

Preliminary Estimation of the Basic Reproduction Number of SARS-CoV-2 in the Middle East

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Abstract

Up to April 9, 2020, 142490 cases have been confirmed as COVID-19 infection including 5705 associated deaths in the Middle East. Most of the countries, such as Qatar, Bahrain, Iraq, Kuwait, United Arab Emirates (UAE), Oman, Lebanon, and Saudi Arabia have imported COVID-19 cases from Iran. Using the available data from WHO webpage, up to 9 April 2020, we traced epidemic curves and estimated the basic reproduction number (R_0) of COVID-19 through the susceptible-infectious-recovered (SIR) model for the Middle East countries. Epidemic curves for Middle East countries and territory show similar trend as Iran, with a couple of weeks' delay in time. In SIR model, R_0 ranged between 7.41 as in Turkey to lowest as 2.60 for Oman whereas basic reproduction number for Iran, Kuwait, Bahrain, Qatar, Saudi Arabia, United Arab Emirates (UAE), Oman, Jordan, Egypt, Lebanon, Syria, Israel, West Bank and Gaza Strip territory, and Cyprus were 4.13, 2.71, 3.39, 4.18, 4.45, 2.75, 2.60, 3.52, 3.35, 3.16, 4.99, 4.08, 2.89, and 4.05, respectively. This study indicates an important trends on an early outbreak of COVID-19 based on estimated R_0 for the Middle East countries, mean $R_0 = 3.76$ for COVID-19, with median = 3.51. and interquartile range (IQR) = 1.16. in the Middle East.

Keywords: The basic reproduction number (R_0), COVID-19, Middle East

1. Introduction

The COVID-19 infection, caused by the novel coronavirus SARS-CoV-2, is a contagious disease that can be transmitted through droplets, aerosols, and contact (Van et al., 2020, Xu et al., 2020 and Morawska et al., 2020). The symptoms of COVID-19 infection appear after approximately 5.2 days (incubation period) (Li et al., 2020), which ranges from most common (fever, sore throat, cough, and fatigue) to variable ones (loss of smell, sputum production, headache, haemoptysis, diarrhoea, dyspnoea, and lymphopenia) (Li et al., 2020 and Huang et al., 2020). In severe cases, infected cases may develop pneumonia, bronchitis, severe acute respiratory distress syndrome (ARDS), multi-organ failure, and death. The first confirmed COVID-19 case was detected in the Chinese city of Wuhan in late December 31, 2019, since then, the virus has spread worldwide. The World Health Organization (WHO) declared COVID-19 outbreak as a pandemic on March 11th, 2020 (6). The reported cases of COVID-19 have since risen exponentially worldwide reaching more than 200 countries (Lewnard, 2020). As of April 9th, 2020, the outbreak has affected around 1521252 people globally and 142490 confirmed cases in the Middle East. The number of cases reported only in Iran until April 9th, 2020 is 68192 which records the highest number of infected cases of coronavirus in the Middle East. Iran has quickly led to

an infection chain that represents the second highest COVID-19 outbreak after Italy, the epicentre outbreak in Europe, with local cycles of transmission have occurred in more than eight countries after imported cases.

In the emergence of a new infectious disease outbreak, predicting the trend of the epidemic is of crucial importance to suggest effective control measures and estimate how contagious it is and how far it could spread (Viboud et al., 2018). Mathematical modelling plays a key role in understanding the transmission rates and prediction evaluation of infectious diseases and their control measures since the early 20th century (Hamer, 1906). Thus, it can provide insights into the epidemiological characteristic which help decision makers to implement restriction strategies and prepare the health system capacities in the course of pandemic (Lauro, 2020 and Wenbao et al., 2020). Rapid research on the prediction and transmissibility of COVID-19 has been focused on Asian and European countries (Yuan, 2019), with less attention in Middle Eastern countries. Increasing number of COVID-19 cases in Middle East, urged us to estimate the prediction and transmissibility in the region to implement appropriate alternative control measures accordingly.

The basic reproductive number (R_0) represents an indication of the initial transmissibility of the virus, i.e., the average number of secondary infections generated by each infected person. If this number is equal to one or less, $R_0 \leq 1$, it indicates that the number of secondary cases will decrease over time and eventually the outbreak will peter out. However, when $R_0 > 1$, the outbreak is expected as transmission to secondary cases increases that urges the implementation of control measures.

