



# Numerical simulation of the force of infection and the typical times of SARS-CoV-2 disease for different location countries

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## Abstract

The new coronavirus disease appeared at the end of 2019 which is now a very big problem by spreading over the world and there are multiple parameters that can be discussed to be tools for the forecasting and the spreading of the pandemic such as the force of infection, the exponential base...etc. In this work, we estimate the force of infection and the specific times of the disease. For estimating the force of infection and the specific times, we use SEIR (susceptible cases of the disease, infectious cases of the disease, and recovered cases of the disease) epidemic model and the numerical analysis methods for simulating the values. We use the collected data of the new coronavirus pandemic reported up to 21 September, 2020 in different geographical location countries, which are, China, USA, Russia, the United Kingdom, Brazil, Spain, Bahrain, Egypt, India, Iran, Cyprus and the Syrian Arab Republic. We found that the force of infection and the specific times of SARS-CoV-2 disease are different for different location in countries. We find that there is no actual relation between the force of infection and the specific times of the pandemic of the new coronavirus disease with the weather and the geographical location of the countries.

**Keywords** The force of infection · COVID-19 · Models · SEIR model · Pandemic · Numerical simulation

## Introduction

The new coronavirus disease appeared at the end of 2019 in China in Wuhan and became a very big problem by spreading over the world; there are multiple parameters that can be discussed to be tools for the forecasting and the spreading of the pandemic such as the basic reproductive ratio, the exponential growth base and so on. The force of infection is a specific tool when we talk about a specific pandemic such as Ebola and the new coronavirus disease because it represents the transmission from susceptible cases to the infectious cases. The force of infection can be estimated from one of the models used in the epidemiology where there are multiple models in epidemiology used to simulate the forecasting and the spreading of a specific pandemic, some use fractional derivatives and others use ordinary differential equations, some with vaccination, and some with the deceased cases (Al-Raei 2018; Tarabichi 2010). The definition and derivation of the first epidemic model, which

is SIR (susceptible cases of the disease, infectious cases of the disease, recovered cases of the disease) model, was by Kermack (1927) and the models derived from this model were used for forecasting lots of disease such as Ebola virus spread as Osemwinyen (2015), Kamara (2020) and Zhu (2019) and with vaccination as (Gao 2007). Recently, the model and the modified models were used for forecasting and spreading of the new coronavirus disease where (Malavika et al 2020) used SIR and logistic growth models for the forecasting of COVID-19 epidemic in India and high incidence states, (Al-Raei 2020a, b) found the basic reproduction number values of the disease for multiple countries, (Lifshits et al. 2020) studied the forecasting of the pandemic in Russia, (Roy et al 2020) discussed the forecasting of the disease in India using ARIMA (autoregressive integrated moving average) model and the same model was applied for Russia by Fang et al. (2020), Rejaur Rahman et al. (2020) studied the forecasting of the disease in Bangladesh with geospatial modelling, Gupta et al (2020) discussed the effect of the geographical locations in India on the disease, Santosh (2020) discussed the prediction models with unexploited data of the disease, Neto et al. (2020) showed the new coronavirus industrial impact with the fourth industrial revolution, Aabed et al. (2020) discussed the analytical study

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of the forecasting factors on the spread of the disease, Ali et al. (2020) discussed the effects of the  $PM_{2.5}$  on the spreading of the disease, Khan et al. (2020) discussed the effects of underlying morbidities on the occurrence of deaths in COVID-19 patients, Al-Raei (2020a, b) discussed the forecasting of the disease for multiple countries with mortality and Bhadra et al (2020) discussed the effects of population density on the infection and the mortality of the disease. In this work, we use the SEIR epidemic-model for simulating force of infection of the new coronavirus disease values for multiple countries. Besides, we use the same model for simulating the values of the specific times namely the typical time between contacts  $T_C$  and the typical times up to removal  $T_R$  of SARS-CoV-2 pandemic. The SEIR model take the exposed cases into part and this model is composed of four differential equations. The first two equations of this model are non-linear equations and describe the change of the susceptible cases and the change of the exposed cases with respect to the time and the others equations describe the rate of the infections and the recovery in respect to the time. The four equations of the SEIR epidemiological model are given as follows:

