Science of the Total Environment 729 (2020) 138959

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Prediction of the COVID-19 spread in African countries and implications for prevention and control: A case study in South Africa, Egypt, Algeria, Nigeria, Senegal and Kenya

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HIGHLIGHTS

- Improved SEIR model that considers quarantine and intervention measures was used.
- The MH algorithm-based parameter estimation improved the model prediction.
- Epidemics under suppression, mitigation, and mildness scenarios were predicted in six African countries.Epidemic controlling measures including risk level classification, and Chinese assistance were proposed.
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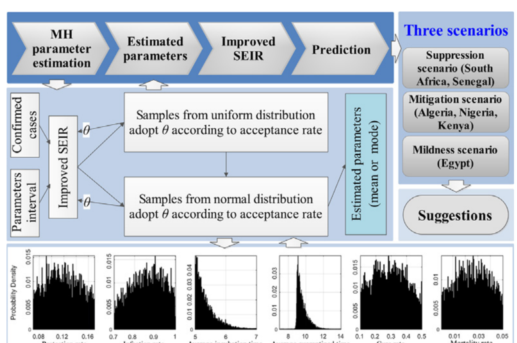
GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 April 2020
Received in revised form 21 April 2020
Accepted 22 April 2020
Available online 25 April 2020

Keywords:
COVID-19
Parameter estimation
SEIR
Scenario analysis
Prediction
Africa

ABSTRACT

COVID-19 (Corona Virus Disease 2019) is globally spreading and the international cooperation is urgently required in joint prevention and control of the epidemic. Using the Maximum-Hasting (MH) parameter estimation method and the modified Susceptible Exposed Infectious Recovered (SEIR) model, the spread of the epidemic under three intervention scenarios (suppression, mitigation, mildness) is simulated and predicted in South Africa, Egypt, and Algeria, where the epidemic situations are severe. The studies are also conducted in Nigeria, Senegal and Kenya, where the epidemic situations are growing rapidly and the socio-economic are relatively under-developed, resulting in more difficulties in preventing the epidemic. Results indicated that the epidemic can be basically controlled in late April with strict control of scenario one, manifested by the circumstance in the South Africa and Senegal. Under moderate control of scenario two, the number of infected people will increase by 1.43–1.55 times of that in scenario one, the date of the epidemic being controlled will be delayed by about 10 days, and Algeria, Nigeria, and Kenya are in accordance with this situation. In the third scenario of weak control, the epidemic will be controlled by late May, the total number of infected cases will double that

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https://doi.org/10.1016/j.scitotenv.2020.138959

in scenario two, and Egypt is in line with this prediction. In the end, a series of epidemic controlling methods are proposed, including patient quarantine, close contact tracing, population movement control, government intervention, city and county epidemic risk level classification, and medical cooperation and the Chinese assistance.

1. Introduction

Since the middle of March in 2020, COVID-19 (Corona Virus Disease 2019) is witnessing explosive growth around the world. Up to April 13, 2020, more than 1,800,000 cases have been confirmed, especially in the United States (558,526 cases), Italy (156,363 cases), and Spain (169,496 cases), presenting a dim trending in effective disease prevention and control. The main reasons include unawareness of the new virus, insufficient detective tools, low efficiency in detection, and the delay in policy-making and implement of proper prevention and control measures during the early stage of the epidemic (Marzia et al., 2020). Currently, COVID-19 is in the state of "pandemic". However, with the situation of no specific drug and the prolonged vaccine development cycle (Paul and Katherine, 2020), effective intervention measures will play a crucial role, and all the world should aggregate to contain the spread of the virus in a more transparent and coordinate manner.

The emergence and prevalence of a virus generally depend on the virulence and infectivity of the virus itself, and other factors including population mobility, economic activities and social environment also impact (Redding et al., 2020), both of which are in complex interaction and mutual feedbacks (Zhao et al., 2020; Chen et al., 2019). The social development and evolution of human civilization have always been facing great challenges of climate/environmental changes and other extreme events including the epidemics (Liu et al., 2017; Gong et al., 2020; Yue and Lee, 2018; Chen et al., 2019). The experience in controlling the SARS epidemic implicated that the protection of vulnerable groups is also our duty, apart from extensive prevention and control measures and cooperative medical treatments, through which to realize the objective of the sustainable development of human society. It also make sense in achieving the third goal of "Good Health and Well-Being" according to the UN Sustainable Development Goals. Africa, as the world's second-largest (3.022×10^7 km^2) and second most-populous (1.23×10^9 until 2016) continent, has relatively little population movement. Till April 13, 14,622 COVID-19 cases have been confirmed across Africa. Early statistics shows that most of the cases were imported (Gilbert et al., 2020) from European countries (for example, the statistics data from February 25 to March 18: 190 input cases, 76 local cases) (https://www.afro.who.int/). Currently, the situation is still under control. However, the social-economic condition in Africa is much less-developed than other countries in the world, a series of factors, i.e., the scarcity of medical supplies, the poor medical conditions and lower virus testing efficiency would facilitate the spread of the epidemic. Additionally, the dry season of Africa is about to come, the abrupt decrease of daily mean temperature would be conducive to the spread of the disease. Consequently, the COVID-19 would probably outbreak in Africa if no strict prevention and control measures are implemented in these countries. This study aims to simulate and predict the epidemic spread in African countries under different epidemic intervention scenarios through modeling, and to propose a series of epidemic prevention and control measures, which will be crucial in containing the epidemic spread in these countries. The researches are mainly conducted in six African countries of South Africa, Egypt, Algeria, Nigeria, Senegal and Kenya. The first three countries are in severe epidemic situation already, while the situation in last three ones are in rapid deterioration with low socio-economic levels, leading to more difficulties in preventing the epidemic.

2. Methods

Metropolis-Hasting (MH) parameter optimization method (Zhu et al., 2014), together with the latest data released by the Johns Hopkins University (https://github.com/CSSEGISandData/COVID-19), are applied to model the spread of the infectious diseases in this study. It is expected to improve the precision of the model parameters, to further improve the predictability of the epidemic.

2.1. Improved SEIR model

Compared with statistical models (Huang and Qiao, 2020; Jonathan et al., 2020), mathematical models based on dynamical equations can provide more transmission mechanism for the epidemic diseases. Currently, the classical Susceptible Exposed Infectious Recovered (SEIR) model has been widely used to model the outbreak of COVID-19 and analyze the epidemic situation. The relationship among susceptible, exposed, infected and recovered cases can be better explained by the model simulation (Wu et al., 2020). However, due to the lack of official data at the early stage of the epidemic and diagnostic calibers vary with regions, the model parameters were not determined accurately, which lead to questionable prediction results.