Initially, WHO estimated the basic reproduction number for COVID-19 between 1.4 and 2.5, as declared in the statement regarding the outbreak of SARS-CoV-2, dated 23th January 2020. Additionally, several articles aimed to more precisely estimate the COVID-19 R_0 . Recently, (Liu, Y. et al., 2020) compared 12 published articles from January 1, 2020 to February 7, 2020 and they reported that mean and median estimates for R_0 were 3.28 and 2.79, respectively. Furthermore, Korolev, I (Korolev, 2020), reported R_0 to be 2 to 3 times higher for the US and Western countries than for Asian countries. Rahman, B. et al. (Rahman, 2020) also reviewed 50 published articles which estimated 103 R_0 of COVID-19 with hovering between 0.32 and 6.47 in different countries including Italy, Iran, South Korea, Singapore, Japan, Israel, Algeria, Brazil and China. These differences are not surprising as transmission of COVID-19 multifaceted involving several changeable factors for deriving R_0 estimates, such as methods for modelling, variables to be considered, conditions on the clinical parameters, and various estimation procedures.

Up to our knowledge, limited number of articles published on prediction and R_0 of COVID-19 in Middle East. A group of researchers at Shahrekord University of Medical Sciences (Ahmadi, 2020), estimated R_0 to be 4.7 at the beginning of the outbreak in Iran and now R_0 has fallen below 2. Moreover, with three different scenarios estimated the prediction of confirmed cases by 3rd April 2020 at 19500, 27000, and 48830, with growth models of von Bertalanffy, Gompertz, and the least squared error, respectively. Authors concluded that the most ideal scenario is the Gompertz model. Current data from the WHO suggest more than a week ahead from Gompertz model prediction, with a reported number of 27017 cases by 25th March 2020. Muniz-Rodriguez K. et al. (Muniz-Rodriguez et al., 2020), estimated R_0 to be 3.6 and they recommended immediate social distancing in Iran. Sahafizadeh E. et al (Sahafizadeh, 2020), considered a basic SIR model by fitting the reported cases and observation for R_0 COVID-19 in Iran which was 4.86 and later reduced to 4.29. Ghaffarzagdegan N. and Rahmandad H. (Ghaffarzagdegan, 2020), developed SEIR epidemic model to predict a reliable figure of COVID-19, according to their trajectory prediction 1.6 million Iranian might get infected with 58000 death cases by the end of June 2020. (Wang J. et al., 2020) used SEIR model and estimated R_0 to be 8.93 with a transmission rate of 0.638 in Iran. Lately, (Klausner Z. et al., 2020), estimated R_0 to be 2.19 and presented deterministic compartment model with emphasizing quarantine and isolation policies. Their analysis showed that a single holiday changed the epidemic curve from flattened to exponential growth in Israel.

2. Method

Considering the daily data of the pandemic on the number of laboratory-confirmed cases reported from WHO situation reports, we employ an epidemic model SIR, a simple and widely-used deterministic, that describes the flow of individuals through three mutually exclusive stages of infection: Susceptible (S), Infected (I) and Removed (R)

$$\begin{aligned}
 \frac{dS}{dt} &= -\frac{\beta SI}{N}, \\
 \frac{dI}{dt} &= \frac{\beta SI}{N} - \alpha I, \\
 \frac{dR}{dt} &= \alpha I, \\
 N &= S + I + R,
 \end{aligned}
 \tag{1}$$

where β is the parameter that controls the transition between S and I and α which controls the transition between I and R . Removed compartment is a combination of both recovered and dead cases. In the absence of vaccine, the whole population assume to be susceptible, $S \approx N$, in this case infected population can be approximated to

$$\frac{dI}{dt} = \frac{\beta SI}{N} - \alpha I = (\beta - \alpha)I. \quad (2)$$

Works out
as

$$I(t) = I_0 e^{(\beta - \alpha)t}, \quad (3)$$

where I_0 is the number of infectious individuals at the beginning of the outbreak. An epidemic occurs if the number of infected individuals increases, i.e. $\beta - \alpha > 0$ which is equivalent to $\frac{\beta}{\alpha} > 1$. According to the definition of R_0 , the transmissibility of a virus is measured by the basic reproduction number, which measures the average number of new cases generated per typical infectious cases, can be estimated throughout system (1), we arrive at the following inequality,