$$\frac{ds(t)}{dt} = -\nu_2 i(t)s(t) + \nu_1 [1 - s(t)] \quad (1)$$

$$\frac{de(t)}{dt} = -(\nu_1 + \nu_3)e(t) + \nu_2 i(t)s(t) \quad (2)$$

$$\frac{di(t)}{dt} = -(\nu_1 + \nu_4)i(t) + \nu_3 e(t) \quad (3)$$

$$\frac{dr(t)}{dt} = -\nu_1 r(t) + \nu_4 i(t) \quad (4)$$

where  $\nu_1$ ,  $\nu_2$ ,  $\nu_3$  and  $\nu_4$  are the parameters of the model and  $s(t)$ ,  $i(t)$ ,  $r(t)$  and  $e(t)$  are the normalized susceptible cases of the disease, the normalized infectious cases of the disease, the normalized recovered cases disease and the normalized exposed cases of the disease, respectively. In this study, we consider the previous SEIR model to estimate the force of infection values and the specific times values of the new coronavirus disease in China, where the first case appeared at the end of 2019, the US, where the first case of the pandemic was observed in January 2020, UK, where the first case of the pandemic was observed in January 2020, Brazil, where the first case of the pandemic was observed in February 2020, Spain, where the first case of the pandemic was observed in January 2020, India, where the first case appeared in February 2020, Russia, where the first case of the pandemic was observed in January 2020, Bahrain, where the first case of the pandemic was observed in February 2020, Egypt, where the first case of the pandemic was

observed in February 2020, Iran, where the first case of the pandemic was observed in February 2020, Cyprus, where the first case of the pandemic was observed in March 2020 and Syrian Arab Republic, where the first case of the pandemic was observed in March 2020. which are considered located in different locations in all of the world and the locations as following: China is located in the Far East, USA is located in north America, Russia located between Asia and Europe, the UK is located at north-west Europe, Brazil is located in south America, Spain is located at south-west Europe, Bahrain is located in Arabian Gulf, Egypt is located in Africa, India and Iran located in west Asia, Cyprus located in Mediterranean and the Syrian Arab Republic is located at East of Mediterranean. In the section-2, we include the principle of the method used to find the force of infection and the specific times of SARS-CoV-2 using the applied epidemiological model and in the section-3, we include the resulted values, in the section-4 we illustrate the discussion of the results and in the last section, we include the conclusion of resulted values.

## Methods

We collected the observed data of the new-coronavirus disease recorded in USA, Russia, the United Kingdom, Brazil, India, Spain, Bahrain, Egypt, Iran, Cyprus and the Syrian Arab Republic up to date 21 September 2020. After that, we applied Runge–Kutta simulation method for the SIER epidemiological model for determining the force of infection of the new coronavirus pandemic by fitting the collected results of the infectious cases, the recovered cases and the total cases of the new coronavirus pandemic in the previous different countries. From the fitting values of the recorded data, we find the coefficient of exposing, the coefficient of infection, the coefficient of recovery and the coefficient of mortality of the SEIR model in case of the new coronavirus disease in the previous countries. Where we used the conservation of the total population condition:

$$\frac{ds(t)}{dt} + \frac{de(t)}{dt} + \frac{di(t)}{dt} + \frac{dr(t)}{dt} = 0 \quad (5)$$

We use the Runge–Kutta method for the purpose of the numerical simulation and in sense of the Runge–Kutta simulation method, the normalized susceptible cases of the pandemic individual, the normalized infectious cases of the pandemic individual, the normalized recovered cases of the pandemic individual and the normalized exposed cases of the pandemic individual are governed by the following four equations:

$$s(t_{n+1}) \approx s(t_n) + \tau \sum_{m=1}^{m=z} l_m^1 k_m^1 \tag{6}$$

$$i(t_{n+1}) \approx i(t_n) + \tau \sum_{m=1}^{m=z} l_m^2 k_m^2 \tag{7}$$

$$r(t_{n+1}) \approx r(t_n) + \tau \sum_{m=1}^{m=z} l_m^3 k_m^3 \tag{8}$$

$$e(t_{n+1}) \approx e(t_n) + \tau \sum_{m=1}^{m=z} l_m^4 k_m^4 \tag{9}$$

With the following functions:

$$k_1^1 = f_1(t_n, s_n) \tag{10}$$

$$k_2^1 = f_1(t_n + c_2^1 \tau, s_n + \tau(a_{21}^1 k_1^1)) \tag{11}$$

$$k_Z^1 = f_1(t_n + c_Z^1 \tau, s_n + \tau(a_{Z1}^1 k_1^1 + a_{Z2}^1 k_2^1 + a_{Z3}^1 k_3^1 + \dots + a_{Z,Z-1}^1 k_{Z,Z-1}^1)) \tag{12}$$

