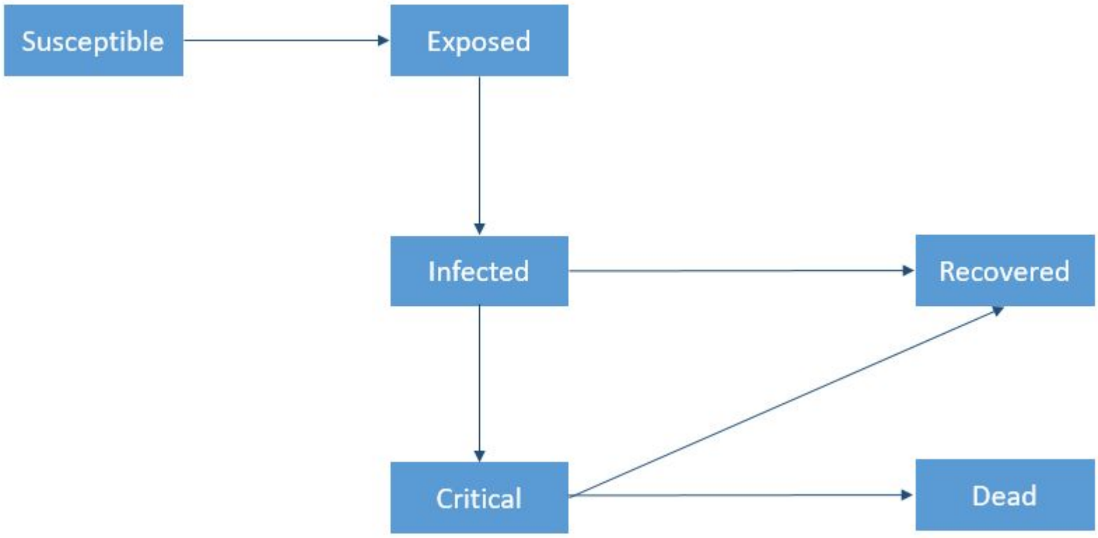
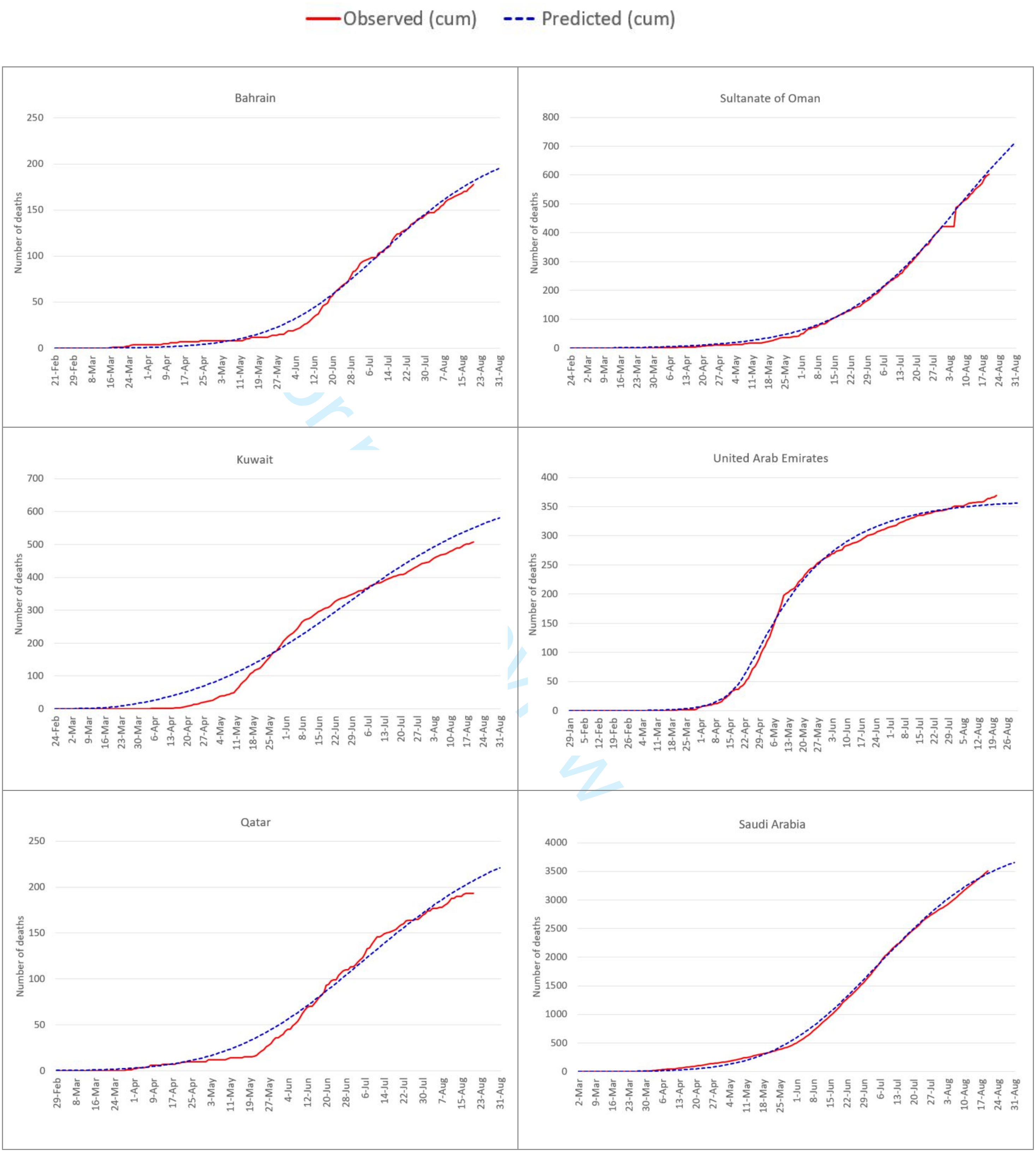


Figure A2. Actual and predicted number of deaths based on SEICRD model, GCC Countries



STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6-7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	N/A
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6, 12
Bias	9	Describe any efforts to address potential sources of bias	9
Study size	10	Explain how the study size was arrived at	N/A
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6-7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6-7
		(*b*) Describe any methods used to examine subgroups and interactions	N/A
		(*c*) Explain how missing data were addressed	N/A
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	N/A
		(*e*) Describe any sensitivity analyses	9
Results			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	N/A
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	N/A
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	N/A
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
Discussion			
Key results	18	Summarise key results with reference to study objectives	10
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	9
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10-11
Generalisability	21	Discuss the generalisability (external validity) of the study results	N/A
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Forecasting SARS COVID-19 pandemic evolution and critical care resources threshold in the Gulf Cooperation Council (GCC) countries

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-044102.R1
Article Type:	Original research
Date Submitted by the Author:	11-Mar-2021
Complete List of Authors:	Al-Aamri, Amira; Ministry of Higher Education, Sultanate of Oman, Statistics Al-Harrasi, Ayaman; Ministry of Health Oman Al-Abdusalam, Abdurahman; Ministry of Higher Education, Sultanate of Oman Al-Maniri, Abdullah; Oman Medical Speciality Board, Strategy and Planning Department Padmadas, sabu; University of Southampton, Social Statistics and Demography
Primary Subject Heading:	Global health
Secondary Subject Heading:	Public health, Epidemiology
Keywords:	COVID-19, EPIDEMIOLOGY, PUBLIC HEALTH

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Forecasting SARS COVID-19 pandemic evolution and critical care resources threshold in the Gulf Cooperation Council (GCC) countries

Amira K Al-Aamri., M.Sc., Ph.D., Ayaman A Al-Harrasi., M.D., Abdurahman K Al-Abdusalam., Ph.D., Abdullah Al-Maniri., M.P.H., Ph.D., Sabu S. Padmadas, M.Sc., Ph.D.

Ministry of Higher Education, Sultanate of Oman, amira.alaamri@mohe.gov.om (AKA); Centre of Studies and Research, Ministry of Health, Sultanate of Oman, ayaman.alharasi@moh.gov.om (AAH),; College of Applied Sciences, Sultanate of Oman, abdulrhman.niz@cas.edu.om (AAA); Strategy and Planning Department, Oman Medical Specialty Board, Sultanate of Oman, abdullah.a@omsb.org (AAM); Social Statistics and Demography and Global Health Research Institute, University Of Southampton, S.Padmadas@soton.ac.uk (SSP)

Revised manuscript submitted to BMJ Open for possible publication
1 March 2021

Correspondence
Sabu S. Padmadas, M.Sc., Ph.D.
Professor of Demography and Global Health
University of Southampton, Highfield Campus
Southampton SO17 1BJ, United Kingdom
Email: S.Padmadas@soton.ac.uk

Word count abstract (298); main text (3525)

Contributors

All authors contributed substantially to the preparation of the manuscript including design, analysis and interpretation, and revising the article for important intellectual content. AKA, SSP and AAM conceived the idea and wrote the first draft of the paper. AAH and AKA conducted the literature review. Both AKA and AAH contributed equally to preparing the database and conducting the statistical analysis with technical support from AAA and SSP. AKA, AAH and SSP interpreted the findings. SSP and AAM revised the draft for intellectual content.

Funding

The Research Council, Sultanate of Oman (Reference: TRC/CRP/MoHE/COVID-19/20/04)

Competing interests

None declared

Patient and public involvement

No patients or public were not involved in the design, or conduct, or reporting, or dissemination of this research.

Patient consent for publication

Not applicable

Ethics approval

No formal ethical approval was required for this study.

Data sharing statement

Data used for the analysis are available in the public domain in anonymous aggregate format for research use. The list of data sources is available in the bibliography.

ABSTRACT

Objective

To generate cross-national forecasts of COVID-19 trajectories and quantify the associated impact on essential critical care resources for disease management in GCC countries.

Design

Population-level aggregate analysis

Setting

Bahrain, Kuwait, Oman, Qatar, United Arab Emirates and Saudi Arabia

Methods

We applied an extended time-dependent SEICRD compartmental model to predict the flow of people between six states: Susceptible- Exposed-Infected-Critical-Recovery-Death, accounting for community mitigation strategies and the latent period between exposure, and infected and contagious states. Then, we used the WHO Adaptt Surge Planning Tool to predict ICU and human resources capacity based on predicted daily active and cumulative infected cases from SEICRD model.

Results

COVID-19 infections vary daily from 498 per million in Bahrain to over 300 per million in UAE and Qatar to9 per million in Saudi Arabia. The cumulative number of deaths vary from 302 per million in Oman to 89 in Qatar. UAE attained its first peak as early as 21 April whereas Oman had its peak on 29 August 2020. In absolute terms, Saudi Arabia is predicted to have the highest COVID-19 mortality burden (7,080 deaths) by 15 September 2021 followed by Oman (1,611 deaths). The predicted maximum number of COVID-19 infected patients in need of oxygen therapy during the peak of emergency admissions vary between 690 in Bahrain, 1440 in Oman and over 10,000 in Saudi Arabia.

Conclusion

Although most GCC countries have managed to flatten the epidemiological curve by August 2021, trends since November 2020 show potential increase in new infections The pandemic is predicted to recede by August 2021, provided the existing infection control measures and data monitoring systems continue effectively and consistently across all countries. Current health infrastructure including the provision of ICUs and nursing staff seem adequate, but health systems should keep ICUs ready for managing critically ill patients.

Keywords: COVID-19; Infectious Disease; Pandemic; Mathematical Model; Forecasting; Intensive Care Resources; Gulf Cooperation Council (GCC)

Strengths and limitations of this study

- The analysis is the first of its kind in GCC countries to generate robust cross-national forecasts of COVID-19 and quantify its associated impact on essential critical care resources for disease management.
- Overall, barring a few fluctuations, the difference between the observed and predicted number of deaths in the SEICRD model is generally marginal across GCC countries.
- The predictions are based on the assumptions that the populations under investigation are stable, asymptomatic population exposed are infectious, those confirmed COVID-19 positive will have no reinfections and no changes in ICU resources during COVID-19. Adaptt Surge Planning tool predictions of ICU resources apply to only inpatient care.
- Lack of availability of demographic and socioeconomic data restrict our understanding of the infection dynamics. Given the high representation of expatriate population across GCC countries, further investigation disaggregated by nationality is pertinent to understand the differential impact of COVID-19 on population sub-groups.