$$R_0 = \frac{\beta}{\alpha} > 1. \quad (4)$$

It is obvious that the basic reproduction number R_0 is dependent on both infection rate β , and removal rate α , which is the inverse of infectious period. As reported in the WHO-China joint mission on COVID-19 (Report of the WHO-China), in our simulation, we assume susceptible individual with COVID-19 takes an average of 7 days to be infected, and takes an average of 14 days from infected to removed, yields $\alpha = \frac{1}{14}$. Next, we used estimation procedure (least-square fitting) similar to Method 2 in (Chowell et al., 2007), and compute the residual sum of squares for the reported cases, given by

$$RSS(B) = \sum_{t=1}^n (RD(t) - FD(t, \beta))^2, \quad (5)$$

where RD stands for real data, and FD is a fitted data, that is the value of data t on the fitted curve, which can be predicted by SIR model, n is the number of daily reported cases of COVID-19. We then estimate the infection rate β by minimizing the RSS .

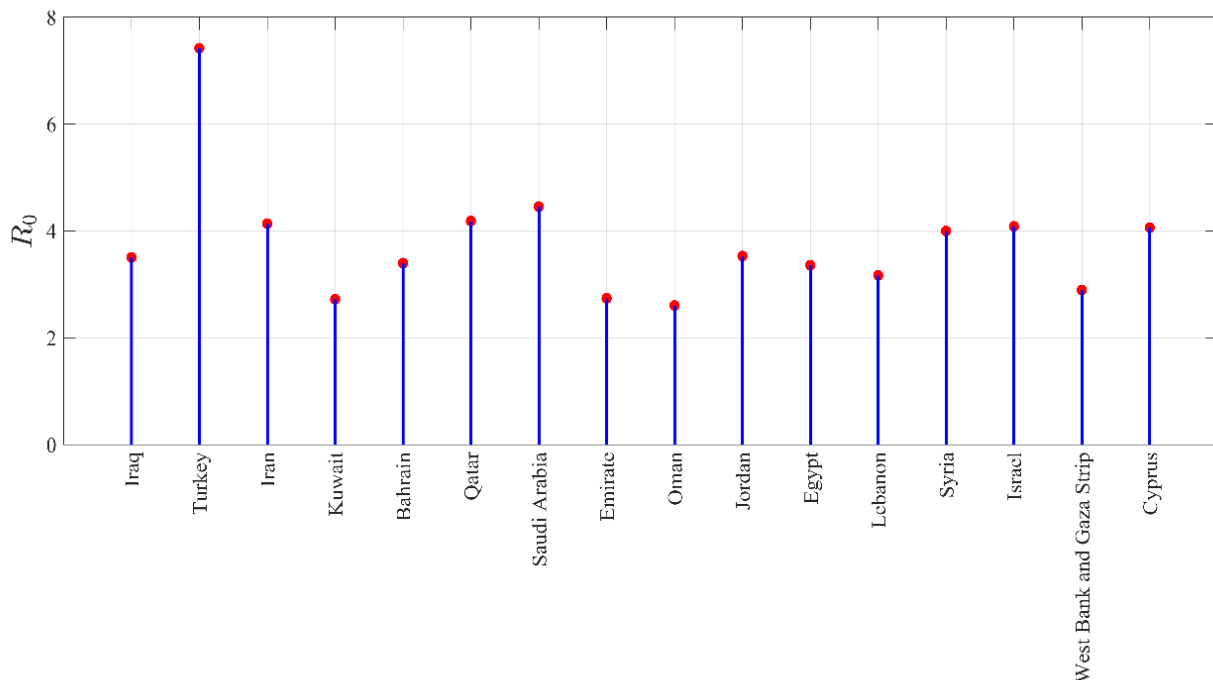


Figure 1. Dot chart showing the estimated R_0 in the Middle Eastern countries and territory

Table 1. The basic reproduction numbers and the corresponding key parameters.