$$k_1^2 = f_2(t_n, i_n) \tag{13}$$

$$k_2^2 = f_2(t_n + c_2^2 \tau, i_n + \tau(a_{21}^2 k_1^2)) \tag{14}$$

$$k_Z^2 = f_2(t_n + c_Z^2 \tau, i_n + \tau(a_{Z1}^2 k_1^2 + a_{Z2}^2 k_2^2 + a_{Z3}^2 k_3^2 + \dots + a_{Z,Z-1}^2 k_{Z,Z-1}^2)) \tag{15}$$

$$k_1^3 = f_3(t_n, r_n) \tag{16}$$

$$k_2^3 = f_3(t_n + c_2^3 \tau, r_n + \tau(a_{21}^3 k_1^3)) \tag{17}$$

$$k_Z^3 = f_3(t_n + c_Z^3 \tau, r_n + \tau(a_{Z1}^3 k_1^3 + a_{Z2}^3 k_2^3 + a_{Z3}^3 k_3^3 + \dots + a_{Z,Z-1}^3 k_{Z,Z-1}^3)) \tag{18}$$

$$k_1^4 = f_4(t_n, e_n) \tag{19}$$

$$k_2^4 = f_4(t_n + c_2^4 \tau, e_n + \tau(a_{21}^4 k_1^4)) \tag{20}$$

$$k_Z^4 = f_4(t_n + c_Z^4 \tau, e_n + \tau(a_{Z1}^4 k_1^4 + a_{Z2}^4 k_2^4 + a_{Z3}^4 k_3^4 + \dots + a_{Z,Z-1}^4 k_{Z,Z-1}^4)) \tag{21}$$

where  $\tau$  is the step of the time and  $s(t_n)$ ,  $i(t_n)$ ,  $r(t_n)$  and  $e(t_n)$  are the normalized susceptible cases of the pandemic

individual, the normalized infectious cases of the pandemic individual, the normalized recovered cases of the pandemic individual and the normalized exposed cases of the pandemic individual, respectively at the moment  $t_n$  and  $s(t_{n+1})$ ,  $i(t_{n+1})$ ,  $r(t_{n+1})$  and  $e(t_{n+1})$  are the normalized susceptible cases of the pandemic individual, the normalized infectious cases of the pandemic individual, the normalized recovered cases of the pandemic individual and the normalized exposed cases of the pandemic individual, respectively at the moment  $t_{n+1}$ . The coefficients  $l_m^j$  and  $c_u^j$  are the weights and the nodes of the function expansion and  $a_{qu}^j$  are the Runge–Kutta matrix coefficients, all the previous coefficients can be found using Butcher tableau and the weights are normalized to one under the following condition:

$$\sum_{m=1}^{m=z} l_m^j = 1 \tag{22}$$

After that, we calculate the force of infection and the specific times of the new coronavirus disease-2019 in the considered countries where the force of infection is given from the normalized infection individual by the following equation:

$$F(t) = \beta i(t) \tag{23}$$

In Fig. 1, we illustrated a schematic chart for clarifying the algorithm we used for the calculations.

### Results

We calculated the coefficient of exposed persons, the coefficient of infectious persons, the coefficient of recovered persons and the coefficient of mortality of SARS-CoV-2 for China, USA, Russia, India, the UK, Brazil, Spain, Bahrain, Egypt, Iran, Cyprus and Syrian-Arab-Republic based on the collected data of all diseased persons of the coronavirus disease-2019 in each country. The results of the coefficients of the SEIR model are included in Table 1 which includes the coefficients in  $d^{-1}$  unit and the countries.

Based on the coefficient of exposed persons, the coefficient of infectious persons, the coefficient of recovered persons and the coefficient of mortality of SARS-CoV-2 pandemic which we determined, we calculated the force of infection values for India, USA, Russia and the Syrian Arab Republic. We included the resulted values of the force of infection values of COVID-19 in Table 2 for the the previous different location countries and this table included the locations of the countries.