Introduction

The pace and magnitude of the novel, highly contagious Severe Acute Respiratory Syndrome (SARS) Coronavirus disease 2019 (COVID-19) pandemic outbreak vary substantially across world regions. COVID-19 first reported in Wuhan region of China[1,2] spread rapidly to European countries of Italy, Spain and the United Kingdom, and in North and Latin America including United States, Canada and Brazil.[3-5]

COVID-19 pandemic outbreak in Gulf Cooperation Council Countries (GCC)

Within the Gulf Cooperation Council (GCC) countries, UAE reported the first four cases as early as 29 January 2020, and other GCC countries including Saudi Arabia, Oman, Bahrain, Qatar and Kuwait reported their first few cases towards the end of February 2020.[4,6,7] Since, then the new COVID-19 infections and deaths have more than doubled within the GCC region. For example, the weekly total number of new infections in GCC countries has doubled from 25,965 for the week May 3-9 to 51,713 for the week June 21-27, whereas the number of deaths per week increased from 144 to 393 during the same period. Saudi Arabia, the most populous country within GCC, has been the worst affected in terms of the total number of positive cases and case fatalities.[8]

Government response and the wider socioeconomic and healthcare context

While most GCC countries responded early to disease control and prevention in terms of enforcing social distancing, lockdown, public health awareness and behavioral change campaigns,[9] the implementation was transient and inconsistent due to economic and demographic challenges. As countries prepare to face another global economic recession post COVID-19, the situation is exacerbated in GCC countries severely affected by the recent oil crash.[10,11] COVID-19 has also extensively disrupted national economic diversification plans and functioning of small and medium industries and businesses in the GCC region. On average, two-thirds of GCC population represent young expatriate workers, working mostly in services and construction sectors, and they live in congested accommodation, often with low wages.[12] The share of expatriate population is the highest in UAE and Qatar (over 80%) and the lowest in Saudi Arabia (33%).[12]

Data from respective government ministries show a disproportionately higher incidence of COVID-19 infections and deaths among expatriate workers. However, these data are currently unavailable for research use in GCC countries. Older people aged 65 and above constitute between 3.3% in Saudi Arabia and 2% or less in the rest of GCC countries, which partly explain the anomaly between high incidences of COVID-19 infections and low case fatalities in the region.

On the other hand, GCC countries have high rates of non-communicable and chronic diseases including ischemic and coronary heart diseases, obesity, hypertension and diabetes mellitus.[13,14] GCC countries spend, on average, 4.3% of their GDP on healthcare, ranging

between 5.8% in Saudi Arabia to 3.1% in Qatar, mostly for treatment and management of non-communicable and chronic diseases.[12]

Research gap

Except for a few review and clinical studies,[9,15] there is no clear understanding of the future trends of COVID-19 in GCC countries and their impact on critical care capacity for disease management. As of 31st July, GCC countries with a combined population of 58.5 million conducted a total of 10.6 million tests, identified 631,628 positive cases, of these 558,693 (88%) recovered and 4,400 (0.7%) died.[8] The number of new cases reported every day at that time remained high in the GCC region, particularly in Saudi Arabia.

The current pandemic situation is rather uncertain in GCC countries, especially with no systematic data on emergency admissions, and adequate population-level testing. The potential peak of the pandemic is uncertain and there is little consensus on resource allocation for emergency care including ICU beds and ventilator support in the event of further increase and new wave of infections.

Research question

Our main research question is: how can we systematically compare and forecast the trends in COVID-19 pandemic across GCC countries, and what are the implications of these trends on critical care resources capacity at the national level? The goal of this article is to apply forecasting techniques to investigate the evolution of COVID-19 pandemic and quantify the critical care resource threshold for infection control and management in GCC countries.

Contributions

In the light of aforementioned research and data gaps, this paper contributes a case study documenting the current and future trajectories of COVID-19 pandemic and associated implications comparing the six GCC countries. The findings of this paper have implications for designing universal public health policies and interventions in the region, especially given the geographic proximity and population movements between GCC countries. The paper highlights the challenges associated with the paucity of existing data and calls for coordinated efforts to share reliable and consistent information in the region.

Materials and Methods

We considered a systematic approach to find the best model to predict the future evolution of COVID-19 pandemic and hospital resources capacity threshold in GCC countries.

Data

The key input variables for mathematical forecasting included: confirmed COVID-19 positive infection cases and deaths. These data derived from various sources including the Johns Hopkins Coronavirus Centre[4], Our World in Data[7], World Health Organization[3], GCC Stat[8] and respective Ministries of individual countries were verified for consistency.

Modelling approach and assumptions

We extended the widely used SIR (Susceptible, Infected and Recovered) compartment model[16] by including variants[6, 17-22] to develop a SEICRD model taking into account of community mitigation strategies and the latent period between when a person is actually exposed and until infected and contagious. SEICRD model incorporates the transition of individuals between six states (**Supplementary file Figure S1**). The states include Susceptible (S): number of individuals susceptible to be exposed; Exposed (E): number of individuals exposed where the disease status is latent, and individuals are infected but not infectious yet; Infected (I): number of individuals actually infected and infectious; Critical (C): infected individuals who need intensive care; Recovered (R): numbers infected who recover with an assumed lifelong immunity and they do not return to the Susceptible (S) state and the absorbing state Death (D).

We assumed that the population is stable, no re-infection of people who already had the infection and there are no changes in the size and composition of ICU resources during COVID-19. The input data included the number of ICU beds per 100,000 population, proportion of population by age group, transition probabilities from infected to critical, critical to dead, and the number of confirmed cases and deaths per day by country. The analysis was conducted in Python Jupyter version 3.7.6.[23] The mathematical equations to predict the outcomes of SEICRD model are described in detail elsewhere.[24]

The SEICRD model predicts the number of ICU beds needed to treat COVID-19 critical cases, taking into account the predicted number of patients with critical conditions and existing bed capacity. Suppose that a given country has B number of ICU beds to treat C_N Coronavirus cases with critical condition. If the number of critically ill patients (C_N) exceeds the *number of* ICU beds (B), then we will have ($C_N – B$) critical cases that cannot be treated, and hence the patient may die due to the shortage in the number of ICU beds. However, if B is greater than C_N, then all critical cases have the chance to be treated.[24]

The predicted number of cases in need of critical care, critical cases requiring oxygen and mechanical ventilation, Extra Corporeal Membrane Oxygenation (ECMO) and Renal Replacement Therapy (RRT), nursing resources and specialized medical practitioners were estimated using WHO Adaptt Surge Planning Tool.[25] The input parameters for the Adaptt tool were based on the outputs from SEICRD model: daily predicted active infected, daily predicted new infected and cumulative infected cases. In the Adaptt tool, we selected the option very low scenario[25] attack rate (5%) which represents the percentage contracting COVID-19 at the population level, and a universal social distancing mitigation measure. The infection transmission rates have been relatively slower across GCC countries.

The Adaptt model predicts the future ICU beds needed by date, for treating patients with moderate, severe and critical symptoms including ECMO and RRT and the human resources needed. Note Adaptt model only considers inpatient care. It takes into account the number of nurses required per shift and the shift configuration for treating COVID-19 patients. The tool enables users to input epidemiological data and generate mitigation scenarios for hospital resources planning and decision-making. It classifies patients into mild, moderate, severe and critical categories according to the level of resources needed.[20] Those classified mild can recover at home without inpatient care, moderate require inpatient care, severe require inpatient care with oxygen therapy, and critical patients require inpatient care with mechanical ventilation.

Patient and Public Involvement

None

Results

COVID-19 trends and national interventions in GCC countries since the outbreak

Four out of six GCC countries confirmed COVID-19 transmission at the community level, whereas clusters of cases were reported in Bahrain, and sporadic transmission in Saudi Arabia (**Table 1**). The number of new confirmed cases of COVID-19 has fallen across GCC countries since August 2020 until early February 2021. However, data during mid-February 2021 show the opposite with a significant increase in the number of new cases in all countries.

Population level infection control measures including social distancing, lockdown, curfew and movement restrictions appear to have had perceptible effects only in UAE initially. Qatar and Saudi Arabia whereas similar measures in other countries seem ineffective or inconsistent (**Figure 1**). As of February 2021, the number of national lockdowns implemented vary from 27 in Qatar, 24 in UAE, 20 in Kuwait, 13 in Bahrain and Saudi Arabia respectively to 5 in Oman, whereas the number of curfews and movement restrictions vary between 194 in Qatar to 39 in Oman.[26]

As illustrated in terms of weekly average trends, Oman, Bahrain, Kuwait and Saudi Arabia recorded a steady increase in new cases until mid-June. **Figure 1** clearly demonstrates evidence of early flattening of the epidemiological curve in Qatar and UAE, although there are signs of potential new wave in these countries. Bahrain and Kuwait are currently (as of February 2021) approaching a potential second wave.

Our data investigations show that the number of daily tests carried out was the lowest in Oman and Kuwait (<1 per 1000 population) and highest in Bahrain and UAE. Saudi Arabia has the lowest testing rates proportionate to population size. Population level testing for COVID-19 infections has been disrupted, and most countries have confined testing to people with symptoms or those seeking institutional healthcare, especially emergency admissions. As of 15 February 2021. Saudi Arabia recorded the highest recovery rate (95%) followed by Oman (94%) and Qatar (89%) whereas UAE recorded the lowest recovery rate.

The total number of deaths varies between 302 per million population in Oman to slightly over 235 per million in Bahrain and Kuwait. Saudi Arabia has the highest mortality burden in absolute terms at the population level. The doubling time for mortality at the initial stage of the pandemic varied between 24-31 days in Oman and Bahrain, and 78 days in UAE.

Future trajectories of COVID-19 in GCC countries

The predicted future trends in COVID-19 based on the SEICRD compartment model are summarised in **Table 2**. The predicted values are based on the probabilities of transition across different states from infected to critical, critical to dead and so on. Note the scale of population size vary by country: Bahrain (1.69 million); Qatar (2.80 million); Kuwait (4.27 million); Oman (5.01 million); UAE (9.88 million) and Saudi Arabia (34.79 million).

To illustrate, in Oman, on the peak date of the infection (29 August), of the 3.99 million people susceptible to COVID-19, 115,841 were infected, 676 cases manifested severe or critical symptoms and 673 died (**Table 2**). By 15 September 2021, Oman will have a predicted cumulative number of 1,611 deaths but almost none needing critical care on that particular date.

The model estimates indicate that there are variations between GCC countries in terms of the date of the infection peak, with UAE as the first country in GCC to achieve a peak towards the end of April 2020. On the other end, Oman and Bahrain attained the peak on 29 August and 18 June respectively. In absolute terms, Saudi Arabia is predicted to have the highest COVID-19 mortality burden (7,080 deaths) by 15 September 2021 followed by UAE (1,895), and Oman (1611 deaths). By then, GCC countries together will have a predicted 12,610 deaths,

The fitted models were robust and there was little difference between the observed and predicted outcomes (**Figure 2**). Overall, barring a few fluctuations in Bahrain and Kuwait, the difference between the observed and predicted number of deaths in the SEICRD model is marginal across GCC countries. In Bahrain, the model slightly over predicted the deaths during the months of October and November 2020, and under-predicted post mid-July to end of August 2020. In UAE, the model over-predicted the deaths during October until December 2020, and under-predicted during February 2021.

The predicted ICU equipment capacity and human resources for COVID-19 management is graphically illustrated in **Figures 3 and 4** respectively. Note that due to technical reasons, we could not provide an update of the prediction beyond December 2020. The model assumes that all active cases are detected at the population level, and also takes into account the lag between date of infection and date when symptoms become critical or severe. Note GCC countries are relatively well equipped with intensive care systems and human resources, and the existing systems are currently able to manage COVID-19 pandemic without disruptions. However, the circumstances could change if the infections surge beyond the predicted levels.

The predicted number of infected persons requiring critical care during the peak of emergency admissions (area shaded in blue) is estimated to vary between 2000 and 22,000 depending on the population exposed and actually infected. Those in need of oxygen therapy is predicted to vary between 690 in Bahrain, 1441 in Oman and over 10,000 in Saudi Arabia (**Figure 3**).