<i>Countries/Territory</i>	<i>Population</i>	<i>n</i>	β	R_0
<i>Iraq</i>	40,222,000	46	0.25012	3.50168
<i>Turkey</i>	83,200,000	30	0.52979	7.41706
<i>Iran</i>	82,914,000	50	0.2952	4.1328
<i>Kuwait</i>	4,700,000	46	0.19422	2.71908
<i>Bahrain</i>	1,443,000	46	0.2425	3.395
<i>Qatar</i>	2,839,000	40	0.29878	4.18292
<i>Saudi Arabia</i>	34,140,000	39	0.31805	4.4527
<i>UAE</i>	9,680,000	50	0.19549	2.73686
<i>Oman</i>	5,107,000	45	0.18585	2.6019
<i>Jordan</i>	10,458,000	39	0.25188	3.52632
<i>Egypt</i>	100,388,000	50	0.23971	3.35594
<i>Lebanon</i>	6,825,000	48	0.22622	3.16708
<i>Syria</i>	17,070,000	18	0.28549	3.99686
<i>Israel</i>	8,972,000	49	0.29162	4.08268
<i>West Bank & Gaza Strip</i>	5,101,000	36	0.20647	2.89058
<i>Cyprus</i>	1,207,000	31	0.28999	4.05986

3. Results and Discussion

The COVID-19 pandemic spread rapidly and crossed borders reaching almost every corner of world and took more than two hundred thousand lives. The current economic and social impact of this pandemic is just the tip of iceberg. Due to lack of population immunity and an effective vaccine, the spread of COVID-19 is still expanding exponentially in many countries. Therefore, evaluating the effectiveness of implemented controlling measures like traffic restriction, lockdown, and social distancing are critical to stop the spread of the COVID-19 and save lives of thousands of people. Here we report the R_0 of all Middle East countries based on SIR model (Figure 1 and Table 1). Interestingly, it was found that Middle East countries seem to follow Iran's trend with just a few week delays in time.

The control and delay in spreading of COVID-19 infection strongly rely on the capabilities of a country's health system. The health system of many developing countries in the Middle East is below the world's standards (Ghsindex, 2020) that make these countries vulnerable to a rapid spread of COVID-19 with higher rate of fatality as a result of current pandemic. It is worthy to note that, current official cases in the region is far behind those in the US, Italy, and Spain.

The overall timeline of the outbreak has provided countries with a window of opportunity for the early implementation of preventive interventions. Thereby, the before math intervention introduced in some Gulf countries play a considerable role in slowing down the number of confirmed cases, or "flattening the curve" of the virus' growth (Vatanka et al., 2020). A recent article illustrates that the government response and population demography in Iraq have a significant role in flattening the epidemiological curve (Jebril, 2020). We suggest all countries need to consider the Chinese and Italian lessons and implement immediate and more powerful control measures in order to stop the spread and break the chain of transmission.

Regarding the used parameters by SIR model for the prediction, the R_0 values shown in Figure 1, is relatively consistent with several mathematical models that have been used so far. Estimated the COVID-19 R_0 varies from 1.69 to 6.47 (Muniz et al. 2020-Jebril). A review written by (Liu et al., 2020) compared 12 published articles from the 1st January to the 7th of February 2020 which estimated for the R_0 for COVID-19 a range of values between 1.5 and 6.68. In a recent article, (Jiang, S et al., 2020), estimated R_0 to be 6.66, 5.03, 5.60, and 8.93 for the four main epicenters Wuhan, Korea, Italy and Iran respectively. (Sardar, et al., 2020), estimated R_0 in different Indian states (Maharashtra, Delhi, Tamil Nadu) and overall India ranged between 1.46 to 8.44. By comparing the various investigation, these different

basic reproduction number arise for many reasons: the virus is shed before symptoms begin, it is hard to identify the incubation period, the proportion of infected cases missed at the tracing and control procedures and the effectiveness of current strategies to prevent the spreading of the infection (Viceconte, 2020).

Based on current model, the trend falls into three different curves which are exponential, sub-exponential, and polynomial (Figure 2). In Iran, Turkey, Saudi Arabia, and Israel, the confirmed cases rise exponentially; in Qatar, UAE, and Egypt increase sub-exponentially; in Iraq, Kuwait, Bahrain, Oman, Jordan, Lebanon, Syria, West Bank and Gaza Strip, and Cyprus grow polynomially. These countries have exponential curves recorded the highest R_0 ranging from 4.08 to 7.41, while countries and territory with polynomial curves reported the lowest ranging between 2.60 to 4.05.