In addition to the force of infection, we determined the typical time between contacts and the typical time between removal of SARS-CoV-2 disease for India, China, the United States, Russia, the United Kingdom, Brazil, Spain, Bahrain,

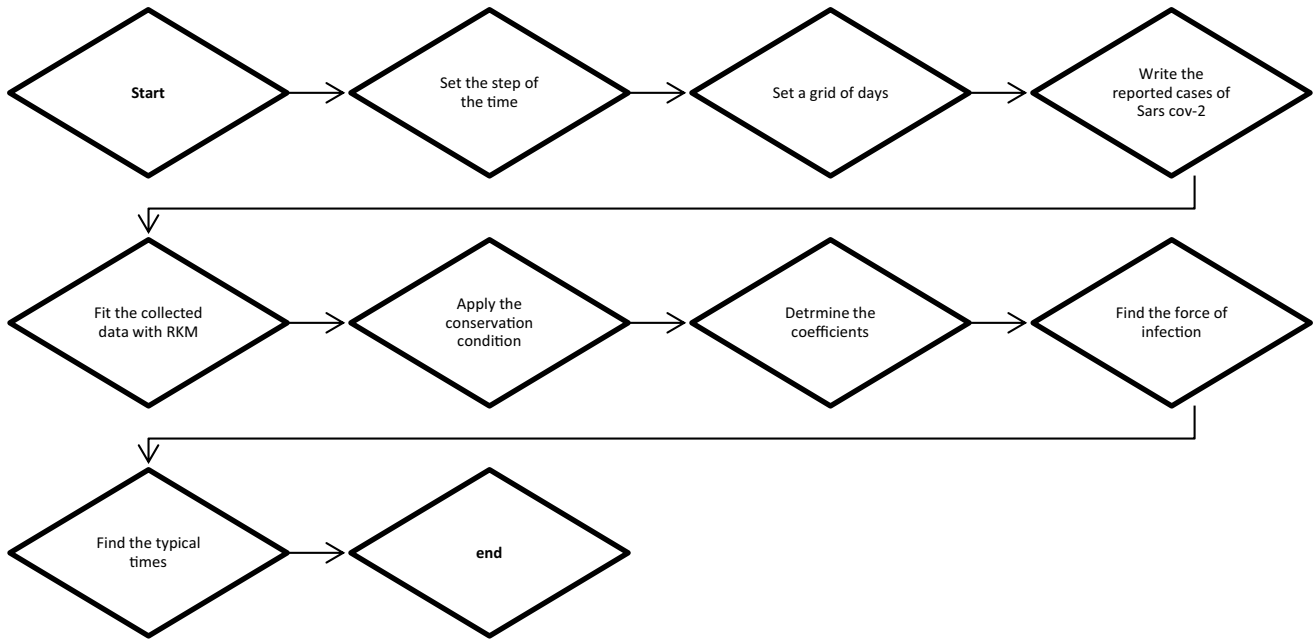


Fig. 1 Schematic plot of the fitting algorithm

**Table 1** The coefficient of exposed persons, the coefficient of infectious persons, the coefficient of recovered person and the coefficient of mortality of the new coronavirus disease in the United States, Russia, the United Kingdom, Brazil, Spain, Bahrain, Egypt, Iran, India, Cyprus and Syrian Arab Republic

	$v_1(d^{-1})$	$v_2(d^{-1})$	$v_3(d^{-1})$	$v_4(d^{-1})$
India	$3.2752 \times 10^{-2}$	$1.2812 \times 10^{-2}$	$1.2812 \times 10^{-3}$	$1.2835 \times 10^{-3}$
USA	$2.2812 \times 10^{-3}$	$624.0641 \times 10^{-3}$	$0.2154 \times 10^{-3}$	$14.3910 \times 10^{-3}$
China	$0.1182 \times 10^{-2}$	$0.2456 \times 10^{-2}$	$0.01 \times 10^{-2}$	$4.90 \times 10^{-2}$
Russia	$0.0901 \times 10^{-3}$	$114.1212 \times 10^{-3}$	$0.0750 \times 10^{-3}$	$23.1612 \times 10^{-3}$
UK	$0.2851 \times 10^{-3}$	$160.153 \times 10^{-3}$	$0.1561 \times 10^{-3}$	$23.2882 \times 10^{-3}$
Brazil	$0.0812 \times 10^{-3}$	$454.476 \times 10^{-3}$	$0.1040 \times 10^{-3}$	$93.4610 \times 10^{-3}$
Spain	$0.1181 \times 10^{-3}$	$60.4712 \times 10^{-3}$	$0.1232 \times 10^{-3}$	$20.4473 \times 10^{-3}$
Bahrain	$0.0600 \times 10^{-2}$	$47.91 \times 10^{-2}$	$0.04 \times 10^{-2}$	$6.06 \times 10^{-2}$
Egypt	$0.0100 \times 10^{-2}$	$22.5 \times 10^{-2}$	$0.01 \times 10^{-2}$	$2.59 \times 10^{-2}$
Iran	$2.63 \times 10^{-2}$	$90.36 \times 10^{-2}$	$0.02 \times 10^{-2}$	$23.83 \times 10^{-2}$
Cyprus	$4.89 \times 10^{-2}$	$68.69 \times 10^{-2}$	$0.01 \times 10^{-2}$	$4.90 \times 10^{-2}$
The Syrian Arab Republic	$0.01 \times 10^{-2}$	$13.67 \times 10^{-2}$	$0.01 \times 10^{-2}$	$0.1000 \times 10^{-2}$