In this study, an improved SEIR model (Peng et al., 2020) was adopted. Compared with the traditional SEIR model, the improved SEIR model was more realistic by introducing both quarantine status and intervention measures. The specific description is as follows:

$$
\begin{cases}
\frac{dS}{dt} = -\beta\frac{SI}{N} - \alpha S \\
\frac{dE}{dt} = \beta\frac{SI}{N} - \gamma E \\
\frac{dI}{dt} = \gamma E - \delta I \\
\frac{dQ}{dt} = \delta I - \lambda Q - \kappa Q \\
\frac{dR}{dt} = \lambda Q \\
\frac{dD}{dt} = \kappa Q \\
\frac{dP}{dt} = \alpha S
\end{cases}
$$

where S denotes the number of susceptible population, E represents the exposed cases, I denotes the infected cases but not quarantined, Q is the confirmed cases and quarantined, R is the recovered cases, D is the dead cases, and P is the unsusceptible population (protected population). These variables in total constitute the whole population. The parameters α, β, γ^{-1}, δ^{-1}, λ and κ represent the protection rate (considering the intervention), infection rate, average incubation time, average quarantined time, cure rate, and mortality rate, respectively. With the laps of time, the recovery rate will increase and the mortality rate will decrease, and the adoption of interventions (such as wearing masks) will reduce the exposed significantly. Assuming the incubation period remains unchanged, the diagnosis of all cases depends on the intervention and the average quarantined time, as well as the exposed cases. The smaller the intervention factor is, the higher the infection rate is, the longer the quarantine time (Peng et al., 2020). This requires the governments and the public to quarantine the infected cases as soon as possible.

2.2. Parameters estimation

Reasonable parameter estimation is very important for the improvement of model simulation accuracy (Zhu et al., 2018). Here, the MH sampling method is used to estimate the parameters of the improved SEIR model. Under the condition that the parameters are independent, the algorithm repeatedly learning the daily confirmed cases data, sampling and iterating in the multidimensional space composed of parameters ($\alpha, \beta, \gamma^{-1}, \delta^{-1}, \lambda, \kappa$), to obtain the optimal estimation of the parameters posterior information by constructing the likelihood function (Li et al., 2020; Liu et al., 2020a; Liu et al., 2020b; Ma et al., 2017; Zhu et al., 2014).

Consider the set of observations Ω under the unknown parameters set, the posterior probability of the model parameters data set θ can be described as

$$P(\theta|\Omega) \propto P(\Omega|\theta) P(\theta),$$

based on the Bayesian inference, where $P(\theta)$ represents the parameters prior distribution, $P(\Omega|\theta)$ as the likelihood function stands for the probability of observation sets Ω when the parameter is θ. Under the assumption of a normal distribution,

$$P(\Omega|\theta) = \prod \prod \frac{1}{\sqrt{2\pi}\sigma(\theta)} e^{-\frac{\varepsilon^2(\theta)}{2\sigma^2(\theta)}},$$

where $\varepsilon(\theta)$ and $\sigma(\theta)$ respectively represent the deviation and standard deviation between the output of the model and the real observation based on the parameter θ. Generally, directly calculate the $P(\Omega|\theta)$ is difficult, an alternative is to generate approximate posterior samples according to a proposal ordinary distribution by Markov Chain Monte Carlo (MCMC) algorithms such as MH. And the calculation steps are as follows:

1) $k = 0$, an initial parameter value $\theta^{(0)}$ is chosen in parameter space θ.
2) sampling the parameters $\theta^{(k+1)}$ based on the prior distribution such as uniform distribution or normal distribution.
3) acceptance rate is obtained based on the $P(\Omega|\theta^{(k)})$, $P(\Omega|\theta^{(k+1)})$ and prior distribution, and then to judge the acceptance level, if yes $k = k + 1$, otherwise remain unchanged.
4) skip to step 2) until the required number of samples is reached.

The MH parameter optimization algorithm requires that the ranges of pre-specified optimized parameters, after that the sampling iteration is carried out on the multidimensional parameter space. According to the prior information, the parameters' intervals in the improved SEIR model are configured (Table 1).

Table 1
The major estimated parameters interval of the improved SEIR model for the computational implementation of MH sampling.

Parameter	Sampling ranges	Reference for the parameter value selection
Protection rate (α)	0.07–0.17	China: 0.172, Wuhan: 0.085 (Peng et al., 2020)
Infection rate (β)	0.7–1	China: 0.78735 (Yang et al., 2020), China close to 1 (Peng et al., 2020)
Average incubation time (γ^{-1})	5–7	5.2 days (Zhu et al., 2020), 5.1 days (https://www.sohu.com/a/379017403_100191057), 3–7 days (https://www.sohu.com/a/369273052_774283)
Average quarantined Time (δ^{-1})	7–14	9.1 days (Zhu et al., 2020), quarantined time: 14 days (http://en.nhc.gov.cn/)
Cure rate (λ)	0.1–0.5	1/7 (Yang et al., 2020), existing data statistics: 0–0.37
Mortality rate (κ)	0.001–0.05	0.001–0.03 (Peng et al., 2020)

2.3. Data

All the data used in this study is obtained from the time series data published on GitHub by Johns Hopkins University (https://github.com/CSSEGISandData/COVID-19). These data sets include the time series of confirmed, recovered and death cases, which can provide an entire raw data for parameter estimation and model simulation of this study.

2.4. Experimental design

It is expected to utilize the optimized parameters generated by MH sampling to improve the prediction ability of the infectious disease model. Specifically (Fig. 1), the improved SEIR model was firstly coupled to the MH parameter estimation model to obtain a series of optimized parameters of COVID-19 spread. The optimized parameters were input into the improved SEIR model to simulate and predict the epidemic spread. Considering that all parameters in the improved SEIR model can be reflected in the intervention factor, therefore, imaginary predictions are made from three scenarios (see Section 3.1) depend on the current state of epidemic prevention, and prevention and control suggestions are further proposed.

3. Results and analysis

We estimated the corresponding parameters of SEIR, by which the epidemic of COVID-19 under different intervention scenarios are modeled.

3.1. Results of parameters estimation

The MH parameter sampling optimization algorithm is used to estimate the parameters of the epidemic spread in each country (see Appendix A for the probability distributions of MH sampling). It is noticeable that the spatial probability distributions of the parameters samples (Fig. 2) in each country are very close, which may be attributed to the similar prevention and control measures were taken by African governments. The statistics were conducted from the mean, mode, median, variance, standard deviation, and skewness values respectively (see Table 2 and Appendix B for the results), which seem basically the same for each parameter. To be simplified, the mean value was adopted since it is reliable and stable for the data statistics, and can reflect the most complete information of a group of data. Therefore, the optimized parameters' results $\alpha = 0.12$, $\beta = 0.8618$, $\gamma^{-1} = 5.4$, $\delta^{-1} = 9.6$, $\lambda = 0.29$, $\kappa = 0.025$ are used in simulation and prediction, which agreement with the current epidemic spread.