The demand for total nursing staff during the peak of emergency admissions is predicted to vary from 2000 in Bahrain, 4000 in Oman to as high as 40,000 in Saudi Arabia (**Figure 4**). However, Saudi Arabia has over 190,000 nurses available within health systems. In comparison, Bahrain has 4254 nurses, UAE 56,375, Kuwait 31602, Qatar 21032 and Oman has 21448 nurses currently in employment.[7,8] The models predict a high demand for specialized ICU nurses during the peak of emergency admissions, which is expected over the period from August to October in most countries, except UAE.

Strengths and limitations of this study

The analysis is the first of its kind in GCC countries to generate robust cross-national forecasts of COVID-19 and its impact on essential critical care resources for disease management. Overall, barring a few fluctuations, the difference between the observed and predicted number of deaths in the SEICRD model is generally marginal across GCC countries. The predictions are based on the assumptions that the populations under investigation are stable, asymptomatic population exposed are infectious, those confirmed COVID-19 positive will have no reinfections and no changes in ICU resources during COVID-19.

Adaptt Surge Planning tool predictions of ICU resources apply to only inpatient care. Unfortunately, the tool does not allow to extend predictions beyond 365 days, and hence we could not present the predictions for future months. Furthermore, we could not validate these predictions with observed data due to lack of access to such information at the time of analysis. Lack of availability of demographic and socioeconomic data restrict our understanding of the infection dynamics. Given the high representation of expatriate population across GCC countries, further investigation disaggregated by nationality is pertinent to understand the differential impact of COVID-19 on population sub-groups.

Discussion

The foregoing analysis yielded robust predictions based on SEICRD model, comparing the trajectories of COVID-19 case incidence and mortality rates across GCC countries, and further quantified the demand for emergency care resources capacity. The scale and community level spread of COVID-19 pandemic has been relatively less severe in GCC countries when compared to other economically advanced nations.[3,4] The infection transmission was initially confined in small clusters during the early phase of the pandemic, subsequently elevated to community level in most countries, with increased risk of transmission amongst expatriate workers living in labor camps and boarding houses near construction sites and service stations. The vast majority of expat workforce is engaged in frontline unskilled and casual work, living in harsh conditions with little income and subsistence.

Most countries in GCC are sparsely populated except in capital cities and adjacent small cities. Infection control measures including travel, international border control, international flight suspensions,[9] quarantine, social and religious congregation restrictions,[27] short curfews, social distancing and lockdown initiated early had some effect in controlling the infection spread, but appear to be not fully effective in most countries, including in Saudi Arabia which had the Middle-East Respiratory Syndrome (MERS) Coronavirus outbreak in 2012.[28] The number of COVID-19 positive cases showed a steady increase towards the end of May 2020, as people returned to work and resumed economic activities after the religious Eid holidays, and then subsequently the infections increased since November. The most recent trends show a spike in the number of new cases across GCC countries, at a time when vaccination is being gradually rolled out.

Our model-based predictions confirmed that UAE attained a peak towards the end of April 2020, and Bahrain and Oman by 18 June and 29 August respectively. In absolute terms, Saudi Arabia has experienced the highest burden of COVID-19 mortality followed by Bahrain, Oman and Kuwait.

These trends are predicted on the assumption that the current infection control measures prevail until the new infections are contained in small clusters, and with adequate testing and surveillance systems to trace, isolate and treat COVID-19 patients. It has become clear that GCC countries have not fully recovered from the pandemic, and new infections attributed to potentially newly mutated strain seem looming large in the region. The variations in infection trends depend on population characteristics: size, composition, density and the readiness of hospitals to manage critical cases.

Our predictions show that the demand for specialized ICU nurses have continued to remain high until October 2020 and further demand is likely to be determined depending on the increase in new cases These predictions are based on the assumption that the current public health interventions continue with adequate surveillance systems, and that the infection recedes without any further outbreak at the community level.

While the current health infrastructure including the provision of ICUs and nursing staff seem intact, health systems should prepare ICUs and be ready for managing patients with severe symptoms and complications at least until cases are brought under control in small clusters. The nursing population across GCC countries are predominantly expatriates from South and South East Asia and Africa. Media reports show trends of return migration of expat frontline health workers to their home countries since the pandemic started. Further investigation is needed reflecting on the demographic and socioeconomic data related to COVID-19. Unfortunately, we could not explore the population level characteristics such as age, sex, nationality and socioeconomic status due to lack of data.

International travel restrictions including flight suspensions and quarantine measures can help reduce the infection rates as well enable systems to better coordinate appropriate public health response within countries.[29] Public health promotion should be intensified providing clear information, education and communication such as the need to maintain social distancing, infection prevention through sanitation and hygiene, proper understanding of the modes of infection spread and management of symptoms. The lack of proper risk communication and the ability to mitigate transmission in small populations highlight the need for strengthening public health expertise and leadership within the health system.

In the longer term, GCC countries need to address the major challenge of health inequity. There is evidence to suggest that expatriate workers, being the most vulnerable economically, die at younger age compared to native Arab population. It is essential to provide expatriate populations with appropriate health coverage, insurance and living standards to reduce the burden of future epidemic outbreaks.

Equally important is the need to strengthen capacity and investment in pandemic research, and ensure monitoring systems to collect systematic data on infectious diseases. Alongside basic science research, we need to apply artificial intelligence, machine learning and data sciences to understand the complexity and uncertainty of the COVID-19 pandemic.[30-33] In addition, concerted efforts are needed to strengthen behavioral, social and cost-benefit economic analyses of government interventions to understand the impact of COVID-19 management and response. Finally, it is important for GCC countries to share a common data repository on critical health and health systems indicators, enabling access to the broader scientific community.

Conclusion

Our study demonstrates evidence of considerable variations in COVID-19 trajectory across GCC countries. Although these countries have managed to flatten the epidemiological curve by early August, trends since November 2020 show potential new wave of infections, especially in countries which had relatively lower number of confirmed cases. The pandemic is predicted to recede over by August 2021, provided the existing infection control measures, population testing and data monitoring systems continue effectively and consistently across all countries. Current health infrastructure including the provision of ICUs and nursing staff seem adequate, but health systems should be alert and keep the ICUs ready for managing critically ill patients.

References

1. Zhu N, Zhang D, Wang W, et al. A novel coronavirus from patients with pneumonia in China, 2019. N Engl J Med 2020; 382: 727-33.
2. Zhou P, Yang X, Wang X. et al. A pneumonia outbreak associated with a new coronavirus of probable bat origin. Nature 2020; 579: 270–273.
3. Coronovirus disease 2019. Situation Report-72. Geneva: World Health Organization. https://apps.who.int/iris/bitstream/handle/10665/331685/nCoVsitrep01Apr2020-eng.pdf (accessed 20 February, 2021).
4. Wuhan coronavirus (2019-nCoV) global cases: Operations dashboard. Johns Hopkins CSSE https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6 (accessed 20 February, 2021).
5. Mahmoudi MR, Heydari MH, Qasem SN, Mosavi A, Band SS. Principal component analysis to study the relations between the spread rates of COVID-19 in high risks countries. Alexandria Engineering Journal 2021; 60(1): 457–464.
6. Oloomi SA, Malayer MA, MOSAVI A. Trends of COVID-19 (Coronavirus Disease) in GCC Countries using SEIR-PAD Dynamic Model. MedRxiv 2020; Jan 1.
7. Roser M, Ritchie H, Ortiz-Ospina E, Hasell J. Coronavirus pandemic (Covid-19). Our World In Data. https://ourworldindata.org/coronavirus (accessed 18 February, 2021)
8. Coronavirus Pandemic Counts Map (COVID-19) for The Cooperation Council for The Arab Countries of The Gulf (GCC). GCC-Stat https://gccstat.org/en/covid-19-en (accessed 28 February, 2021).
9. Alandijany TA, Faizo AA, Azhar EI. Coronavirus disease of 2019 (Covid-19) in the Gulf Cooperation Council (GCC) countries: Current status and management practices. Journal of Infection and Public Health 2020; 13: 839-842.
10. Nasir MA, Al-Emadi AA, Shahbaz M, Hammoudeh S. Importance of oil shocks and the GCC macroeconomy: A structural VAR analysis. Resource Policy 2019; 61: 166-179.
11. El-Saharty S, Kheyfets I, Herbst CH, Ajwad MI. The GCC countries response to Covid-19. Fostering Human Capital in the Gulf Cooperation Council Countries 2020; 39-57.
12. Gulf Cooperation Council Statistics, GCC-STAT 2020. https://www.gccstat.org/en (accessed 28 February, 2021)
13. Rahim, HFA. Sibai A, Khader Y et al. Non-communicable diseases in the Arab world. The Lancet 2014; 383: 356-367.
14. Ng SW, Zaghloul S. Ali HI, Popkin BM. The prevalence and trends of overweight, obesity and nutrition-related non-communicable diseases in the Arabian Gulf States. Obesity Reviews 2010; 12: 1-13.
15. Uddin M, Mustafa F, Rizvi TA et al. SARS-CoV-2/Covid-19: Viral genomics, epidemiology, vaccines, and therapeutic interventions. Viruses 2020; 12:526.
16. Tolles J, Luong T. Modelling epidemics with compartment models. JAMA 2020: 323: 2515-2516.
17. Mwalili S, Kimathi M, Ojiambo V, Gathungu D, Mbogo R. SEIR model for COVID-19 dynamics incorporating the environment and social distancing. BMC Research Notes 2020; 13(1): 1–5.

18. Harko T, Lobo FSN, Mak MK. Exact analytical solutions of the Susceptible-Infected-Recovered (SIR) epidemic model and of the SIR model with equal death and birth rates. Applied Mathematics and Computation 2014; 236: 184–194.

19. Sedaghat A, Oloomi SAA, Malayer A, Rezaei M, Mosavi A (2020) Coronavirus (COVID-19) Outbreak Prediction Using Epidemiological Models of Richards Gompertz Logistic Ratkowsky and SIRD. doi: 10.31219/osf.io/c7twb

20. He S, Peng Y, Sun K. SEIR modeling of the COVID-19 and its dynamics. Nonlinear Dynamics 2020; 101(3): 1667–1680.

21. Murray JD. Mathematical Biology: An introduction. USA: Springer 2002.

22. Harir A, Melliani S, El Harfi H, Chadli LS. Variational iteration method and differential transformation method for solving the SEIR epidemic model. International Journal of Differential Equations 2020; 1-7.

23. Pérez F, Granger BE. IPython. A system for interactive scientific computing, Computing in Science and Engineering 2007; 9: 21-29, May/June 2007, doi:10.1109/MCSE.2007.53. https://github.com/henrifroese/infectious_disease_modelling/blob/master/part_three.ipynb (accessed 18 July, 2020)

24. Henri F. Infectious disease modelling: Fit your model to Coronavirus data. 2020 https://towardsdatascience.com/infectious-disease-modelling-fit-your-model-to-coronavirus-data-2568e672dbc7 (accessed 10 July, 2020)

25. WHO Adaptt Surge Planning Support Tool. Regional Office for Europe. Geneva: World Health Organization 2020. https://www.euro.who.int/en/health-topics/Health-systems/pages/strengthening-the-health-system-response-to-covid-19/surge-planning-tools/adaptt-surge-planning-support-tool (accessed 9 July, 2020).

26. UN OCHA Humanitarian Data Exchange 2021. https://data.humdata.org/dataset/acaps-covid19-government-measures-dataset (accessed February 27, 2021).

27. Ebrahim SH, Memish ZA. Saudi Arabia's drastic measures to curb the COVID-19 outbreak: temporary suspension of the Umrah pilgrimage. Journal of Travel Medicine 2020; 27(3); taaa029.

28. Algaissi AA, Alharbi NK, Hassanain M, Hashem AM. Preparedness and response to Covid-19 in Saudi Arabia: Building on MERS experience. Journal of Infection and Public Health 2020; 13: 834-838.

29. Wells CR, Sah P, Moghadas SM, et al. Impact of international travel and border control measures on the global spread of the novel 2019 coronavirus outbreak. Proceedings of the National Academy of Sciences 2020; 117: 7504-7509.

30. Alimadadi A, Aryal S, Manandhar I, Munroe PB, Joe B, Cheng X. Artificial intelligence and machine learning to fight COVID-19. Physiol Genomics 2020; 52: 200 –202.