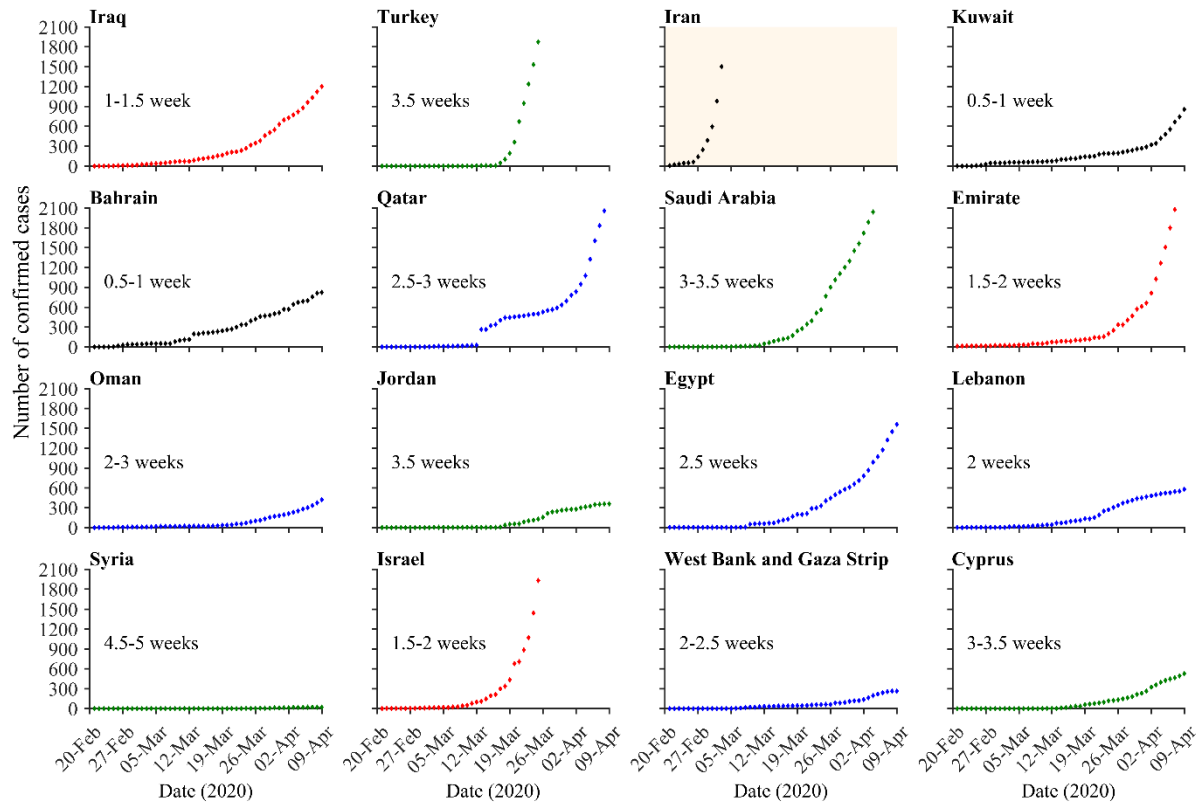


Figure 2. Cumulative of confirmed cases for Middle East countries and territory, with estimated delay in time from Iran's situation, as of 9th April 2020. black dots are for countries with less than 1 week delay in time from Iran; red is for countries with 1–2 weeks delay in time; blue is for countries and territory with 2–3 weeks delay in time; and green is for countries with more than 3. The Iranian and Turkish data curves are cut at 2100 cases in order to compare delay in time with other countries. Source of data: WHO.

4. Conclusions

Basic reproduction number of COVID-19 is crucial parameter during a pandemic which is used to estimate the risk of COVID-19 outbreak and evaluate the effectiveness of implemented measures. For the first time, we report estimates of the basic reproduction number R_0 of COVID-19 outbreak in the Middle East countries and territory together using SIR model by fitting the model to official reported data from WHO. It is also observed the Middle East countries epidemic curves is just a couple of weeks behind Iran. According to the result Turkey has the highest R_0 and Oman has the lowest. This study also found that the estimated mean R_0 for COVID-19 is around 3.76, with a median of 3.51 and IQR of 1.16. This mean R_0 is close to the two recent review articles by (Liu et al., 2020 and Alimohamadi, Y. et al., 2020) which estimated R_0 to be 3.38 and 3.28 respectively. Due to short onset time, current estimates of R_0 for COVID-19 in the Middle East might be biased. Moreover, the basic reproduction number is continuously modified during a pandemic by accurate assumptions introduced and becomes more reliable R_0 as more data and information come to light. The limitations of this study as it is applied to all other similar studies, due to limited number of tests in the whole population, the number of asymptomatic cases which may account about 25% of the population have been excluded and also the reported confirmed cases are believed to be lower than the actual cases.