The prevention and control of the epidemic are mainly reflected by the intervention factor. The sooner the epidemic is controlled, the more powerful the intervention is. Epidemic prevention and control measures for reference to China, the country (except Wuhan) intervention factor value α is 0.172, whereas Wuhan value is 0.085 (Peng et al., 2020). China's prevention and control measures including to quarantine and trace all close contacts, everyone home quarantined, traffic control, set up the square cabin hospital (e.g., Huoshenshan hospital and Leishenshan hospital), and treat all suspected and confirmed cases. In contrast, although African countries are introduced to quarantine all cases, due to the medical conditions only critical cases and mild cases are quarantined, and some mild cases are self-quarantined (https://www.africanews.com/), which may increase the risk of infection in susceptible populations to a certain extent. Considering the uniqueness of China's epidemic prevention measures, the African countries may hardly follow the work of China. Therefore, this study assumes that the intervention intensity of the prevention and control measures of African countries is 0.15 at most (the first scenario: suppression). From the

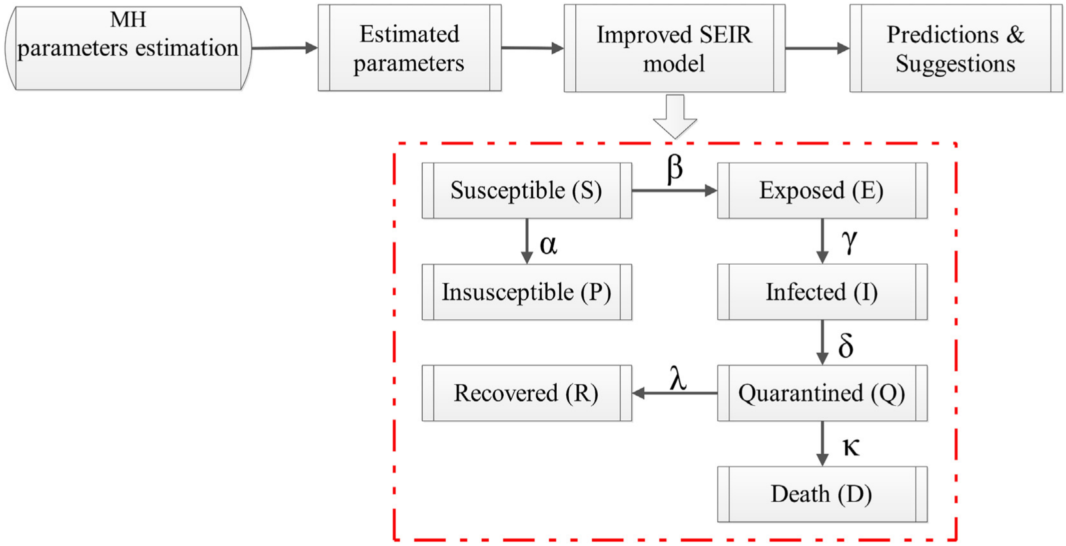


Fig. 1. Flow chart of experimental.

number of confirmed cases until April 3, South Africa, Egypt, Algeria, Nigeria, Senegal, Kenya has confirmed 1505, 985, 1171, 210, 207, 122 cases (https://github.com/CSSEGISandData/COVID-19) respectively under the conditions of interventions, the third intervention scenario (mildness) is assumed, that is, the intervention factor value is 0.09. Certainly, the second scenario (mitigation) is the intervention factor after MH parameter sampling and optimized in this study, with a value of 0.12.

3.2. Scenario forecast

Statistics (Fig. 3) of existing data (https://github.com/CSSEGISandData/COVID-19) in six countries shows that the dates of first confirmed case are on March 5 (South Africa), February 14 (Egypt), February 25 (Algeria), February 28 (Nigeria), March 2 (Senegal), March 13 (Kenya), respectively. Since the first case, the inflected cases of South Africa grew slowly until March 17,

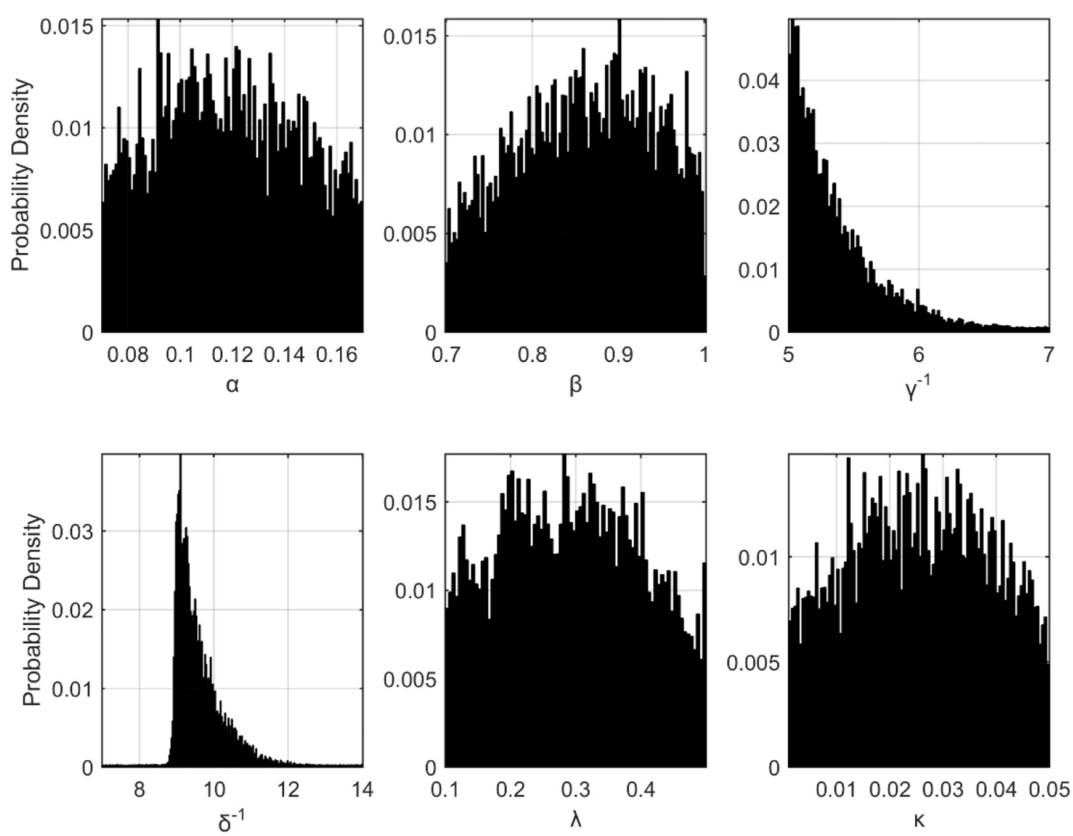


Fig. 2. The probability distributions of parameters' samples for improved SEIR epidemic model ($\alpha = 0.1195$, $\beta = 0.8618$, $\gamma^{-1} = 5.3904$, $\delta^{-1} = 9.6447$, $\lambda = 0.2910$, $\kappa = 0.0253$).