31. Naudé W. Artificial intelligence vs COVID-19: limitations, constraints and pitfalls. AI & Society 2020; 35(3): 761–765.

32. Pinter G, Felde I, Mosavi A, Ghamisi P, Gloaguen R. COVID-19 pandemic prediction for Hungary; a hybrid machine learning approach. Mathematics 2020; 8(6): 890.

33. Ardabili SF, Mosavi A, Ghamisi P, Ferdinand F, Varkonyi-Koczy AR, Reuter U, Rabczuk T, Atkinson PM. Covid-19 outbreak prediction with machine learning. Algorithms 2020; 13(10): 249.

Table 1. COVID-19 testing, confirmed cases, recovered and deaths, GCC Countries

Key indicators	Bahrain	Sultanate of Oman	Kuwait	United Arab Emirates	Qatar	Saudi Arabia	GCC total
Transmission classification	Cluster	Community	Community	Community	Community	Sporadic	na
Number of observations							
Total confirmed cases (15/02/2021)	113,590	137,592	178,524	351,895	158,1[illegible]2	373,046	1,312,779
New cases (15/08/2020)	378	181	512	283	277	1,413	3,044
Daily cases per million (15/08/2020)	222.15	35.44	119.89	28.61	96.1[illegible]	40.59	51.89
New cases (15/10/2020)	333	520	746	1398	200	472	3,669
Daily cases per million (15/10/2020)	195.7	101.83	174.68	141.35	69.42	13.56	62.54
New cases (15/01/2021)	208	263	530	3407	196	173	4,777
Daily cases per million (15/01/2021)	122.24	51.50	124.11	344.48	60.03	9.97	81.43
New cases (15/02/2021)	848	286	823	3123	888	314	6,282
Daily cases per million (15/02/2021)	498	56	193	316	308	9	107
Total recovered (15/02/2021)	89,326	129,291	145,380	177,407	140,6[illegible]7	353,004	1,035,095
Total deaths(15/02/2021)	406	1,543	1,009	1,027	255	6,438	10,678
Total deaths per million (15/02/2021)	239	302	236	104	89	185	182
Daily deaths per million (15/02/2021)	2	0	1	1	0	0	0
Doubling time of deaths (in days)	31	24	54	78	37	32	43

Contd.

Table 1. COVID-19 testing, confirmed cases, recovered and deaths in GCC Countries (contd.)

Key indicators	Bahrain	Sultanate of Oman	Kuwait	United Arab Emirates	Qatar	Saudi Arabia	GCC total
Key dates in 2020 (day/month)							
First confirmed case	24-Feb	24-Feb	24-Feb	29-Jan	29-Feb	02-Mar	na
First death reported	16-Mar	31-Mar	04-Apr	20-Mar	28-Mar	24-Mar	na
Cases first exceeded 500 per day	31-May	24-May	05-May	23-Apr	20-Apr	16-Apr	na
Initiation of lockdown/restrictions	26-Mar	10-Apr	13-Apr	26-Mar	23-Mar	25-Mar	na

Source: compiled from World Health Organisation[3] Johns Hopkins CSSE,[4] Our World in Data,[5] GCC Stats,[6]
na: not applicable; last updated: 28 Feb 2021

Table 2. Predicted cumulative number of COVID-19 events by date based on SEICRD model

Country	Susceptible	Infected	Critical*	Recovered	Dead
Peak date (2020)					
Bahrain (18 Jun)	1,682,725	3,715	23	12,248	53
Oman (29 Aug)	3,992,252	115,841	676	960,053	673
Kuwait (04 May)	4,266,452	1,226	39	1,836	45
UAE (21 Apr)	9,890,028	309	18	1463	79
Qatar (25 May)	2,879,414	544	21	810	29
Saudi Arabia (01 Jun)	34,287,212	187,672	855	276,199	387
Predicted date (15 March 2021)					
Bahrain	1,624,428	825	6	74,067	416
Oman	3,028,262	5,411	37	2,071,254	1,587
Kuwait	4,242,023	391	16	26,375	1,071
UAE	9,873,674	621	37	16,448	1,015
Qatar	2,876,199	6	0	4,543	250
Saudi Arabia	31,944,385	16,740	102	2,841,028	6,693
Predicted date (15 June 2021)					
Bahrain	1,618,696	437	3	80,274	453
Oman	3,010,366	725	5	2,095,103	1,608
Kuwait	4,238,871	274	11	29,552	1,205
UAE	9,866,704	748	45	22,842	1,415
Qatar	2,876,174	1	0	4,573	251
Saudi Arabia	31,847,639	6,442	39	2,950,967	6,973
Predicted date (15 Sept 2021)					
Bahrain	1,615,696	227	2	83,532	473
Oman	3,007,998	95	1	2,098,270	1,611
Kuwait	4,236,671	191	8	31,771	1,299
UAE	9,858,340	895	54	30521	1,895
Qatar	2,876,167	0	0	4,580	252
Saudi Arabia	31,810,746	2,444	15	2,992,979	7,080

*figures shown as of that date and not-cumulative

Figure 1. Number of COVID-19 confirmed cases from 21/02/2020 to 15/02/2021 in GCC countries

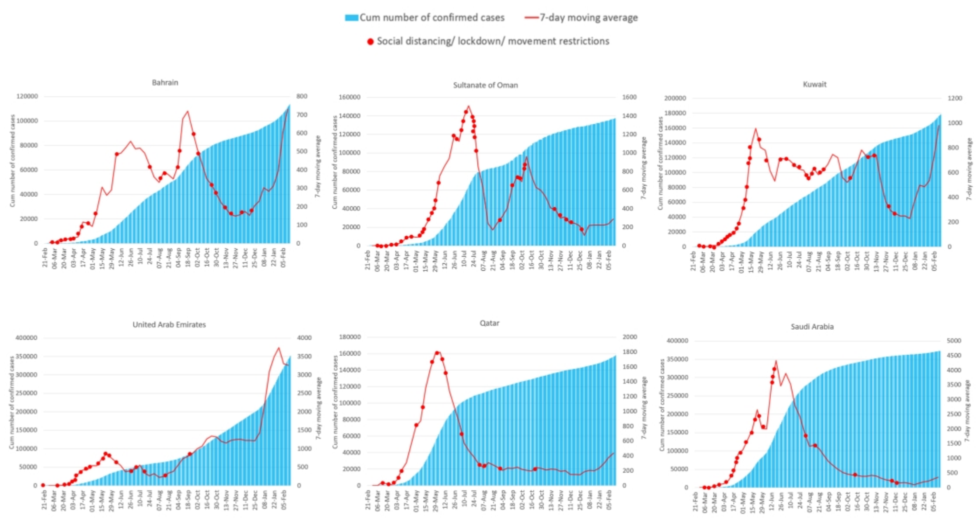
Figure 2. Observed and predicted cumulative number of COVID-19 deaths based on SEICRD model, GCC Countries (from 01/06/2020 to 15/09/2021)

Figure 3. Predicted ICU equipment capacity for COVID-19 management applying SEICRD model estimates to WHO Surge Planning Tool, GCC Countries

Figure 4. Predicted ICU human resources capacity for COVID-19 management applying SEICRD model estimates to WHO Surge Planning Tool, GCC Countries

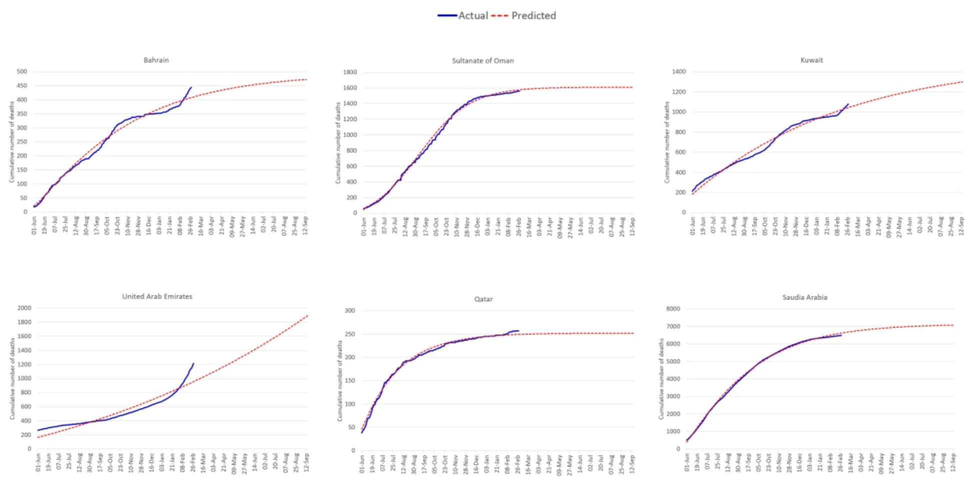
Supplementary file

Figure S1. COVID-19 infection transition states based on SEICRD model



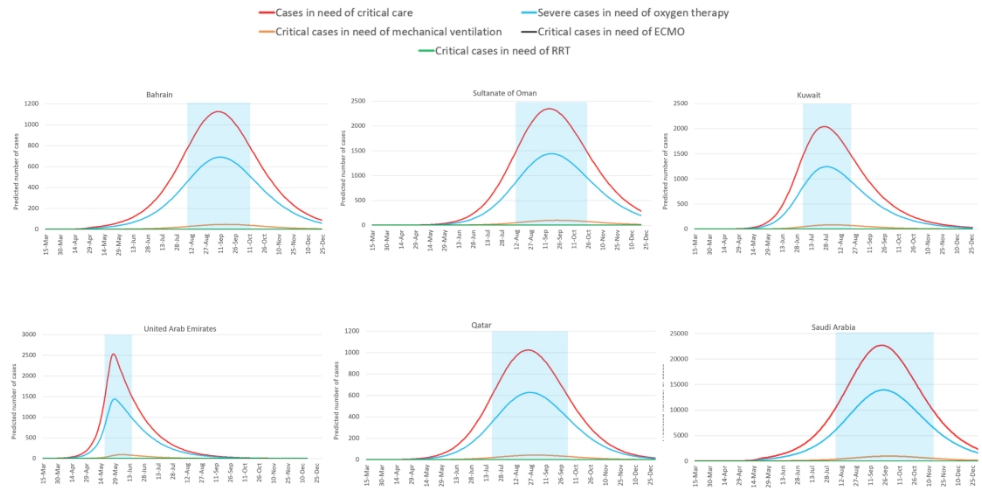
Number of COVID-19 confirmed cases from 21/02/2020 to 15/02/2021 in GCC countries

338x190mm (300 x 300 DPI)



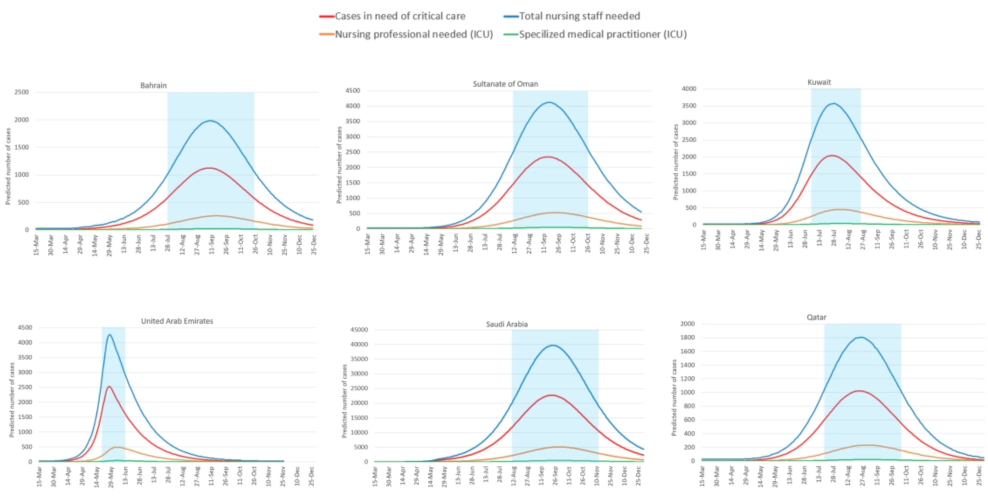
Observed and predicted cumulative number of COVID-19 deaths based on SEICRD model, GCC Countries (from 01/06/2020 to 15/09/2021)