Middle East Coronavirus Cases

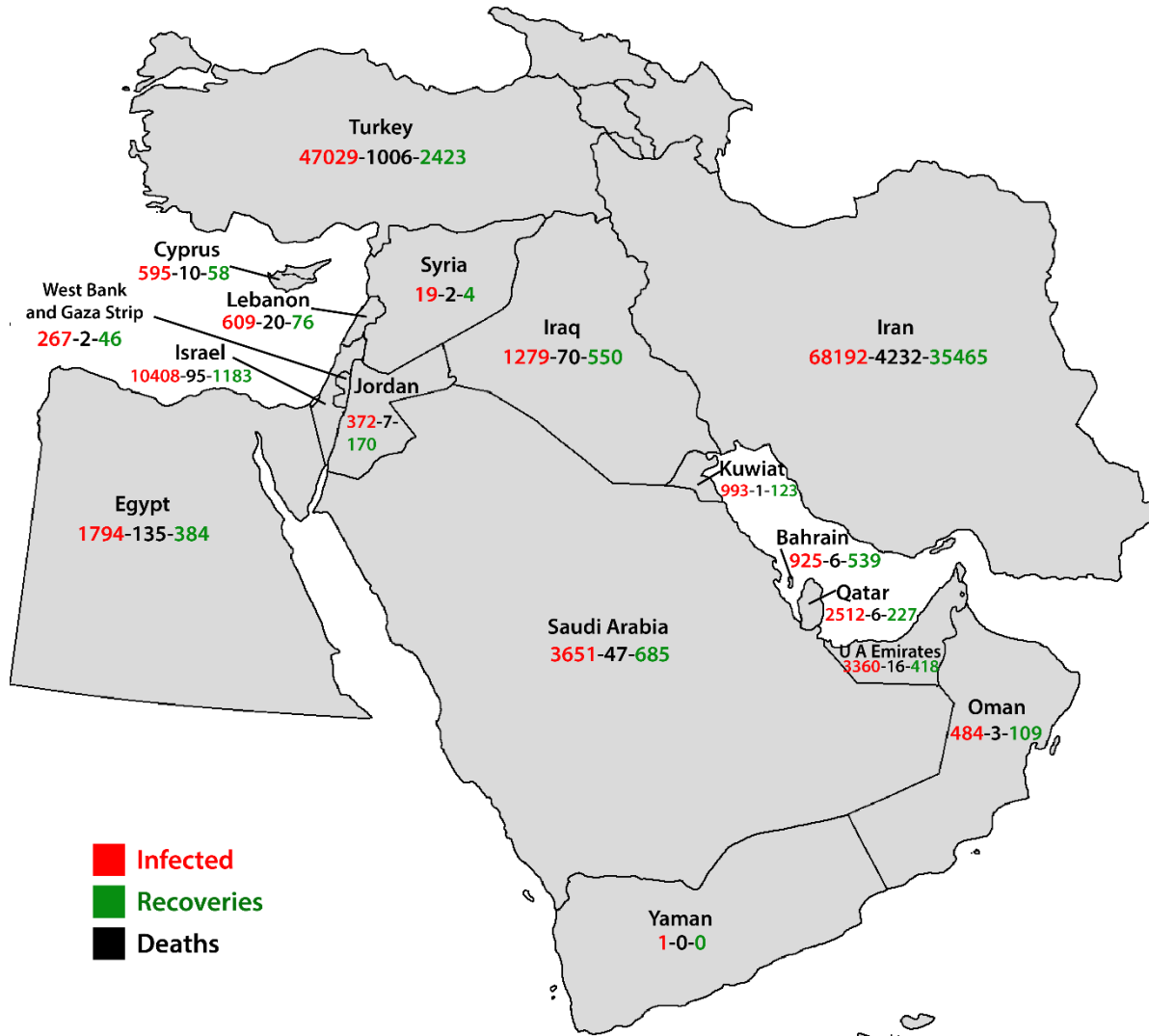


Figure 2. Infected, recoveries and deaths cases in the Middle Eastern countries and territory.