Table 2
Statistics of optimized parameters' results of MH (including statistics: mean, mode, median, variance, standard deviation and skewness).

Parameter	Statistics					
	Mean	Mode	Median	Variance	Standard deviation	Skewness
α	0.1195	0.1074	0.1195	0.0007	0.0267	0.0093
β	0.8618	0.8874	0.8666	0.0063	0.0795	−0.1766
γ^{-1}	5.3904	5.0471	5.2752	0.1394	0.3737	1.6305
δ^{-1}	9.6447	9.0056	9.4347	0.6373	0.7983	1.8039
λ	0.2910	0.3040	0.2878	0.0115	0.1073	0.0739
κ	0.0253	0.0877	0.0689	0.0021	0.0337	0.0041

then exponentially, and then significantly less increased since March 27. Egypt's growth spurt began on March 7 and Algeria is on March 13 but the growth rate was slowly until April 3. And the other three countries grow slightly slow. On March 25 African countries (https://www.africanews.com/) have put forward a series of prevention and control measures, including quarantining all cases, testing and tracking all close contacts, and social alienation, etc. The statistical result showed that South Africa and Algeria have been more responsive to the government's prevention and control measures, while the Egypt does not.

To further predict the development trends of the epidemic in these six countries, we used the parameters optimized by the MH sampling algorithm to drive the improved SEIR model. Predictions are conducted based on the three scenarios of epidemic prevention and control intervention intensity. The results are shown in the figures below (Fig. 4). Considering the uncertainties of existing data (such as low detection rate), 10% errors were added to the simulated prediction' results.

The basic reproductive number R_0 of COVID-19 in China is 2–2.5 based on World Health Organization (WHO) report, however, these six countries (South Africa, Egypt, Algeria, Nigeria, Senegal and Kenya) are more than 2 (3.20, 2.29, 2.66, 2.29, 2.36, and 2.82) by calculation with $R_0 = 1 + aT_g + \rho(1-\rho) * (aT_g)^2$ (a is the grow rate, T_g is the generation time and ρ is the ratio of exposed period to generation time). In order to reduce R_0 rapidly, more aggressive actions of prevention and control measures should be taken urgently for curbing the spread of the disease in these six countries.

Taking the strongest epidemic prevention and control in China as a reference, the six countries can basically control outbreaks in late April with $\alpha = 0.15$, while the number of infected cases may be separately in 2760–3380 (South Africa), 1300–1600 (Egypt), 1640–2100 (Algeria), 270–340 (Nigeria), 300–370 (Senegal), 180–220 (Kenya). However, considering the low social economy level, and the limitation of medical condition, the methods of epidemic prevention and control used in Africa cannot reach that used in China. Therefore, the second intervention scenario (after the MH parameter optimization, the scenario intervention factor $\alpha = 0.12$) is slightly better. Forecasting trends indicated that the six countries can basically control outbreaks in early May (compared with the first scenario, basically controlled will delay about 10 days). The number of confirmed cases will probably be 4200–5150 (South Africa), 1900–2300 (Egypt), 2500–3060 (Algeria), 420–520 (Nigeria), 440–540 (Senegal), 270–340 (Kenya). The infected cases will be increased by 1.43–1.55 times as that in scenario one, and the medical overstretched will highlight and this is bad for the development of the social economy. Therefore, it is crucial to take effective measures (such as quarantine all cases in an attempt to cut off the source of infection) to put the "mitigation" scenario closer to the "suppression". The epidemic spread could belong to the third scenario ($\alpha = 0.09$) under the conditions of a lower understanding of the epidemic and the government adopted effective prevention measures lag behind, as well as the public self-protection consciousness is weak, and poor medical conditions (such as lower virus testing efficiency). In this case, the infection cases will exponentially increase, the medical overstretched phenomenon becoming serious, and there will emerge a large number of death cases. The epidemic outbreak will be by and large controlled in late May (about 20 days later than the second scenario), when the number of cases could reach between 8000 and 10,000 (South Africa), 3470–4250 (Egypt), 4850–5950 (Algeria), 825–1010 (Nigeria), 850–1050 (Senegal), 540–670 (Kenya), which will be doubled of that in the second scenario. It can be found that earlier implementation of reasonable interventions will significantly reduce the number of infections. If government interventions does not work, i.e., populations are devoid of self-awareness. Combined with the poor social environment in African countries, epidemic will be a comprehensive "outbreak" from the middle to late April. African countries will face more severe social and economic challenges. And it will be unfavorable to realize the objective of the sustainable development of human society for achieving "Good Health and Well-Being".

Fig. 4 presents the current epidemics and the corresponding simulations of these three scenarios. It is obvious that the severe prevention and control measures are implemented by both South Africa and Senegal, where the spread curves are closer to the first scenario (2760–3380, 300–370). Mitigation measures are implemented in Algeria, Nigeria and Kenya, and the curves correspond to the second scenario (2500–306, 420–520, 270–340). However, the response of prevention and control measures in Egypt lags behind obviously. Therefore, both South Africa and Senegal should continue to maintain and strengthen the current prevention and control measures. The Algeria, Nigeria and Kenya should strengthen their prevention and control measures to reduce the infections. In particular, Egypt must adjust the control strategies and take defensive measures

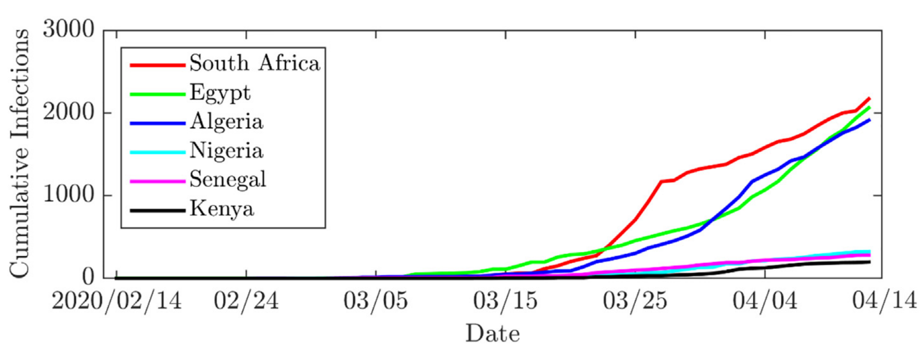


Fig. 3. Growth trends of the confirmed cases in South Africa, Egypt, Algeria, Nigeria, Senegal, and Kenya.