338x190mm (300 x 300 DPI)



Predicted ICU equipment capacity for COVID-19 management applying SEICRD model estimates to WHO Surge Planning Tool, GCC Countries

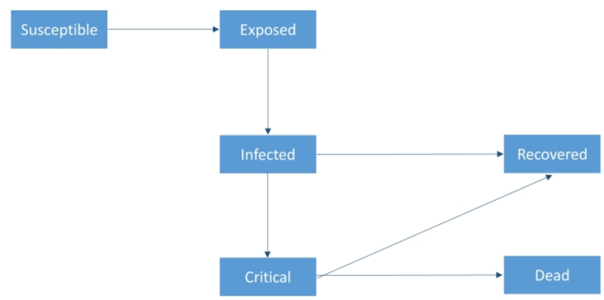
338x190mm (300 x 300 DPI)



Predicted ICU human resources capacity for COVID-19 management applying SEICRD model estimates to WHO Surge Planning Tool, GCC Countries

338x190mm (300 x 300 DPI)

Figure S1. COVID-19 infection transition states based on SEICRD model



COVID-19 infection transition states based on SEICRD model

338x190mm (300 x 300 DPI)

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6-7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	N/A
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7, 9
Bias	9	Describe any efforts to address potential sources of bias	10
Study size	10	Explain how the study size was arrived at	N/A
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7-8
		(*b*) Describe any methods used to examine subgroups and interactions	N/A
		(*c*) Explain how missing data were addressed	N/A
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	N/A
		(*e*) Describe any sensitivity analyses	9
Results			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	N/A
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	N/A
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	N/A
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
Discussion			
Key results	18	Summarise key results with reference to study objectives	11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	10
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	11-12
Generalisability	21	Discuss the generalisability (external validity) of the study results	N/A
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Forecasting SARS COVID-19 pandemic and critical care resources threshold in the Gulf Cooperation Council (GCC) countries: population analysis of aggregate data

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-044102.R2
Article Type:	Original research
Date Submitted by the Author:	20-Apr-2021
Complete List of Authors:	Al-Aamri, Amira; Ministry of Higher Education, Sultanate of Oman, Statistics Al-Harrasi, Ayaman; Ministry of Health Oman Al-Abdusalam, Abdurahman; Ministry of Higher Education, Sultanate of Oman Al-Maniri, Abdullah; Oman Medical Speciality Board, Strategy and Planning Department Padmadas, sabu; University of Southampton, Social Statistics and Demography
Primary Subject Heading:	Global health
Secondary Subject Heading:	Public health, Epidemiology
Keywords:	COVID-19, EPIDEMIOLOGY, PUBLIC HEALTH

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Forecasting SARS COVID-19 pandemic and critical care resources threshold in the Gulf Cooperation Council (GCC) countries: population analysis of aggregate data

Amira K Al-Aamri., M.Sc., Ph.D., Ayaman A Al-Harrasi., M.D., Abdurahman K Al-Abdusalam., Ph.D., Abdullah Al-Maniri., M.P.H., Ph.D., Sabu S. Padmadas, M.Sc., Ph.D.

Ministry of Higher Education, Sultanate of Oman, amira.alaamri@mohe.gov.om (AKA); Centre of Studies and Research, Ministry of Health, Sultanate of Oman, ayaman.alharasi@moh.gov.om (AAH),; College of Applied Sciences, Sultanate of Oman, abdulrhman.niz@cas.edu.om (AAA); Strategy and Planning Department, Oman Medical Specialty Board, Sultanate of Oman, abdullah.a@omsb.org (AAM); Social Statistics and Demography and Global Health Research Institute, University Of Southampton, S.Padmadas@soton.ac.uk (SSP)

Revised (R2) manuscript submitted to BMJ Open for possible publication
18 April 2021

Correspondence
Sabu S. Padmadas, M.Sc., Ph.D.
Professor of Demography and Global Health
University of Southampton, Highfield Campus
Southampton SO17 1BJ, United Kingdom
Email: S.Padmadas@soton.ac.uk

Word count abstract (300); main text (3549)

Contributors

All authors contributed substantially to the preparation of the manuscript including design, analysis and interpretation, and revising the article for important intellectual content. AKA, SSP and AAM conceived the idea and wrote the first draft of the paper. AAH and AKA conducted the literature review. Both AKA and AAH contributed equally to preparing the database and conducting the statistical analysis with technical support from AAA and SSP. AKA, AAH and SSP interpreted the findings. SSP and AAM revised the draft for intellectual content.

Funding

The Research Council, Sultanate of Oman (Reference: TRC/CRP/MoHE/COVID-19/20/04)

Competing interests

None declared

Patient and public involvement

No patients or public were not involved in the design, or conduct, or reporting, or dissemination of this research.

Patient consent for publication

Not applicable

Ethics approval

No formal ethical approval was required for this study.

Data sharing statement

Data used for the analysis are available in the public domain in anonymous aggregate format for research use. The list of data sources is available in the bibliography.

ABSTRACT

Objective

To generate cross-national forecasts of COVID-19 trajectories and quantify the associated impact on essential critical care resources for disease management in GCC countries.

Design

Population-level aggregate analysis

Setting

Bahrain, Kuwait, Oman, Qatar, United Arab Emirates and Saudi Arabia

Methods

We applied an extended time-dependent SEICRD compartmental model to predict the flow of people between six states: Susceptible- Exposed-Infected-Critical-Recovery-Death, accounting for community mitigation strategies and the latent period between exposure, and infected and contagious states. Then, we used the WHO Adaptt Surge Planning Tool to predict ICU and human resources capacity based on predicted daily active and cumulative infections from SEICRD model.

Main outcome measures

Predicted COVID-19 infections, deaths, and ICU and human resources capacity for disease management.

Results

COVID-19 infections vary daily from 498 per million in Bahrain to over 300 per million in UAE and Qatar to 9 per million in Saudi Arabia. The cumulative number of deaths vary from 302 per million in Oman to 89 in Qatar. UAE attained its first peak as early as 21/04/2020 whereas Oman had its peak on 29/08/2020. In absolute terms, Saudi Arabia is predicted to have the highest COVID-19 mortality burden followed by UAE and Oman. The predicted maximum number of COVID-19 infected patients in need of oxygen therapy during the peak of emergency admissions vary between 690 in Bahrain, 1,440 in Oman and over 10,000 in Saudi Arabia.

Conclusion

Although most GCC countries have managed to flatten the epidemiological curve by August 2021, trends since November 2020 show potential increase in new infections The pandemic is predicted to recede by August 2021, provided the existing infection control measures continue effectively and consistently across all countries. Current health infrastructure including the provision of ICUs and nursing staff seem adequate, but health systems should keep ICUs ready for managing critically-ill patients.

Keywords: COVID-19; Infectious Disease; Pandemic; Mathematical Model; Forecasting; Intensive Care Resources; Gulf Cooperation Council (GCC)

Strengths and limitations of this study

- Overall, barring a few fluctuations, the difference between the observed and predicted number of deaths in the SEICRD model is generally marginal across GCC countries.
- The predictions are based on public health interventions prevailing at the time, and the assumptions that the populations under investigation are stable, asymptomatic population exposed are infectious, those confirmed COVID-19 positive will have no reinfections and no changes in ICU resources during COVID-19.
- Adaptt Surge Planning tool predictions of ICU resources apply to only inpatient care.
- Lack of availability of demographic and socioeconomic data restrict our understanding of the infection dynamics.
- Given the high representation of expatriate population across GCC countries, further analysis disaggregated by nationality is pertinent to understand the differential impact of COVID-19 on population sub-groups.

Introduction

The pace and magnitude of the novel, highly contagious Severe Acute Respiratory Syndrome (SARS) Coronavirus disease 2019 (COVID-19) pandemic outbreak vary substantially across world regions. COVID-19 first reported in Wuhan region of China[1,2] spread rapidly to European countries of Italy, Spain and the United Kingdom, and in North and Latin America including United States, Canada and Brazil.[3-5]

COVID-19 pandemic outbreak in Gulf Cooperation Council Countries (GCC)

Within the Gulf Cooperation Council (GCC) countries, UAE reported the first four cases as early as 29 January 2020, and other GCC countries including Saudi Arabia, Oman, Bahrain, Qatar and Kuwait reported their first few cases towards the end of February 2020.[4,6,7] Since then, the new COVID-19 infections and deaths have more than doubled within the GCC region. For example, the weekly total number of new infections in GCC countries has doubled from 25,965 for the week May 3-9 to 51,713 for the week June 21-27, whereas the number of deaths per week increased from 144 to 393 during the same period. Saudi Arabia, the most populous country within GCC, has been the worst affected in terms of the total number of positive cases and case fatalities.[8]

Government response and the wider socioeconomic and healthcare context

While most GCC countries responded early to disease control and prevention in terms of enforcing social distancing, lockdown, public health awareness and behavioral change campaigns,[9] the implementation was transient and inconsistent due to economic and demographic challenges. As countries prepare to face another global economic recession post COVID-19, the situation is exacerbated in GCC countries severely affected by the recent oil crash.[10,11] COVID-19 has also extensively disrupted national economic diversification plans and functioning of small and medium industries and businesses in the GCC region. On average, two-thirds of GCC population represent young expatriate workers, working mostly in services and construction sectors, and they live in congested accommodation, often with low wages.[12] The share of expatriate population is the highest in UAE and Qatar (over 80%) and the lowest in Saudi Arabia (33%).[12]

Data from respective government ministries show a disproportionately higher incidence of COVID-19 infections and deaths among expatriate workers. However, these data are currently unavailable for research use in GCC countries. Older people aged 65 and above constitute between 3.3% in Saudi Arabia and 2% or less in the rest of GCC countries, which partly explain the anomaly between high incidences of COVID-19 infections and low case fatalities in the region.

On the other hand, GCC countries have high rates of non-communicable and chronic diseases including ischemic and coronary heart diseases, obesity, hypertension and diabetes mellitus.[13,14] GCC countries spend, on average, 4.3% of their GDP on healthcare, ranging

between 5.8% in Saudi Arabia to 3.1% in Qatar, mostly for treatment and management of non-communicable and chronic diseases.[12]

Research gap

Except for a few review and clinical studies,[9,15] there is no clear understanding of the future trends of COVID-19 in GCC countries and their impact on critical care capacity for disease management. As of 31st July 2020, GCC countries with a combined population of 58.5 million conducted a total of 10.6 million tests, identified 631,628 positive cases, of these 558,693 (88%) recovered and 4,400 (0.7%) died.[8] The number of new cases reported every day at that time remained high in the GCC region, particularly in Saudi Arabia.

The current pandemic situation is rather uncertain in GCC countries, especially with no systematic data on emergency admissions, and adequate population-level testing. The potential (subsequent) peaks of the pandemic are uncertain and there is little consensus on resource allocation for emergency care including ICU beds and ventilator support in the event of further increase and new wave of infections.

Research question

Our main research question is: how can we systematically compare and forecast the trends in COVID-19 pandemic across GCC countries, and what are the implications of these trends on critical care resources capacity at the national level? The goal of this article is to apply forecasting techniques to investigate the evolution of COVID-19 pandemic and quantify the critical care resource threshold for infection control and management in GCC countries.

Contributions

In the light of aforementioned research and data gaps, this paper contributes a case study documenting the current and future trajectories of COVID-19 pandemic and associated implications comparing the six GCC countries. The findings of this paper have implications for designing universal public health policies and interventions in the region, especially given the geographic proximity and population movements between GCC countries. The paper highlights the challenges associated with the paucity of existing data and calls for coordinated efforts to share reliable and consistent information in the region.

Materials and Methods

We considered a systematic approach to find the best model to predict the future evolution of COVID-19 pandemic and hospital resources capacity threshold in GCC countries.

Data

The key input variables for mathematical forecasting included: confirmed COVID-19 positive infection cases and deaths. These data derived from various sources including the Johns Hopkins Coronavirus Centre[4], Our World in Data[7], World Health Organization[3], GCC Stat[8] and respective Ministries of individual countries were verified for consistency.

