Simulations of the COVID-19 Epidemic in Nigeria Using SIR Model

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Abstract. This study aims to review some applications of SIR model in COVID-19 epidemic situations, and tries to simulate the predictions of COVID-19 epidemic in a specific country using SIR model and R coding. This article picks Nigeria as the example, applying data from 28 February to 31 May and simulating the infected cases with Coronavirus. Based on literature review about usage of SIR model in this epidemic, the current trend is focusing on the optimization of parameters and algorithm. As a consequence, this study specifically initializes the SIR model with certain parameters and optimizes it through Maximum Likelihood Estimation using the Nelder-Mead algorithm. As the results show, the epidemic peak of Coronavirus cases in Nigeria is predicted to be reached around 20 May 2020, yet the peak has not been reached in reality and the growing rate is also quite different from the predicted curve. This phenomenon is considered as a consequence of a combined action and multiple factors that might attribute to it are discussed.

1. Introduction
The Coronavirus epidemic situation broke out in December 2019, as China reported their cases of pneumonia with uncertain cause in Wuhan City. The first case in China was reported on 12 December 2019, and the Chinese authorities finished and reported the sequencing of virus to the United Nations on 7 January 2020. On 23 January, the Chinese government announced to shut down Wuhan City to control the further spread, especially during the Chinese Spring Festival. This epidemic continues to spread among other cities in China and starts to cause infections around the world. On 11 February 2020, the World Health Organization (WHO) named this Coronavirus as COVID-19 officially and announced the epidemic situation as pandemic on 11 March 2020. According to the latest statistical data from Johns Hopkins University, the total number of confirmed cases has exceeded 10 million with over half a million deaths up to 28 June 2020. Up to now, the sources and cause of this series Coronavirus still remains unknown, which means the predictions of this epidemic and protective measures and suggestions are of vital importance.

Nigeria reported its first confirmed case on 28 February 2020 and this patient is an Italian national who came back from Milan, which is also the first Coronavirus case in Sub-Saharan Africa. After that, there were only two cases up to 13 March and the epidemic situation seems to be positive. However, the number of infected cases has been growing quickly and raised up the attention of government. Related measures has been taken in a short time, including shutting down the land border, implementing curfew, suspending major airlines, following guidelines from WHO for social distance, etc. Minister of Health in Nigeria Osagie Ehanire announced that they would follow China’s
therapeutic regimen and they have four experimental labs in total that are capable of testing Coronavirus.

2. Experiment and Method

2.1. Data Resource
As the reference, this article looked up the World Health Organization (WHO) website and downloaded the official resources of time series of infected cases[1]. Up to 31 May 2020, the government of Nigeria has declared 9855 confirmed cases with 273 deaths. After fitting the data resources of daily confirmed cases in Nigeria downloaded into R program with certain code from 28 February to 31 May 2020, the epidemic prediction in Nigeria can be simulated.

2.2. Model
This article applies the Susceptible-Infected-Removed (SIR) model without demographics, which equals there is no births, deaths, or migration, to simulate the daily confirmed cases of COVID-19 infection in Nigeria. The Susceptible-Infected-Removed (SIR) model is a simple model that is widely used in the epidemic prediction and simulation of an infectious disease among a large population. The assumption of SIR model is that the whole population can be divided into three parts: S is the number of susceptible, I is the number of infectives and R is the number of removed individuals. Meanwhile, this model considers that the births, deaths or migration can be neglected. Here is the expression of ordinary differential equations of SIR models[2].

\[
\begin{align*}
\frac{dS(t)}{dt} &= -\beta S(t)I(t), \\
\frac{dI(t)}{dt} &= \beta S(t)I(t) - \gamma I(t), \\
\frac{dR(t)}{dt} &= \gamma I(t).
\end{align*}
\]

(1)

The function \(S(t)\) represents the number of susceptible cases at time \(t\), the function \(I(t)\) represents the number of infected cases at time \(t\), and the function \(R(t)\) is the compartment of removed cases from the disease, where: Removed cases = Death cases + Recovered cases. The parameter \(\beta\) is called the contact rate while \(\gamma\) is the removed rate. Based on the assumption of SIR model, the initial condition of this model must satisfy the condition \(S(0)+I(0)+R(0)=N\), where \(N\) is the population size. Additional, the basic reproduction number \(R_0=\beta/\gamma\), which has a various determinants such as social behavior, population structure, immunity as well as healthcare, etc.

There are certain extraordinary advantages of SIR model for being universally used in infectious disease around the world. Basing on differential equation of SIR model, the solutions can fit to the realistic curve approximately. Meanwhile, by analyzing with trajectory, the results show that the theoretical basis is practicable. Therefore, it can reflect the differences between predicted curve and realistic curve sensitively, which provide ideas to control the illness from spreading and also show efforts caused by human interference visually. However, the disadvantages are inevitable. For instance, the method of classifying people is too simple that doesn’t consider about artificial factors such as quarantine and incubation. Another point is the lack of feedback mechanism in this model since most of influence factors are dynamically changed by time. Data collected before cannot reflect the changes such as improvements of medicine and hygiene level, and this drawback will let down the accuracy for forecasting a long run data. As a consequence, further modifications of this model are required in real simulation to improve the accuracy, and the optimization of parameters and algorithms are the common aspects.
2.3. Method
Various earlier studies have been done to forecast the confirmed cases of COVID-19 infection in lots of countries. Based on the related literature review, it is easy to find out that many studies are focusing on the optimization of parameters and algorithm in SIR model or the further modifications.