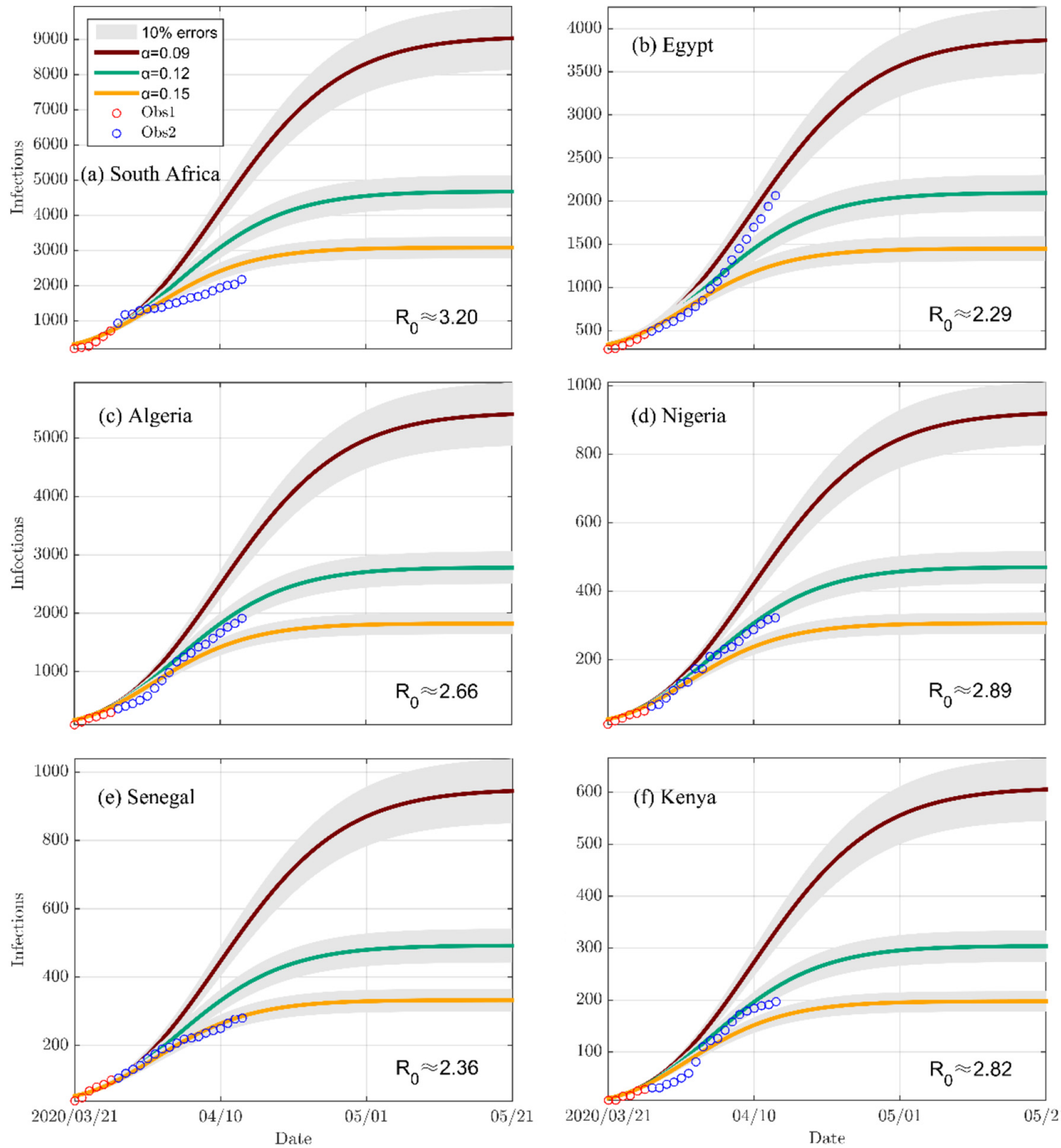


Fig. 4. Simulated prediction of epidemic spreading trends in (a) South Africa, (b) Egypt, (c) Algeria, (d) Nigeria, (e) Senegal and (f) Kenya (both Obs1 and Obs2 mean the confirmed cases before and after March 25, R_0 is the basic reproduction number).

implemented timely to make the curve as close to the second scenario as possible.

4. Conclusion and suggestions for intervention

4.1. Conclusion

In this study, the MH parameter optimization algorithm and an improved SEIR model was used to predict the epidemic spreading trends in six African countries (South Africa, Egypt, Algeria, Nigeria, Senegal and Kenya).

The epidemic spreading trends from three intervention scenarios were respectively predicted. The first scenario (suppression) is the ideal situation, which depends on strong government measures, abundancy of medical supplies and good personal protective behavior. Once the intervention measures implement as soon as possible, the epidemic spread in six countries are likely to be quickly curbed with finite infected. Fortunately, the South Africa and Senegal are in line with this scenario. If the response speed of the governments to take prevention measures is slow and there are loopholes in the intervention measures (such as lower testing rate), the spread of the epidemic may meet the second scenario (mitigation) and the basically control time will be delayed by about 10 days by comparison with the first scenario. The results showed that Algeria, Nigeria and Kenya are adopted the palliative measures, and the curves are accord with this scenario. By comparison, the third scenario (mildness) is the worst, with the outbreak being basically contained in late May, when the number of infections doubled. Presently, the changes of the epidemic spread in Egypt is similar to the third scenario, so it is necessary to timely adjust the strategies to make the curve as close as possible to the second scenario. Besides, the epidemic will be probably uncontrolled without the rapid public health response, along with the poor awareness of the disease, insufficient prevention and control measures, and the lack of self-protection awareness. Although the relevant national departments (such as Egypt) have issued strict prevention and control measures, the containing effects on the spread of the virus are not significant according to the simulation and prediction results. Therefore, stronger, earlier interventions and a sense of public self-protection will be the essential measures to fight this disaster (John and Wessam, 2020). It should be pointed out that this prediction is a conservative estimate under the condition of the uncertainty of the data (such as low testing rate).