Modelling approach and assumptions

We extended the widely used SIR (Susceptible, Infected and Recovered) compartment model[16] by including variants[6, 17-22] to develop a SEICRD model taking into account of community mitigation strategies and the latent period between when a person is actually exposed and until infected and contagious. SEICRD model incorporates the transition of individuals between six states (**Supplementary file Figure S1**). The states include Susceptible (S): number of individuals susceptible to be exposed; Exposed (E): number of individuals exposed where the disease status is latent, and individuals are infected but not infectious yet; Infected (I): number of individuals actually infected and infectious; Critical (C): infected individuals who need intensive care; Recovered (R): numbers infected who recover with an assumed lifelong immunity and they do not return to the Susceptible (S) state and the absorbing state Death (D).

We assumed that the population is stable, no re-infection of people who already had the infection and there are no changes in the size and composition of ICU resources during COVID-19. The input data included the number of ICU beds per 100,000 population, proportion of population by age group, transition probabilities from infected to critical, critical to dead, and the number of confirmed cases and deaths per day by country. The analysis was conducted in Python Jupyter version 3.7.6.[23] The mathematical equations to predict the outcomes of SEICRD model are described in detail elsewhere.[24]

The SEICRD model predicts the number of ICU beds needed to treat COVID-19 critical cases, taking into account the predicted number of patients with critical conditions and existing bed capacity. Suppose that a given country has B number of ICU beds to treat C_N Coronavirus cases with critical condition. If the number of critically ill patients (C_N) exceeds the *number of* ICU beds (B), then we will have ($C_N - B$) critical cases that cannot be treated, and hence the patient may die due to the shortage in the number of ICU beds. However, if B is greater than C_N, then all critical cases have the chance to be treated.[24]

The predicted number of cases in need of critical care, critical cases requiring oxygen and mechanical ventilation, Extra Corporeal Membrane Oxygenation (ECMO) and Renal Replacement Therapy (RRT), nursing resources and specialized medical practitioners were estimated using WHO Adaptt Surge Planning Tool.[25] The input parameters for the Adaptt tool were based on the outputs from SEICRD model: daily predicted active infected, daily predicted new infected and cumulative infected cases. In the Adaptt tool, we selected the option very low scenario[25] attack rate (5%) which represents the percentage contracting COVID-19 at the population level, and a universal social distancing mitigation measure. The infection transmission rates have been relatively slower across GCC countries.

The Adaptt model predicts the future ICU beds needed by date, for treating patients with moderate, severe and critical symptoms including ECMO and RRT and the human resources needed. Note Adaptt model only considers inpatient care. It takes into account the number of nurses required per shift and the shift configuration for treating COVID-19 patients. The tool enables users to input epidemiological data and generate mitigation scenarios for hospital resources planning and decision-making. It classifies patients into mild, moderate, severe and critical categories according to the level of resources needed.[20] Those classified mild can recover at home without inpatient care, moderate require inpatient care, severe require inpatient care with oxygen therapy, and critical patients require inpatient care with mechanical ventilation.

Patient and Public Involvement

None

Results

COVID-19 trends and national interventions in GCC countries since the outbreak

Four out of six GCC countries confirmed COVID-19 transmission at the community level, whereas clusters of cases were reported in Bahrain, and sporadic transmission in Saudi Arabia (**Table 1**). The number of new confirmed cases of COVID-19 has fallen across GCC countries since August 2020 until early February 2021. However, data during mid-February 2021 show the opposite with a significant increase in the number of new cases in all countries.

Population level infection control measures including social distancing, lockdown, curfew and movement restrictions appear to have had perceptible effects only in UAE initially. Qatar and Saudi Arabia whereas similar measures in other countries seem ineffective or inconsistent (**Figure 1**). As of February 2021, the number of national lockdowns implemented vary from 27 in Qatar, 24 in UAE, 20 in Kuwait, 13 in Bahrain and Saudi Arabia respectively to 5 in Oman, whereas the number of curfews and movement restrictions vary between 194 in Qatar to 39 in Oman.[26]

As illustrated in terms of weekly average trends, Oman, Bahrain, Kuwait and Saudi Arabia recorded a steady increase in new cases until mid-June. **Figure 1** clearly demonstrates evidence of early flattening of the epidemiological curve in Qatar and UAE, although there are signs of potential new wave in these countries. Bahrain and Kuwait are currently (as of February 2021) approaching a potential second wave.

Our data investigations show that the number of daily tests carried out was the lowest in Oman and Kuwait (<1 per 1000 population) and highest in Bahrain and UAE. Saudi Arabia has the lowest testing rates proportionate to population size. Population level testing for COVID-19 infections has been disrupted, and most countries have confined testing to people with symptoms or those seeking institutional healthcare, especially emergency admissions. As of 15 February 2021. Saudi Arabia recorded the highest recovery rate (95%) followed by Oman (94%) and Qatar (89%) whereas UAE recorded the lowest recovery rate.

The total number of deaths varies between 302 per million population in Oman to slightly over 235 per million in Bahrain and Kuwait. Saudi Arabia has the highest mortality burden in absolute terms at the population level. The doubling time for mortality at the initial stage of the pandemic varied between 24-31 days in Oman and Bahrain, and 78 days in UAE.

Future trajectories of COVID-19 in GCC countries

The predicted future trends in COVID-19 based on the SEICRD compartment model are summarised in **Table 2**. The predicted values are based on the probabilities of transition across different states from infected to critical, critical to dead and so on. Note the scale of population size vary by country: Bahrain (1.69 million); Qatar (2.80 million); Kuwait (4.27 million); Oman (5.01 million); UAE (9.88 million) and Saudi Arabia (34.79 million).

To illustrate, in Oman, on the peak date of the infection (29 August), of the 4.95 million people susceptible to COVID-19, 11,192 were infected, 337 cases manifested severe or critical symptoms and 730 died (**Table 2**). By 15 September 2021, Oman will have a predicted cumulative number of 2,067 deaths and 57 needing critical care on that particular date.

The model estimates indicate that there are variations between GCC countries in terms of the date of the infection peak, with UAE as the first country in GCC to achieve a peak towards the end of April 2020. On the other end, Oman and Bahrain attained the peak on 29 August and 18 June respectively. In absolute terms, Saudi Arabia is predicted to have the highest COVID-19 mortality burden (6,930 deaths) by 15 September 2021 followed by UAE (3,648), and Oman (2,067 deaths). By then, GCC countries together will have a predicted 15,193 deaths.

The fitted models were robust and there was little difference between the observed and predicted outcomes (**Figure 2**). Overall, barring a few fluctuations in Bahrain and Kuwait, the difference between the observed and predicted number of deaths in the SEICRD model is marginal across GCC countries. In Bahrain, the model slightly over predicted the deaths during the months of October-November 2020 and January-February 2021. In UAE, the model over-predicted the deaths between mid-November 2020 and January 2021, and under-predicted during June 2020.

The predicted ICU equipment capacity and human resources for COVID-19 management is graphically illustrated in **Figures 3 and 4** respectively. Note that due to technical reasons, we could not provide an update of the prediction beyond December 2020. The model assumes that all active cases are detected at the population level, and also takes into account the lag between date of infection and date when symptoms become critical or severe. Note GCC countries are relatively well equipped with intensive care systems and human resources, and the existing systems are currently able to manage COVID-19 pandemic without disruptions. However, the circumstances could change if the infections surge beyond the predicted levels.

The predicted number of infected persons requiring critical care during the peak of emergency admissions (area shaded in blue) is estimated to vary between 2000 and 22,000 depending on the population exposed and actually infected. Those in need of oxygen therapy is predicted to vary between 690 in Bahrain, 1441 in Oman and over 10,000 in Saudi Arabia (**Figure 3**).

The demand for total nursing staff during the peak of emergency admissions is predicted to vary from 2000 in Bahrain, 4000 in Oman to as high as 40,000 in Saudi Arabia (**Figure 4**). However, Saudi Arabia has over 190,000 nurses available within health systems. In comparison, Bahrain has 4,254 nurses, UAE 56,375, Kuwait 31,602, Qatar 21,032 and Oman has 21,448 nurses currently in employment.[7,8] The models predict a high demand for specialized ICU nurses during the peak of emergency admissions over the period from August to October in most countries, except UAE.

Strengths and limitations of this study

The analysis is the first of its kind in GCC countries to generate robust cross-national forecasts of COVID-19 and its impact on essential critical care resources for disease management. Overall, barring a few fluctuations, the difference between the observed and predicted number of deaths in the SEICRD model is generally marginal across GCC countries. The predictions are based on public health interventions prevailing at the time and the assumptions that the populations under investigation are stable, asymptomatic population exposed are infectious, those confirmed COVID-19 positive will have no reinfections and no changes in ICU resources during COVID-19.

Adaptt Surge Planning tool predictions of ICU resources apply to only inpatient care. Unfortunately, the tool does not allow to extend predictions beyond 365 days, and hence we could not present the predictions for future months. Furthermore, we could not validate these predictions with observed data due to lack of access to such information at the time of analysis. Lack of availability of demographic and socioeconomic data restrict our understanding of the infection dynamics. Given the high representation of expatriate population across GCC countries, further investigation disaggregated by nationality is pertinent to understand the differential impact of COVID-19 on population sub-groups.

Discussion

The foregoing analysis yielded robust predictions based on SEICRD model, comparing the trajectories of COVID-19 case incidence and mortality rates across GCC countries, and further quantified the demand for emergency care resources capacity. The scale and community level spread of COVID-19 pandemic has been relatively less severe in GCC countries when compared to other economically advanced nations.[3,4] The infection transmission was initially confined in small clusters during the early phase of the pandemic, subsequently elevated to community level in most countries, with increased risk of transmission amongst expatriate workers living in labor camps and boarding houses near construction sites and service stations. The vast majority of expat workforce is engaged in frontline unskilled and casual work, living in harsh conditions with little income and subsistence.

Most countries in GCC are sparsely populated except in capital cities and adjacent small cities. Infection control measures including travel, international border control, international flight suspensions,[9] quarantine, social and religious congregation restrictions,[27] short curfews, social distancing and lockdown initiated early had some effect in controlling the infection spread, but appear to be not fully effective in most countries, including in Saudi Arabia which had the Middle-East Respiratory Syndrome (MERS) Coronavirus outbreak in 2012.[28] The number of COVID-19 positive cases showed a steady increase towards the end of May 2020, as people returned to work and resumed economic activities after the religious Eid holidays, and then subsequently the infections increased since November. The most recent trends show a spike in the number of new cases across GCC countries, at a time when vaccination is being gradually rolled out.

Our model-based predictions confirmed that UAE attained a peak towards the end of April 2020, and Bahrain and Oman by 18 June and 29 August respectively. In absolute terms, Saudi Arabia has experienced the highest burden of COVID-19 mortality followed by UAE and Oman.

These trends are predicted on the assumption that the current infection control measures prevail until the new infections are contained in small clusters, and with adequate testing and surveillance systems to trace, isolate and treat COVID-19 patients. It has become clear that GCC countries have not fully recovered from the pandemic, and new infections attributed to potentially newly mutated strain seem looming large in the region. The variations in infection trends depend on population characteristics: size, composition, density and the readiness of hospitals to manage critical cases.

Our predictions show that the demand for specialized ICU nurses have continued to remain high until October 2020 and further demand is likely to be determined depending on the increase in new cases These predictions are based on the assumption that the current public health interventions continue with adequate surveillance systems, and that the infection recedes without any further outbreak at the community level.

While the current health infrastructure including the provision of ICUs and nursing staff seem intact, health systems should prepare ICUs and be ready for managing patients with severe symptoms and complications at least until cases are brought under control in small clusters. The nursing population across GCC countries are predominantly expatriates from South and South East Asia and Africa. Media reports show trends of return migration of expat frontline health workers to their home countries since the pandemic started. Further investigation is needed reflecting on the demographic and socioeconomic data related to COVID-19. Unfortunately, we could not explore the population level characteristics such as age, sex, nationality and socioeconomic status due to lack of data.