**Table 2** The force of infection of the new coronavirus disease in India, the United States, Russia and Syrian Arab Republic for the middle of three months of 2020 year

	$F_L(d^{-1})$ June	$F_L(d^{-1})$ July	$F_L(d^{-1})$ August
India	7.2838e-006	5.0284e-006	5.4519e-005
USA	0.0020	0.0032	0.0013
Russia	4.0872e-005	1.8345e-004	1.9950e-004
The Syrian Arab Republic	1.0007e-005	2.2307e-006	6.3176e-007

Egypt, Iran, Cyprus and the Syrian Arab Republic. The results of the specific times are illustrated in Table 3 which contains the different geographical locations of the countries.

### Discussions

As we see from the second table, the force of infection in India, Russia and the Syrian Arab Republic increases up to middle of August 2020 and in the United States increases up

**Table 3** The typical time between contacts and the typical time between removal of the new-coronavirus-2019 pandemic in India, China, the United States, Russia, the United Kingdom, Brazil, Spain, Bahrain, Egypt, Iran, Cyprus and the Syrian Arab Republic

The country	The location of the country	$T_C$ (days)	$T_R$ (days)
India	South Asia	78.0518	779.1196
USA	North America	1.6024	69.4879
China	Far East-Asia	407.1661	20.4082
Russia	Easter Europe–Northern Asia	8.7626	43.1757
UK	North-West Europe	6.2440	42.9402
Brazil	South America	2.2003	10.6997
Spain	South-Western Europe	16.5368	48.9062
Bahrain	Arabian Gulf	2.0872	16.5017
Egypt	North Africa	4.4444	38.6100
Iran	West Asia	1.1067	4.1964
Cyprus	Mediterranean	1.4558	20.4082
Syrian Arab Republic	East of Mediterranean	7.3153	1000

to middle of September 2020 and then decreases. Also, we see from Table 3 that the value of the typical time between contacts of the coronavirus-2019 pandemic for China is the greatest value in the previous different countries and the value of this typical time of the coronavirus-2019 pandemic for Iran is the smallest between the previous different countries and the values of this time are located in the interval [1–500] for the different geographical location countries. Besides, the values of the typical time of removal are located in the interval [1–1000] in the same countries.

## Conclusions

We employ one of the epidemic models, namely, the SEIR model with the normalized cases for estimating the values of the force of infection and the values of the typical times between contents and removal of SARS-CoV-2 in twelve different location countries, namely, India, China, USA, Russia, the United Kingdom, Brazil, Spain, Bahrain, Egypt, Iran, Cyprus and Syrian Arab Republic. The choice of the countries was based on the different geographical location of the countries on the earth and the different with the type of the weather in each countries. We used the recorded data, up to date 21 September 2020, of the collected cases of the coronavirus-2019 pandemic in the different countries to find the coefficient of exposing, the coefficient of infection, the coefficient of recovery and the coefficient of mortality of the new coronavirus pandemic for every country. We calculated the force of infection and the values of the specific times of the new coronavirus pandemic in the different countries based

on the coefficients of the SEIR model and the Runge–Kutta simulation method.

We found that typical time between contacts values of COVID-19 pandemic (Table 3) are in the interval [1–500] for the different countries. Besides, we found that the values of the typical time between removal are in the interval [1–1000] for the same countries. We can use the same method for determining the same variables for other countries with different numbers of the new coronavirus pandemic, however, we chose the previous countries to clarify the relation between the force of infection and the typical times of SARS-CoV-2 with the geographical location and the weather of the country.

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**Code availability** MATLAB software was used for purpose of doing the numerical simulation.