For example, there is the SEIR model[3,4] is more dynamic through adding the exposed (E), which means individuals that have been infected but haven’t been infectious. In addition, the SIQR model[5] includes the extra index quarantined (Q), from which the existence and asymptotically stability of the endemic equilibrium and disease-free equilibrium can be proved[6]. The Bayesian Optimization can also be used in epidemic situation[7]. Last is the generalized logistic growth model, the Richards growth model, and a sub-epidemic wave model[8]. This model allows predicting the incidence and the reproduction number R0 in the upcoming months.

Among them, the usage of Maximum Likelihood Estimation[10] is relative less and this article picked up this specific method. Following Boudrioiu et al[10,11], they came up with the method of using maximum likelihood estimation to get estimated parameters and applied it in the prediction of the COVID-19 epidemic in Algeria. The final log likelihood function is showed as below. The objective is estimating the parameters $\beta$ and $\gamma$ that give the optimum solution.

$$LL(\lambda = I_{\beta,\gamma}(t)) = \sum_{t=0}^{n} \log(\hat{I}_{\beta,\gamma}(t)) - \hat{I}_{\beta,\gamma}(t)$$

Specifically, they suggest to find the minimum of the negative log likelihood function through running the Nelder-Mead algorithm, which is equal to the maximum of log likelihood function. Using this method, they have successfully simulated the daily confirmed individuals in Algeria and predicted the time that the expected peak would be reached. This study chooses the similar method to simulate our confirmed cases predictions in Nigeria too.

2.4. Procedure
Therefore, the overall procedure of estimation can be resumed in the following two steps: step one is selecting the initial parameters $\beta$ and $\gamma$ initializing the SIR model, and step two is running the Nelder-Mead algorithm to get new parameters which will be used in the simulation and the prediction of the COVID-19 epidemic. After studying the figures outputted by the R program, lots of relative factors can be referred between the predicted one and the actual one.

3. Results and Analysis
Firstly, inputting data of daily confirmed cases in Nigeria from 28 February to 31 May 2020 and simulating the incidence trend, as showed in Figure 1. In this condition, this curve is just a normal reference that reflects the trend of accumulation of infected individual, and further modeling basing on parameters and algorithm should be done to understand this epidemic situation better.

![Figure 1. Simulation of incidence trend in Nigeria](image-url)
Next, when setting the SIR model, the assumption is that the whole population is susceptible, which means $N$ is equal to the number of the whole population in Nigeria ($N\approx 201000000$). As a consequence of this assumption, the epidemic situation might be the worst-scenario and the contact rate $\beta$ and removed rate $\gamma$ must be relatively high. In this condition, the initial parameters can be set as $\beta=0.95$ and $\gamma=0.75$. The simulation of infected cases with COVID-19 in Nigeria is showed in Figure 2, from which can be extracted that comparing the actual curve and the predicted curve, it is obvious that the actual curve is more smooth and growing slower. Therefore, the real situation in Nigeria is not the worst-scenario and the human interference such as protective measures and medical treatment might attribute to this positive outcome.

![Figure 2](image)

**Figure 2.** Fit of SIR model for Nigeria infected cases using the initial parameters

At last, applying the Maximum Likelihood Estimation and running the Nelder-Mead algorithm to optimize the initial parameters. After processing this method and running the code, the program can output the estimated parameters and the simulation and prediction of the COVID-19 epidemic situation in Nigeria with new parameters (Figure 3). In addition, the basic reproduction number $R_0$ is calculated through the algorithm as 1.4. This curve can be a valuable reference since it can reflect many vital factors. Compared with the predicted curve, the actual individual is growing in a smaller rate and the peak of the COVID-19 in reality is far more to reach yet. According to the SIR model simulation, the confirmed cases are expected reach their peak around 20 May 2020. Whether the actual will reach the highest cases and when the peak will come still remained to be observed, and this can be a sophisticated consequence of a combined action, which will be discussed in detail in the results.

![Figure 3](image)

**Figure 3.** Fit of SIR model for Nigeria infected cases using the estimated parameters

### 4. Conclusion

As the figures and results show, in this certain assumption, which can also be considered as the worst-case scenario, we can exact that the epidemic peak of COVID-19 in Nigeria is predicted around 20 May 2020, with about 13000 infected cases. It seems that the peak hasn’t been reached yet compared to the actual curve, and the speed of increase is obviously slower. This might be a consequence of a combined action depending on multiple factors. Firstly, since this epidemic situation...
has raised the public attention in a short time, lots of protective measures are taken properly, such as wearing face masks, being aware of social distance, shutting down activities. Thus, the real situation is much better than our worst-scenario model, leading to less infected cases and slower increase speed. Second, the vital parameter R0, the basic reproduction number, is determined by so many objective factors, such as social behavior, viral evolution, and political strategies including quarantine limitation and healthcare level. Up to current, Nigeria has executed strict exit and entry management and stopped the unnecessary contact with affected countries, which might modify the initial R0 as well.

An vital point that should be paid attention is the challenge Nigeria might meet. Firstly, the average medical level might be lower compared to other major countries that this crisis occurred, leading to a weaker defense. Next, the civic awareness are remained to be raised up further, as a comprehensive result of lifestyles, education level and social behaviors. Third, the lack of essential protective equipment and potential drastic competition on them. Therefore, the government should still keep strict measures and continuously update efforts from both WHO and other countries.

Following the differences between reality and predictions of COVID-19 epidemic in Nigeria, we can learn that protection measures and human intervention is very influential. The WHO and the UK National Health Services also point out that the peak might be reached later and the increasing spend can be controlled to a certain extent. Here we suggest strict containment strategies must be executed further by governments all over the world and citizens should pay much attention to their daily individual protection, to restraint this outbreak public health emergency.

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