International travel restrictions including flight suspensions and quarantine measures can help reduce the infection rates as well enable systems to better coordinate appropriate public health response within countries.[29] In December 2020, all GCC countries have rolled out mass COVID-19 vaccination campaigns. Alongside inoculating people with COVID-19 vaccine, public health promotion should be intensified providing clear information, education and communication such as the need to maintain social distancing, infection prevention through sanitation and hygiene, proper understanding of the modes of infection spread and management of symptoms. The lack of proper risk communication and the ability to mitigate transmission in small populations highlight the need for strengthening public health expertise and leadership within the health system.

In the longer term, GCC countries need to address the major challenge of health inequity. There is evidence to suggest that expatriate workers, being the most vulnerable economically, die at younger age compared to native Arab population. It is essential to provide expatriate populations with appropriate health coverage, insurance and living standards to reduce the burden of future epidemic outbreaks.

Equally important is the need to strengthen capacity and investment in pandemic research, and ensure monitoring systems to collect systematic data on infectious diseases. Alongside basic science research, we need to apply artificial intelligence, machine learning and data sciences to understand the complexity and uncertainty of the COVID-19 pandemic.[30-33] In addition, concerted efforts are needed to strengthen behavioral, social and cost-benefit economic analyses of government interventions to understand the impact of COVID-19 management and response. Finally, it is important for GCC countries to share a common data repository on critical health and health systems indicators, enabling access to the broader scientific community.

Conclusion

Our study demonstrates evidence of considerable variations in COVID-19 trajectory across GCC countries. Although these countries have managed to initially flatten the epidemiological curve by early August, trends since November 2020 show potential new wave of infections, especially in countries which had relatively lower number of confirmed cases. The pandemic continues to spread in GCC countries but predicted to recede over by August 2021, provided the existing infection control measures, population testing and data monitoring systems continue effectively and consistently across all countries. Current health infrastructure including the provision of ICUs and nursing staff seem adequate, but health systems should be alert and keep the ICUs ready for managing critically ill patients.

References

1. Zhu N, Zhang D, Wang W, et al. A novel coronavirus from patients with pneumonia in China, 2019. N Engl J Med 2020; 382: 727-33.
2. Zhou P, Yang X, Wang X. et al. A pneumonia outbreak associated with a new coronavirus of probable bat origin. Nature 2020; 579: 270–273.
3. Coronovirus disease 2019. Situation Report-72. Geneva: World Health Organization. https://apps.who.int/iris/bitstream/handle/10665/331685/nCoVsitrep01Apr2020-eng.pdf (accessed 20 February, 2021).
4. Wuhan coronavirus (2019-nCoV) global cases: Operations dashboard. Johns Hopkins CSSE https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6 (accessed 20 February, 2021).
5. Mahmoudi MR, Heydari MH, Qasem SN, Mosavi A, Band SS. Principal component analysis to study the relations between the spread rates of COVID-19 in high risks countries. Alexandria Engineering Journal 2021; 60(1): 457–464.
6. Oloomi SA, Malayer MA, MOSAVI A. Trends of COVID-19 (Coronavirus Disease) in GCC Countries using SEIR-PAD Dynamic Model. MedRxiv 2020; Jan 1.
7. Roser M, Ritchie H, Ortiz-Ospina E, Hasell J. Coronavirus pandemic (Covid-19). Our World In Data. https://ourworldindata.org/coronavirus (accessed 18 February, 2021)
8. Coronavirus Pandemic Counts Map (COVID-19) for The Cooperation Council for The Arab Countries of The Gulf (GCC). GCC-Stat https://gccstat.org/en/covid-19-en (accessed 28 February, 2021).
9. Alandijany TA, Faizo AA, Azhar EI. Coronavirus disease of 2019 (Covid-19) in the Gulf Cooperation Council (GCC) countries: Current status and management practices. Journal of Infection and Public Health 2020; 13: 839-842.
10. Nasir MA, Al-Emadi AA, Shahbaz M, Hammoudeh S. Importance of oil shocks and the GCC macroeconomy: A structural VAR analysis. Resource Policy 2019; 61: 166-179.
11. El-Saharty S, Kheyfets I, Herbst CH, Ajwad MI. The GCC countries response to Covid-19. Fostering Human Capital in the Gulf Cooperation Council Countries 2020; 39-57.
12. Gulf Cooperation Council Statistics, GCC-STAT 2020. https://www.gccstat.org/en (accessed 28 February, 2021)
13. Rahim, HFA. Sibai A, Khader Y et al. Non-communicable diseases in the Arab world. The Lancet 2014; 383: 356-367.
14. Ng SW, Zaghloul S. Ali HI, Popkin BM. The prevalence and trends of overweight, obesity and nutrition-related non-communicable diseases in the Arabian Gulf States. Obesity Reviews 2010; 12: 1-13.
15. Uddin M, Mustafa F, Rizvi TA et al. SARS-CoV-2/Covid-19: Viral genomics, epidemiology, vaccines, and therapeutic interventions. Viruses 2020; 12:526.
16. Tolles J, Luong T. Modelling epidemics with compartment models. JAMA 2020: 323: 2515-2516.
17. Mwalili S, Kimathi M, Ojiambo V, Gathungu D, Mbogo R. SEIR model for COVID-19 dynamics incorporating the environment and social distancing. BMC Research Notes 2020; 13(1): 1–5.

18. Harko T, Lobo FSN, Mak MK. Exact analytical solutions of the Susceptible-Infected-Recovered (SIR) epidemic model and of the SIR model with equal death and birth rates. Applied Mathematics and Computation 2014; 236: 184–194.

19. Sedaghat A, Oloomi SAA, Malayer A, Rezaei M, Mosavi A (2020) Coronavirus (COVID-19) Outbreak Prediction Using Epidemiological Models of Richards Gompertz Logistic Ratkowsky and SIRD. doi: 10.31219/osf.io/c7twb

20. He S, Peng Y, Sun K. SEIR modeling of the COVID-19 and its dynamics. Nonlinear Dynamics 2020; 101(3): 1667–1680.

21. Murray JD. Mathematical Biology: An introduction. USA: Springer 2002.

22. Harir A, Melliani S, El Harfi H, Chadli LS. Variational iteration method and differential transformation method for solving the SEIR epidemic model. International Journal of Differential Equations 2020; 1-7.

23. Pérez F, Granger BE. IPython. A system for interactive scientific computing, Computing in Science and Engineering 2007; 9: 21-29, May/June 2007, doi:10.1109/MCSE.2007.53. https://github.com/henrifroese/infectious_disease_modelling/blob/master/part_three.ipynb (accessed 18 July, 2020)

24. Henri F. Infectious disease modelling: Fit your model to Coronavirus data. 2020 https://towardsdatascience.com/infectious-disease-modelling-fit-your-model-to-coronavirus-data-2568e672dbc7 (accessed 10 July, 2020)

25. WHO Adaptt Surge Planning Support Tool. Regional Office for Europe. Geneva: World Health Organization 2020. https://www.euro.who.int/en/health-topics/Health-systems/pages/strengthening-the-health-system-response-to-covid-19/surge-planning-tools/adaptt-surge-planning-support-tool (accessed 9 July, 2020).

26. UN OCHA Humanitarian Data Exchange 2021. https://data.humdata.org/dataset/acaps-covid19-government-measures-dataset (accessed February 27, 2021).

27. Ebrahim SH, Memish ZA. Saudi Arabia's drastic measures to curb the COVID-19 outbreak: temporary suspension of the Umrah pilgrimage. Journal of Travel Medicine 2020; 27(3); taaa029.

28. Algaissi AA, Alharbi NK, Hassanain M, Hashem AM. Preparedness and response to Covid-19 in Saudi Arabia: Building on MERS experience. Journal of Infection and Public Health 2020; 13: 834-838.

29. Wells CR, Sah P, Moghadas SM, et al. Impact of international travel and border control measures on the global spread of the novel 2019 coronavirus outbreak. Proceedings of the National Academy of Sciences 2020; 117: 7504-7509.

30. Alimadadi A, Aryal S, Manandhar I, Munroe PB, Joe B, Cheng X. Artificial intelligence and machine learning to fight COVID-19. Physiol Genomics 2020; 52: 200 –202.

31. Naudé W. Artificial intelligence vs COVID-19: limitations, constraints and pitfalls. AI & Society 2020; 35(3): 761–765.

32. Pinter G, Felde I, Mosavi A, Ghamisi P, Gloaguen R. COVID-19 pandemic prediction for Hungary; a hybrid machine learning approach. Mathematics 2020; 8(6): 890.

33. Ardabili SF, Mosavi A, Ghamisi P, Ferdinand F, Varkonyi-Koczy AR, Reuter U, Rabczuk T, Atkinson PM. Covid-19 outbreak prediction with machine learning. Algorithms 2020; 13(10): 249.

Table 1. COVID-19 testing, confirmed cases, recovered and deaths, GCC Countries

Key indicators	Bahrain	Sultanate of Oman	Kuwait	United Arab Emirates	Qatar	Saudi Arabia	GCC total
Transmission classification	Cluster	Community	Community	Community	Community	Sporadic	na
Number of observations							
Total confirmed cases (15/02/2021)	113,590	137,592	178,524	351,895	158,1[illegible]2	373,046	1,312,779
New cases (15/08/2020)	378	181	512	283	277	1,413	3,044
Daily cases per million (15/08/2020)	222.15	35.44	119.89	28.61	96.1[illegible]	40.59	51.89
New cases (15/10/2020)	333	520	746	1398	200	472	3,669
Daily cases per million (15/10/2020)	195.7	101.83	174.68	141.35	69.42	13.56	62.54
New cases (15/01/2021)	208	263	530	3407	196	173	4,777
Daily cases per million (15/01/2021)	122.24	51.50	124.11	344.48	60.03	9.97	81.43
New cases (15/02/2021)	848	286	823	3123	888	314	6,282
Daily cases per million (15/02/2021)	498	56	193	316	308	9	107
Total recovered (15/02/2021)	89,326	129,291	145,380	177,407	140,687	353,004	1,035,095
Total deaths(15/02/2021)	406	1,543	1,009	1,027	255	6,438	10,678
Total deaths per million (15/02/2021)	239	302	236	104	89	185	182
Daily deaths per million (15/02/2021)	2	0	1	1	0	0	0
Doubling time of deaths (in days)	31	24	54	78	37	32	43

Contd.

Table 1. COVID-19 testing, confirmed cases, recovered and deaths in GCC Countries (contd.)

Key indicators	Bahrain	Sultanate of Oman	Kuwait	United Arab Emirates	Qatar	Saudi Arabia	GCC total
Key dates in 2020 (day/month)							
First confirmed case	24-Feb	24-Feb	24-Feb	29-Jan	29-Feb	02-Mar	na
First death reported	16-Mar	31-Mar	04-Apr	20-Mar	28-Mar	24-Mar	na
Cases first exceeded 500 per day	31-May	24-May	05-May	23-Apr	20-Apr	16-Apr	na
Initiation of lockdown/restrictions	26-Mar	10-Apr	13-Apr	26-Mar	23-Mar	25-Mar	na

Source: compiled from World Health Organisation[3] Johns Hopkins CSSE,[4] Our World in Data,[5] GCC Stats,[6]
na: not applicable; last updated: 28 Feb 2021

Table 2. Predicted cumulative number of COVID-19 events by date based on SEICRD model

Country	Susceptible	Infected	Critical*	Recovered	Dead
Peak date (2020)					
Bahrain (18 Jun)	1,679,348	3,477	117	15,852	63
Oman (29 Aug)	4,947,724	11,192	337	144,412	730
Kuwait (04 May)	4,267,199	600	36	1,879	92
UAE (21 Apr)	9,890,527	219	13	1,107	61
Qatar (25 May)	2,872,960	2,308	78	4,935	35
Saudi Arabia (01 Jun)	34,036,468	271,698	1,255	414,789	392
Predicted date (15 March 2021)					
Bahrain	1,594,781	1982	69	102,073	468
Oman	4,777,582	5,218	160	321,702	1,701
Kuwait	4,249,282	458	28	18,905	1,179
UAE	9,868,036	1,249	73	20,943	1,274
Qatar	2,854,276	80	3	26,351	266
Saudi Arabia	30,553,242	21,187	128	4,226,506	6,628
Predicted date (15 June 2021)					
Bahrain	1,579,152	1,321	46	118,519	547
Oman	4,738,676	3,163	98	363,148	1,930
Kuwait	4,244,989	415	25	22,996	1,440
UAE	9,851,108	2,001	117	35,903	2190
Qatar	2,853,846	28	1	26,845	271
Saudi Arabia	30,439,112	7,184	44	4,358,674	6,854
Predicted date (15 Sept 2021)					
Bahrain	1,569,120	830	29	129,163	598
Oman	4,715,791	1,829	57	387,688	2,067
Kuwait	4,241,115	374	23	26,692	1,677
UAE	9,824,269	3,153	185	59,674	3,648
Qatar	2,853,698	10	1	27,015	273
Saudi Arabia	30,400,825	2,396	15	4,403,124	6,930