## Compliance with ethical standards

**Conflict of interest** The author confirmed that he does not have a conflict of interest.

## References

- Aabed K et al (2020) An analytical study of the factors that influence COVID-19 spread. Saudi J Biol Sci. <https://doi.org/10.1016/j.sjbs.2020.11.067>
- Ali SM, et al (2020) Exploring the linkage between PM2.5 levels and COVID-19 spread and its implications for socio-economic circles. Environ Res. <https://doi.org/10.1016/j.envres.2020.110421>
- Al-Raei M (2018) Using Methods of Statistical Mechanics in the Study of Soft Condensed Matter Materials and Complex Structures. Damascus University publishing, Damascus, Syrian Arab Republic
- Al-Raei M (2020a) The basic reproduction number of the new coronavirus pandemic with mortality for India, the Syrian Arab Republic, the United States, Yemen, China, France, Nigeria and Russia with different rate of cases. Clin Epidemiol Global Health. <https://doi.org/10.1016/j.cegh.2020.08.005>
- Al-Raei M (2020b) The forecasting of COVID-19 with mortality using SIRD epidemic model for the United States, Russia, China and Syrian Arab Republic. AIP Adv 10:065325. <https://doi.org/10.1063/5.0014275>
- Bhadra A et al (2020) Impact of population density on COVID-19 infected and mortality rate in India. Model Earth Syst Environ. <https://doi.org/10.1007/s40808-020-00984-7>
- Fang L et al (2020) Analysis and estimation of COVID-19 spreading in Russia based on ARIMA model. SN Comprehen Clin Med. <https://doi.org/10.1007/s42399-020-00555-y>
- Gao S et al (2007) Analysis of an SIR Epidemic Model with pulse vaccination and distributed time delay. J Biomed ND Biotechnol 10:64870

- Gupta A et al (2020) Significance of geographical factors to the COVID-19 outbreak in India. *Model Earth Syst Environ* 6:2645–2653. <https://doi.org/10.1007/s40808-020-00838-2>
- Kamara AA et al (2020) Analytical solution for post-death transmission model of Ebola epidemics. *Appl Math Comput* 367:124776. <https://doi.org/10.1016/j.amc.2019.124776>
- Kermack WO (1927) A contribution to the mathematical theory of epidemic. *Proc R Soc Lond* 115:700–721
- Khan MdMA et al (2020) Effects of underlying morbidities on the occurrence of deaths in COVID-19 patients: a systematic review and meta-analysis. *J Global Health* 10(2):020503. <https://doi.org/10.7189/jogh.10.020503>
- Lifshits ML, et al (2020) COVID-19 mortality rate in Russian regions: forecasts and reality. *R-ECONOMY* 6: 171–182. <https://doi.org/10.15826/recon.2020.6.3.015>
- Malavika B et al (2020) Forecasting COVID-19 epidemic in India and high incidence states using SIR and logistic growth models. *Clin Epidemiol Global Health*. <https://doi.org/10.1016/j.cegh.2020.06.006>
- Neto RS et al (2020) The fourth industrial revolution and the coronavirus: a new era catalyzed by a virus. *Res Global* 2:100024. <https://doi.org/10.1016/j.resglo.2020.100024>
- Osemwinyen AC, et al (2015) Mathematical modelling of the transmission dynamics of ebola virus. *Appl Comput Math* 4:313–320. <https://doi.org/10.11648/j.acm.20150404.19>
- Rejaur Rahman M et al (2020) Geospatial modelling on the spread and dynamics of 154 day outbreak of the novel coronavirus (COVID-19) pandemic in Bangladesh towards vulnerability zoning and management approaches. *Model Earth Syst Environ*. <https://doi.org/10.1007/s40808-020-00962-z>
- Roy S et al (2020) Spatial prediction of COVID-19 epidemic using ARIMA techniques in India. *Model Earth Syst Environ*. <https://doi.org/10.1007/s40808-020-00890-y>
- Santosh KC (2020) COVID-19 prediction models and unexploited data. *J Med Syst* 44:170. <https://doi.org/10.1007/s10916-020-01645-z>
- Tarabichi S (2010) *Oscillations and waves, linear and non-linear*. Damascus University publishing, Damascus, Syrian Arab Republic
- Zhu P et al (2019) Investigation of epidemic spreading process on multiplex networks by incorporating fatal properties. *Appl Math Comput* 359:512–524. <https://doi.org/10.1016/j.amc.2019.02.049>

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