Methodologically, a more realistic improved SEIR model was adopted. Different from traditional SEIR models, this model fully considered the quarantine status and intervention measures, and could better simulate the current confirmed cases and the future development trend of the epidemic. More importantly, the MH optimal parameter estimation algorithm is adopted based on the range of prior parameters intervals. The algorithm can estimate the corresponding reasonable parameters according to the reference values, the optimal parameters of the sampling frequency were significantly higher than that of other samples in the sampling probability space, and this sampling results can provide an accurate model parameterization to improve SEIR simulation.

4.2. Suggestions for intervention

China has taken effective measures to curb the rapid spread of COVID-19, protecting the lives of hundreds of thousands of people (Huang and Qiao, 2020; Wang et al., 2020; Huang et al., 2020). We suggest the relevant countries can take China's epidemic spread prevention and control as a reference, and to formulate suitable epidemic prevention and control strategies for their own countries. According to the analysis in this research, we have the following suggestions:

(1) Quarantine all confirmed cases, test and track all close contacts. Due to the scarcity of medical resources in African countries, all severe cases should be strictly controlled and quarantined. Mild cases can quarantine at the hotel near hospitals and healthcare professionals should be arranged to take enhanced observations. Asymptomatic cases should also be taken seriously and quarantined for attention. All close contacts of the confirmed and asymptomatic cases should be followed up and quarantined for 14 days to completely cut off the source of infection.
(2) Strictly control the population flow and take personal protective measures. Strengthen border (entry quarantine), and domestic traffic control and restrict all travel issues. All individuals should be stay at home, ban all social gatherings and keep a safe social distance from each other. Prevent external input and internal spread of the virus.
(3) Government intervention, rational allocation of medical supplies. The government should take strict anti-epidemic measures as soon as possible, take the overall situation into account systematically, and seriously condemns those who do not comply, such as detention, fine, etc. The government should do epidemic prevention knowledge propaganda everywhere, leave no blind spots at the same time. Security personnel shall be arranged to patrol the epidemic areas around the clock. Medical supplies should be reasonably distributed. Considering the shortage of materials in African countries, there should be enough supplies to ensure the disaster areas, other areas can be reduced appropriately, but people's protective materials (such as masks) should be able to satisfy the needs of daily life and shopping. Besides, the government should focus on the inspection rate (testing efficiency), and reasonably set up as many detection points as possible for free testing.
(4) City and county epidemic risk level zones classification. All the cities and counties are divided into three levels, namely “high, medium and low” risk areas referring to China's COVID-19 prevention and control measures (http://www.nhc.gov.cn/wjw/index.shtml). According to the different risk areas, on the one hand, take active measures to prevent the epidemic spread, on the other hand, restoration of normal social and economic operations in an orderly manner. Therefore, these measures can not only form the epidemic spread into an encirclement, but also the resumption of work and production of enterprises can alleviate the predicament of lack of medical supplies to some extent.
(5) Expand medical cooperation between countries and regions. Actively carry out international and regional medical cooperation. Modestly learn the experience of the countries and regions where the epidemic spread is basically under control, and adjust the domestic epidemic prevention and control measures timely. Doctors and nurses in low- and medium-risk areas should fully support the worst-hit areas.
(6) China maybe volunteer to suggest reasonable prevention and control measures for different countries respectively. The local epidemic spread in China has been basically controlled. The technical supports (medical teams, treatment methods), medical supplies (such as virus-detection boxes, respirators, protective clothing, and surgical masks) and other assistance should be provided by China within its power.

In particular, it should be pointed out that the number of infected cases in African countries are still small at present, however, if the implementation of severe epidemic prevention measures is delayed, the model prediction will be ineffective, and then a large number of cases will emerge. The epidemic prevention and control measures will not take effect in the short term, and African society and the economy will be in a condition of depression again. Considering the rapidest increase of confirmed cases reported in Niger and Cameroon, with the accumulated confirmed cases doubled in 2.5 days by April 5 (https://www.nytimes.com/interactive/2020/world/cor-onavirus-maps.html), more attention should be drawn by the corresponding governments.

It is hoped that this study can provide some useful references for the epidemic prevention and control work to relevant countries and departments. We are united in our efforts to defeat the epidemic as soon as possible.

CRediT authorship contribution statement

Zebin Zhao: Writing - original draft, Methodology, Validation, Formal analysis, Investigation, Visualization. **Xin Li:** Conceptualization, Writing - review & editing, Supervision, Project administration, Formal analysis. **Feng Liu:** Methodology, Writing - review & editing, Formal analysis. **Gaofeng Zhu:** Formal analysis, Writing - review & editing. **Chunfeng Ma:** Formal analysis, Writing - review & editing. **Liangxu Wang:** Investigation, Writing - review & editing.