*figures shown are non-cumulative

Figure 1. Number of COVID-19 confirmed cases from 21/02/2020 to 15/02/2021 in GCC countries

Figure 2. Observed and predicted cumulative number of COVID-19 deaths based on SEICRD model, GCC Countries (from 01/06/2020 to 15/09/2021)

Figure 3. Predicted ICU equipment capacity for COVID-19 management applying SEICRD model estimates to WHO Surge Planning Tool, GCC Countries

Figure 4. Predicted ICU human resources capacity for COVID-19 management applying SEICRD model estimates to WHO Surge Planning Tool, GCC Countries

Supplementary file

Figure S1. COVID-19 infection transition states based on SEICRD model

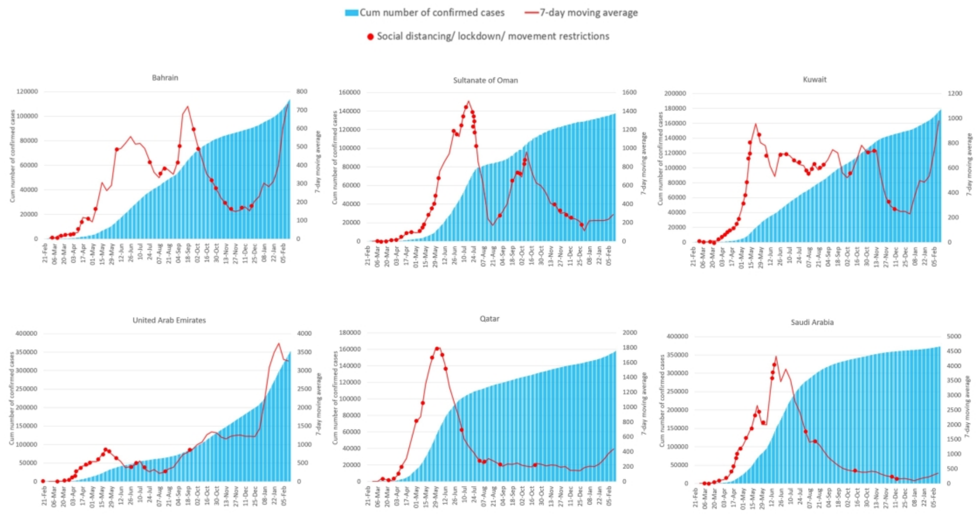


Figure 1

338x190mm (300 x 300 DPI)

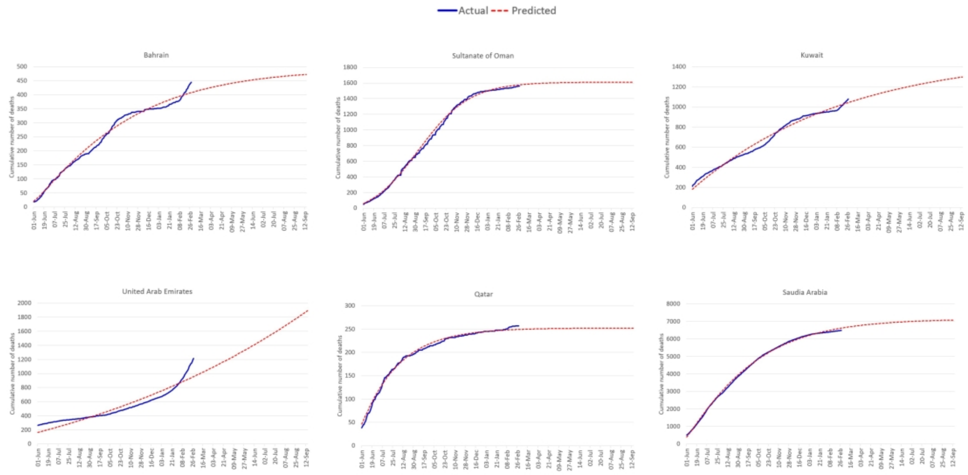


Figure 2

338x190mm (300 x 300 DPI)

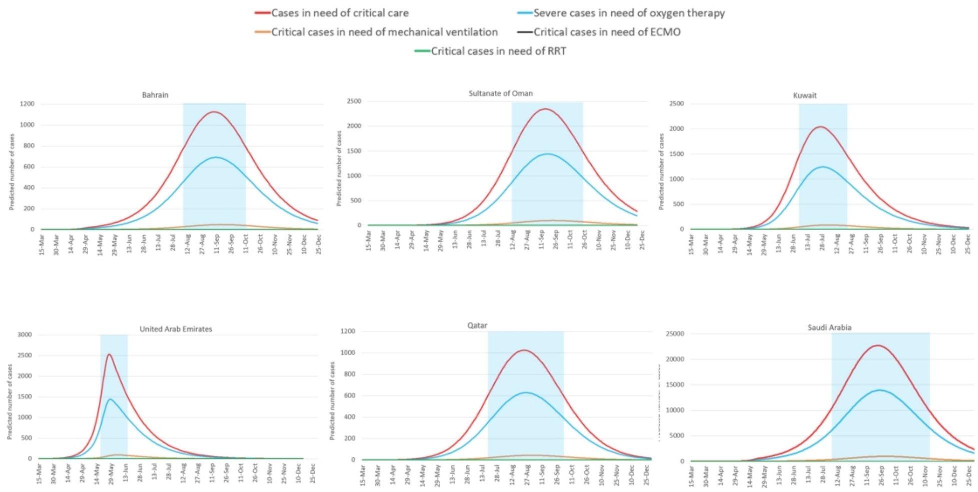


Figure 3

338x190mm (300 x 300 DPI)

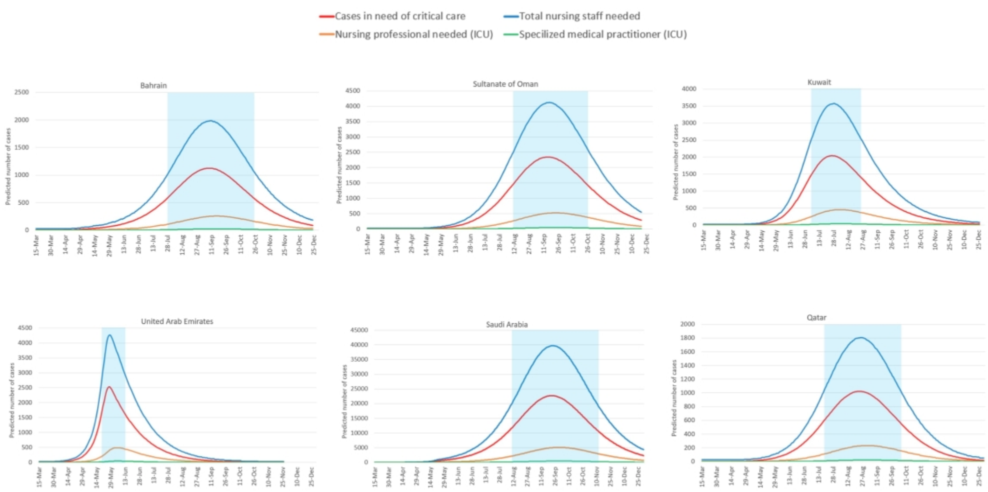
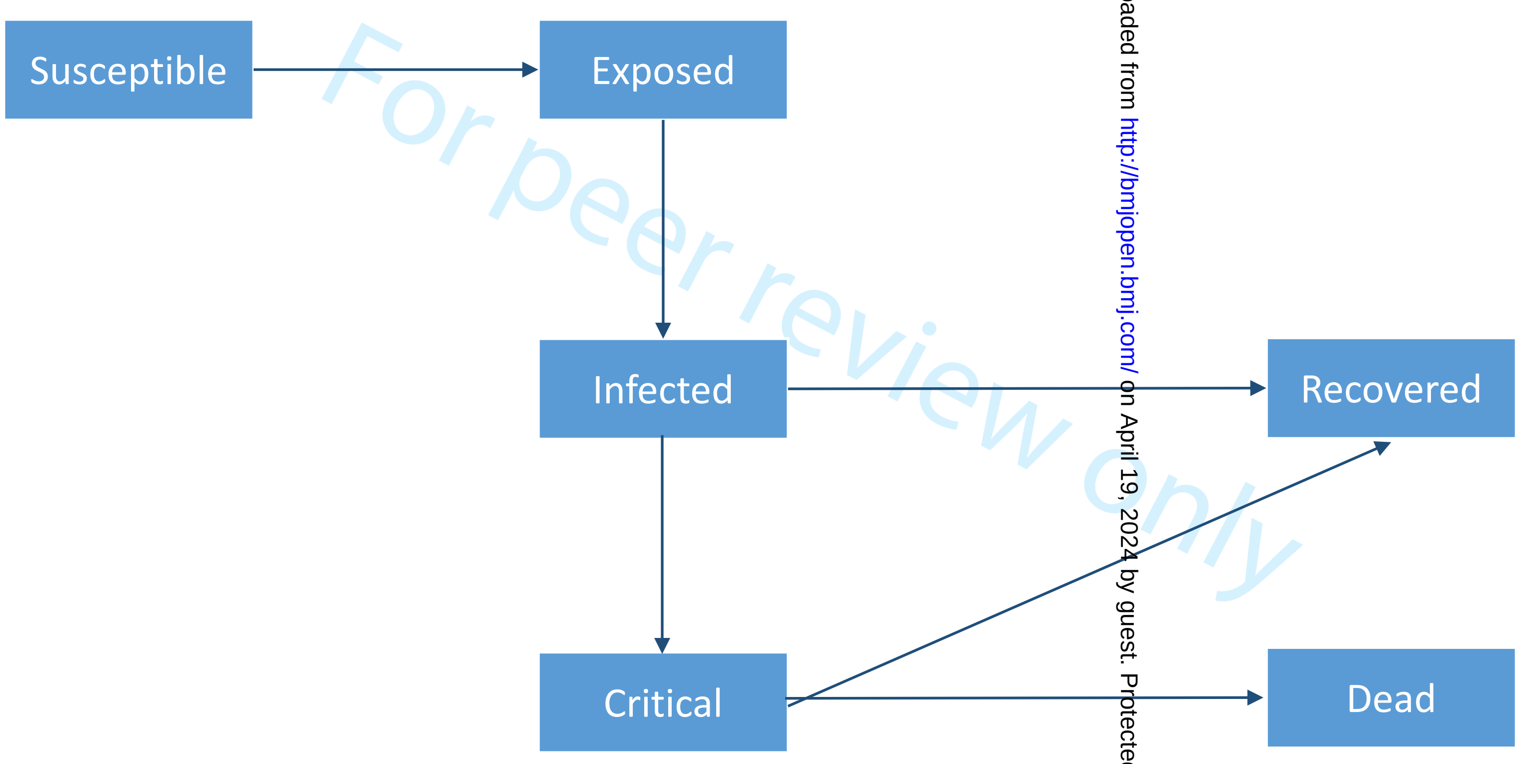


Figure 4

338x190mm (300 x 300 DPI)

Figure S1. COVID-19 infection transition states based on SEICRD model



STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6-7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	N/A
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7, 9
Bias	9	Describe any efforts to address potential sources of bias	10
Study size	10	Explain how the study size was arrived at	N/A
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7-8
		(*b*) Describe any methods used to examine subgroups and interactions	N/A
		(*c*) Explain how missing data were addressed	N/A
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	N/A
		(*e*) Describe any sensitivity analyses	9
Results			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	N/A
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	N/A
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	N/A
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
Discussion			
Key results	18	Summarise key results with reference to study objectives	11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	10
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	11-12
Generalisability	21	Discuss the generalisability (external validity) of the study results	N/A
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.