In summary, this study provides important findings on an early outbreak of COVID-19 in the Middle East. In theory, most the Middle East countries are in better positions than many other countries to react to the current outbreak. Nevertheless, health care system in some countries and territories of Middle East may face serious challenges as COVID-19 cases overwhelm hospitals, therefore, governments should work closely with the WHO to visit countries in need to provide recommendations, support control and prevention efforts. In the meantime, the Middle East countries and territory should continue to prepare for and respond to COVID-19 and learn from China on relevant preventive and control measures.

Reference

- N.D. van, T. Bushmaker, D.H. Morris, M. G. Holbrook, A. Gamble, B.N. Williamson, et al. (2020). "Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1," *N Engl J Med* [Internet], 03/17. 2020 Apr 16;382(16):1564–7, Available from: <https://pubmed.ncbi.nlm.nih.gov/32182409>
- R. Xu, B. Cui, X. Duan, P. Zhang, X. Zhou, Q. Yuan. Saliva (2020). " potential diagnostic value and transmission of 2019-nCoV," *Int J Oral Sci* [Internet], Apr 17;12(1):11, Available from: <https://pubmed.ncbi.nlm.nih.gov/32300101>
- L. Morawska, J. Cao (2020). " Airborne transmission of SARS-CoV-2: The world should face the reality," *Environ Int* [Internet]. Apr 10;139:105730. Available from: <https://pubmed.ncbi.nlm.nih.gov/32294574>
- Q. Li , X. Guan, P. Wu, X. Wang, L. Zhou, Y. Tong, et al. (2020) "Early Transmission Dynamics in Wuhan, China, of

Novel Coronavirus–Infected Pneumonia," *N Engl J Med.* ,1–9.

C. Huang, Y. Wang, X. Li, L. Ren, J. Zhao, Y. Hu, et al. (2020) "Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China," *Lancet (London, England)* [Internet],/01/24. 2020 Feb 15;395(10223):497–506. Available from: <https://pubmed.ncbi.nlm.nih.gov/31986264>

WHO. Emergency Committee regarding the outbreak of Coronavirus disease 2019 (COVID-19), Accessed 11th March 2020. <https://www.who.int/dg/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020>.

J.A. Lewnard, N.C. Lo. (2020) "Scientific and ethical basis for social-distancing interventions against COVID-19," *Lancet Infect Dis* [Internet], Available from: <http://www.sciencedirect.com/science/article/pii/S1473309920301900>

C. Viboud, K. Sun, R. Gaffey, M. Ajelli, L. Fumanelli, S. Merler, et al. (2018) "The RAPIDD ebola forecasting challenge: Synthesis and lessons learnt," *Epidemics* [Internet]. 2018;22:13–21. Available from: <http://www.sciencedirect.com/science/article/pii/S1755436517301275>

W.H. Hamer The Milroy Lectures on Epidemic Diseases in England: The Evidence of Variability and of Persistency of Type; Delivered Before the Royal College of Physicians of London, March 1st, 6th, and 8th, 1906. Bedford Press; 1906.

F.D. Lauro, I.Z. Kiss, J. Miller (2020) "The timing of one-shot interventions for epidemic control," *medRxiv*, 03.02.20030007.

W. Wenbao, C. Yiqin, W. Qi, C. Ping, H. Ye, H. Shanwen, et al. (2020) "Transmission dynamics of SARS-COV-2 in China: impact of public health interventions," *medRxiv* [Internet],03.24.20036285. Available from: <http://medrxiv.org/content/early/2020/03/27/2020.03.24.20036285.abstract>

Y. Liu, A.A. Gayle, A. Wilder-Smith, J. Rocklöv (2020) "The reproductive number of COVID-19 is higher compared to SARS coronavirus," *J Travel Med* [Internet], 27(2):1–4. Available from: <https://doi.org/10.1093/jtm/taaa021>

J. Yuan, M. Li, G. Lv, Z.K. Lu (2019) "Monitoring Transmissibility and Mortality of COVID-19 in Europe," *Int J Infect Dis* [Internet]. Available from: <http://www.sciencedirect.com/science/article/pii/S120197122030182X>

WHO. Emergency Committee regarding the outbreak of novel coronavirus 2019 (n-CoV), Accessed 23rd January 2020. [https://www.who.int/news-room/detail/23-01-2020-statement-on-the-meeting-of-the-international-health-regulations-\(2005\)-emergency-committee-regarding-the-outbreak-of-novel-coronavirus-\(2019-ncov\)](https://www.who.int/news-room/detail/23-01-2020-statement-on-the-meeting-of-the-international-health-regulations-(2005)-emergency-committee-regarding-the-outbreak-of-novel-coronavirus-(2019-ncov)).