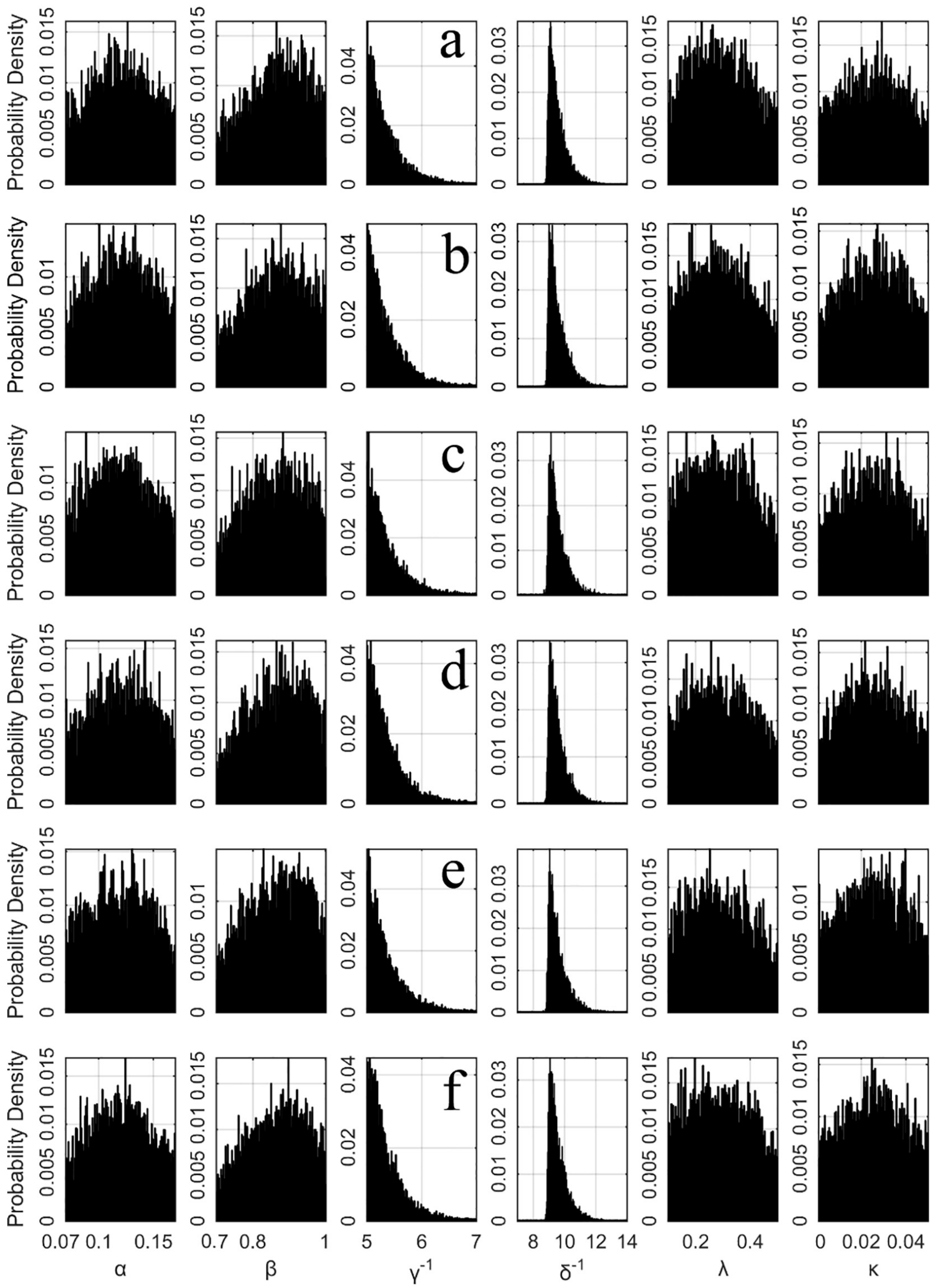
Declaration of competing interest

The authors declare that they have no conflict of interest.

Acknowledgements

This work was supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (Grant No. XDA19070104), the National Natural Science Foundation of China (Grant No. 41801270) and the 13th Five-year Informatization Plan of the Chinese Academy of Sciences (Grant No. XXH13505-06) and the Foundation for Excellent Youth Scholars of NIEER, CAS (Grant No. Y851D41).

Appendix A. The probability distributions of parameters' samples for improved SEIR epidemic model in South Africa (a), Egypt (b), Algeria (c), Nigeria (d), Senegal (e) and Kenya (f), respectively



Appendix B. Statistics of optimized parameters' results of MH (including statistics: mean, mode, median, variance, standard deviation and skewness)

Parameter	Country	Mean	Mode	Median	Variance	Standard deviation	Skewness
α	South Africa	0.1197	0.1403	0.1196	0.0007	0.0268	−0.0091
	Egypt	0.1184	0.0839	0.1179	0.0007	0.0267	−0.0099
	Algeria	0.1193	0.1279	0.1190	0.0007	0.0269	0.0220
	Nigeria	0.1205	0.0997	0.1209	0.0007	0.0268	0.0276
	Senegal	0.1193	0.0885	0.1197	0.0007	0.0267	−0.0146
	Kenya	0.1199	0.1038	0.1198	0.0007	0.0265	0.0400
Average		0.1195	0.1074	0.1195	0.0007	0.0267	0.0093
β	South Africa	0.8595	0.8087	0.8639	0.0062	0.0790	−0.2021
	Egypt	0.8612	0.9680	0.8649	0.0064	0.0800	−0.2292
	Algeria	0.8599	0.9639	0.8641	0.0064	0.0797	−0.1682
	Nigeria	0.8643	0.7685	0.8701	0.0063	0.0794	−0.1675
	Senegal	0.8624	0.9638	0.8679	0.0064	0.0797	−0.1702
	Kenya	0.8633	0.8516	0.8688	0.0063	0.0793	−0.1225
Average		0.8618	0.8874	0.8666	0.0063	0.0795	−0.1766
γ^{-1}	South Africa	5.4012	5.0043	5.2803	0.1454	0.3814	1.6340
	Egypt	5.3892	5.1605	5.2741	0.1385	0.3722	1.6141
	Algeria	5.3900	5.0594	5.2719	0.1415	0.3761	1.6595
	Nigeria	5.3891	5.0006	5.2813	0.1370	0.3701	1.6577
	Senegal	5.3874	5.0138	5.2723	0.1402	0.3745	1.6352
	Kenya	5.3856	5.0445	5.2714	0.1354	0.3679	1.5824
Average		5.3904	5.0471	5.2752	0.1394	0.3737	1.6305
δ^{-1}	South Africa	9.6670	8.9812	9.4425	0.6648	0.8153	1.8199
	Egypt	9.6417	9.1667	9.4356	0.6309	0.7943	1.8128
	Algeria	9.6452	8.9884	9.4253	0.6416	0.8010	1.8536
	Nigeria	9.6411	8.9992	9.4445	0.6286	0.7928	1.8412
	Senegal	9.6389	8.8769	9.4336	0.6360	0.7975	1.7504
	Kenya	9.6341	9.0214	9.4266	0.6221	0.7888	1.7457
Average		9.6447	9.0056	9.4347	0.6373	0.7983	1.8039
λ	South Africa	0.2940	0.2525	0.2927	0.0115	0.1070	0.0611
	Egypt	0.2911	0.2856	0.2908	0.0111	0.1054	0.1058
	Algeria	0.2909	0.4087	0.2875	0.0115	0.1073	0.0329
	Nigeria	0.2908	0.3796	0.2856	0.0117	0.1080	0.0996
	Senegal	0.2891	0.3788	0.2828	0.0115	0.1072	0.0513
	Kenya	0.2904	0.1185	0.2875	0.0119	0.1089	0.0924
Average		0.2910	0.3040	0.2878	0.0115	0.1073	0.0739
κ	South Africa	0.0251	0.0213	0.0247	0.0002	0.0132	0.0123
	Egypt	0.0252	0.0278	0.0251	0.0002	0.0133	−0.0030
	Algeria	0.0253	0.4087	0.2875	0.0115	0.1073	−0.0131
	Nigeria	0.0255	0.0420	0.0252	0.0002	0.0420	0.0089
	Senegal	0.0254	0.0226	0.0256	0.0002	0.0226	0.0075
	Kenya	0.0255	0.0040	0.0255	0.0002	0.0040	0.0119
Average		0.0253	0.0877	0.0689	0.0021	0.0337	0.0041

References

Chen, F., Fu, B., Xia, J., Wu, D., Wu, S., Zhang, Y., Sun, H., Liu, Y., Fang, X., Qin, B., Li, X., Zhang, T., Liu, B., Dong, Z., Hou, S., Tian, L., Xu, B., Dong, G., Zheng, J., Yang, W., Wang, X., Li, Z., 2019. Major advances in studies of the physical geography and living environment of China during the past 70 years and future prospects. Sci. China Earth Sci. 62 (11), 1665–1701. https://doi.org/10.1007/s11430-019-9522-7.