I. Korolev Identification and Estimation of the SEIRD Epidemic Model for COVID-19. 2020;1–27.

B. Rahman, E. Sadraddin, A. Porreca (2020) "The basic reproduction number of SARS-CoV-2 in Wuhan is about to die out, how about the rest of the World," *Rev Med Virol* [Internet]. (e2111). Available from: <https://doi.org/10.1002/rmv.2111>

A. Ahmadi, M. Shirani, F. Rahmani (2020) "Modeling and Forecasting Trend of COVID-19 Epidemic in Iran," *medRxiv* [Internet]. 2020.03.17.20037671. Available from: <http://medrxiv.org/content/early/2020/03/20/2020.03.17.20037671.abstract>

K. Muniz-Rodriguez, I.C-H. Fung, S.R. Ferdosi, S.K. Ofori, Y. Lee, A. Tariq, et al. (2020) "Transmission potential of COVID-19 in Iran," *medRxiv* [Internet]. 2020.03.08.20030643. Available from: <http://medrxiv.org/content/early/2020/03/10/2020.03.08.20030643.abstract>

E. Sahafizadeh, S. Sartoli (2020) "Estimating the reproduction number of COVID-19 in Iran using epidemic modeling," *medRxiv* [Internet]. 2020.03.20.20038422. Available from: <http://medrxiv.org/content/early/2020/03/29/2020.03.20.20038422.abstract>

N. Ghaffarzadegan, H. Rahmandad (2020) "Simulation-based Estimation of the Spread of COVID-19 in Iran," *medRxiv* [Internet]. 2020.03.22.20040956. Available from: <http://medrxiv.org/content/early/2020/03/27/2020.03.22.20040956.abstract>

J. Wang, J. Distric, S. Jiang, S. Jiang, Q. Li, C. Li, et al. Mathematical models for devising the optimal SARS-CoV-2

eradication in China , South Korea , Iran , and Italy. *Lancet Glob Heal*.

Z. Klausner, E. Fattal, E. Hirsch, S.C. Shapira (2020) "A single holiday was the turning point of the COVID-19 policy of Israel," *medRxiv* [Internet]. 2020.03.26.20044412. Available from:

<http://medrxiv.org/content/early/2020/03/31/2020.03.26.20044412.abstract>

Report of the WHO-China joint mission on Coronavirus disease 2019 (COVID-19).

G. Chowell, H. Nishiura, L.M.A. Bettencourt (2007) "Comparative estimation of the reproduction number for pandemic influenza from daily case notification data," *J R Soc Interface* [Internet]. (12):155–66. Available from:

<https://pubmed.ncbi.nlm.nih.gov/17254982>

Ghsindex. 2020 Global Health Security Index. <https://www.ghsindex.org/> , 2020 (accessed 24 March 2020).

A. Vatanka, N.A. -D.R. Slim, C. Lister, Tol MFMMGWG, Elgindy GMFK, Pack J, et al. (2020) "COVID-19 and the Middle East," accessed on 18 March 2020, <https://www.mei.edu/blog/covid-19-and-middle-east>.

N.M.T. Jebril Distinguishing epidemiological curve of novel coronavirus disease (COVID-19) cases in Iraq : How it does not follow the epidemic curve of China.

T. Sardar, S.S. Nadim, J. Chattopadhyay(2020) "Assessment of 21 Days Lockdown Effect in Some States and Overall India: A Predictive Mathematical Study on COVID-19 Outbreak," Available from: <http://arxiv.org/abs/2004.03487>

G. Viceconte, N. Petrosillo (2020) "COVID-19 R0: Magic number vidual affected by a transmittable disease is or conundrum" 2020;12:12–3.

Y. Alimohamadi, M. Taghdir, M. Sepandi (2020) "The Estimate of the Basic Reproduction Number for Novel Coronavirus disease (COVID-19): A Systematic Review and Meta-Analysis," *Korean J Prev Med* [Internet], 0(0). Available from: <https://doi.org/10.3961/jpmph.20.076>