Gilbert, M., Pullano, G., Pinotti, F., Valdano, E., Poletto, C., Boëlle, P., D'Ortenzio, E., Yazdanpanah, E., Paul Eholie, S., Altmann, M., Gutierrez, B., Kraemer, M., Colizza, V., 2020. Preparedness and vulnerability of African countries against importations of COVID-19: a modelling study. Lancet 395 (10227), 871–877.

Gong, S., Xie, H., Chen, F., 2020. Spatiotemporal change of epidemics and its relationship with human living environments in China over the past 2200 years. Sci. China Earth Sci. 63. https://doi.org/10.1007/s11430-020-9608-x.

Huang, E., Qiao, F., 2020. A data driven time-dependent transmission rate for tracking an epidemic: a case study of 2019-nCoV. Sci. Bull. 65 (6), 425–427. https://doi.org/10.1016/j.scib.2020.0 2.005.

Huang, C., Wang, Y., Li, X., Li, X., Ren, L., Zhao, J., Hu, Y., Zhang, L., Fan, G., Xu, J., Gu, X., Cheng, Z., Yu, T., Xia, J., Wei, Y., Wu, W., Xie, X., Yin, W., Li, H., Liu, M., Xiao, Y., Gao, H., Guo, L., Xie, J., Wang, G., Jiang, R., Gao, Z., Jin, Q., Wang, J., Cao, B., 2020. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. Lancet 395 (10223), 497–506. https://doi.org/10.1016/S0140-6736(20)30183-5.

John, N., Wessam, M., 2020. Looming threat of COVID-19 infection in Africa: act collectively, and fast. Lancet 395, 841–842.

Jonathan, M., Jessica, R., Derek, A., Ho, Antonia, Chris, P., 2020. Novel coronavirus 2019-ncov: early estimation of epidemiological parameters and epidemic predictions. medRxiv https://doi.org/10.1101/2020.01.23.20018549 (2020 Jan 28).

Li, X., Liu, F., Fang, M., 2020. Harmonize model and data: the data assimilation for Earth System Science. Sci. China Earth Sci. https://doi.org/10.1007/s11430-019-9620-x.

Liu, F., Li, X., Zhu, G., 2020a. Using the contact network model and Metropolis-Hastings sampling to reconstruct the COVID-19 spread on the "Diamond Princess". Sci. Bull. https://doi.org/10.1016/j.scib.2020.04.043.

Liu, M., Liu, X., Huang, Y., Ma, Z., Bi, J., 2017. Epidemic transition of environmental health risk during China's urbanization. Sci. Bull. 62 (2), 92–98.

Liu, F., Wang, L., Li, X., Huang, C., 2020b. ComDA: a common software for nonlinear and non-Gaussian land data assimilation. Environ. Model. Softw. 127, 104638. https://doi.org/10.1016/j.envsoft.2020.104638.

Ma, C., Li, X., Notarnicola, C., Wang, S., Wang, W., 2017. Uncertainty quantification of soil moisture estimations based on a Bayesian probabilistic inversion. IEEE Trans. Geosci. Remote Sens. 55 (6), 3–94–3207.

Marzia, L., Egidio, B., Andrea, A., Federico, Ma., Fabio, C., Gianluca, T., 2020. Delayed access or provision of care in Italy resulting from fear of COVID-19. Lancet https://doi.org/10.1016/S2352-4642(20)30108-5 (2020 Apr 9).

Paul, N., Katherine, C., 2020. COVID-19 and risks to the supply and quality of tests, drugs, and vaccines. Lancet https://doi.org/10.1016/S2214-109X(20)30136-4 https://www.thelancet.com/pdfs/journals/langlo/PIIS2214-109X(20)30136-4.pdf.

Peng, L., Yang, W., Zhang, D., Zhuge, C., Hong, L., 2020. Epidemic analysis of COVID-19 in China by dynamical modeling. medRxiv. https://doi.org/10.1101/2020.02.16.20023465 (2020 Feb 16).

Redding, W., Atkinson, M., Cunningham, A., Lacono, G., Moses, L., Wood, J., Jones, K., 2020. Impacts of environmental and socio-economic factors on emergence and epidemic potential of Ebola in Africa. Nat. Commun. 10, 4531.

Wang, G., Huang, N., Qiao, F., 2020. Quantitative evaluation on control measures for an epidemic: a case study of COVID-19 (in Chinese). Chin. Sci. Bull. 65 (11), 1009–1015. https://doi.org/10.1360/TB-2020-0159.

Wu, J., Leung, K., Leung, G., 2020. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study. Lancet 395 (10225), 689–697. https://doi.org/10.1016/S0140-6736(20)30260-9.

Yang, Z., Zeng, Z., Wang, K., Wong, S., Liang, W., Zanin, M., Liu, P., Cao, X., Gao, Z., Mai, Z., Liang, J., Liu, X., Li, S., Li, Y., Ye, F., Guan, W., Yang, Y., Li, F., Luo, S., Xie, Y., Liu, B., Wang, Z., Zhang, S., Wang, Y., Zhong, N., He, J., 2020. Modified SEIR and AI prediction of the epidemics trend of COVID-19 in China under public health interventions. J. Thorac. Dis. 12, 165–174.

Yue, R., Lee, H., 2018. Climate change and plague history in Europe. Sci. China Earth Sci. 61, 163–177.

Zhao, W., Zhang, J., Meadows, M., Liu, Y., Hua, T., Fu, B., 2020. A systematic approach is needed to contain COVID-19 globally. Sci. Bull. 65 (11), 876–878. https://doi.org/10.1016/j.scib.2020.03.024.

Zhu, G., Li, X., Su, Y., Zhang, K., Bai, Y., Ma, J., Li, C., Hu, X., He, J., 2014. Simultaneous parameterization of the two-source evapotranspiration model by Bayesian approach: application to spring maize in an arid region of northwest China. Geosci. Model Dev. 7, 741–775.

Zhu, G., Li, X., Ma, J., Wang, Y., Liu, S., Huang, C., Zhang, K., Hu, L., 2018. A new moving strategy for the sequential Monte Carlo approach in optimizing the hydrological model parameters. Adv. Water Resour. 114, 164–179.

Zhu, X., Zhang, A., Xu, S., Jia, P., Tan, X., Tian, J., Wei, T., Quan, Z., Yu, J., 2020. Spatially Explicit Modeling of 2019-nCoV Epidemic Trend based on Mobile Phone Data in Mainland China. medRxiv https://doi.org/10.1101/2020.02.09.20021360.