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Susceptible Infectious and Recovered Model for Transmission of COVID-19 Pandemic in Nigeria

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Abstract

The COVID-19 pandemic has posed a serious threat to the lives of many people across the globe. In Nigeria, the first COVID-19 case was reported on 27th February 2020, after an Italian citizen tested positive for Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2), the causative agent of COVID-19. The spread of SARS-CoV-2 remained stable until 21st April 2020, when the number of infections in three digits emerged and as of June 20th, 2020, Nigeria recorded a total of 19,808 confirmed cases, a total discharged 6,718 and 506 deaths recorded. The severity of SARS-CoV-2 by far surpasses the coronaviruses that were so far discovered in 2003 and 2012. In this study, a Susceptible Infectious and Recovered (SIR) model for transmission of the COVID-19 pandemic in Nigeria has been developed to obtain the overall picture of the severity of the disease in Nigeria. The model is applied to the Nigerian COVID-19 data recorded from 28 February 2020 to 20 May 2021. The dataset comprised three variables, daily confirmed positive, death, and recovery cases. The parameters of the model are estimated by minimizing the negative log-likelihood function using the Nelder- Mead method. Based on the simulation of the fitted model, it can be concluded that the basic reproductive number, *Ro,* is 1.533931. The value of *R0* obtained showed that on average one infected individual would spread the COVID-19 virus to two susceptible individuals. And an infected individual required 9 days to recover from the disease. The *Ro* is computed using the estimated model parameters. The findings indicated that the fitted model satisfactorily mimicked the actual data reported by the Nigeria Center for Disease Control (NCDC).

Keywords: Coronaviruses, COVID-19, Basic Reproductive Number, SIR Model, Severity.

1. Introduction

Novel coronavirus which also called COVID-19 or 2019-nCoV is a lethal respiratory disease caused by a newly coronavirus known as Severe Acute Respiratory Syndrome Coronavirus two (SARS-CoV

2) which was first emerged in December, 2019 in Wuhan in Hubei Province of China (Ling et al. 2020; Zhu et al. 2020; Li et al. 2020). SARS-CoV-2 has so far spread rapidly to 210 countries and territories around the world and 2 international conveyances with 8,687,390 confirmed cases, 4,577,476 recovered cases and 459,098 deaths recorded as of June 19th, 2020, 18:34 GMT (Worldometer, 2020). World Health Organization (WHO) had declared COVID-19 as a global pandemic owing to its sustained transmission on six continents (Muhammad et al. 2020; Roberto et al. 2021; Giuseppe, 2021).

As all the continents reported confirmed cases of COVID-19, Africa confirmed its first case on 14th February, 2020 in Egypt (Muhammad et al. 2020; Marius et al. 2020). While in Sub-Saharan Africa, the first case of the COVID-19 has been confirmed in Lagos State, Nigeria on 27th February, 2020 where Italian citizen who works in that country appears to have tested positive for the virus (Muhammad et al. 2020; Adegboye et al. 2020). The victim was reported to have been flown from Milan to Nigeria on 25th February, 2020 (BBC, 2020). Immediately, Emergency Response Team (ERT) in Nigeria for public health emergencies known as Multi-Sectoral National Emergency Operation Center activated at level three which was led by Nigeria Center for Disease Control (NCDC) to trace the close contact of the patient. It was found that 27 suspected cases had been identified on 9th March, 2020 across five states namely Lagos, Edo, Ogun, Abuja and Kano, out of which two were confirmed to be positive (NCDC, 2020; Bassey and Akaninyene, 2020).

As of June 21st, 2020, a total of 19,808 SARS-CoV-2 confirmed cases, 6,718 discharged and 506 deaths recorded in 35 states and Federal Capital Territory, Abuja (NCDC, 2020). The first case of COVID-19 pandemic in Nigeria did not lead to immediate outbreak, due to the public intervention implemented in Nigeria, which reduced the local transmission of the pandemic and importation from other counties especially China (Adegboye et al. 2020; NCDC, 2020). Some of the prompt public intervention implemented in Nigeria include prompt activation of Multi-Sectoral Emergency Operation Center, risk transmission and commutation campaign across the country, two Rapid Response Teams of NCDC were deployed to Ogun and Lagos States. Lagos and Ogun States respectively activated State-Level Emergency Operation Centers with press briefing by their respective governors.

On 30th March, 2020, the President of Nigeria signed THE QUARANTINE ACT (CAP Q2 LFN 2004) for COVID-19 Regulation, 2020, in which the restriction/cessation of movement in Lagos, FCT and Ogun States were enforced. Moreover, the citizens are advice to stay at home, all travel to or from states are banned, all businesses and public offices are closed excluding hospital and all related medical; establishments, organizations in health care related manufacturing and distribution (Algehyne et. al, 2022, Alsayed et. al,2021). Suspension of passenger aircraft, both commercial and private were also enforced. Although several models for COVID-19 pandemic have been developed as reported by NCDC (2020), Li (2020) an Kucharski et al. (2020), however, Nigeria is still lagging behind. Proper understanding of the Susceptible Infectious and Recovered (SIR) model for human-to-human transmission via three mutually exclusive stages of infection namely susceptible, infected and recovered is very important. This study is not only intending to fulfill the lagging of the model used in Nigeria but also the main key to planning effective control strategies for COVID-19 pandemic in Nigeria. Thus, documenting the knowledge for severity of COVID-19 pandemic in Nigeria using SIR model is of significant importance since it would properly guide the government at all levels to handle and manage the pandemic effectively. In this study, daily confirmed cases, daily death cases and daily recovery cases of COVID-19 in Nigerian dataset were obtained and SIR model for transmission of COVID-19 pandemic in Nigeria was developed with the main aim to prepare for an effective control s trategy for Nigeria policy maker.

2. Materials and Methods

2.1 Dataset

The dataset of COVID-19 daily confirmed cases, daily death cases and daily recovery cases was obtained from official website of Nigeria center for disease control (NCDC), https://ncdc.gov.ng/. The dataset comprised of 456 days from 28th February, 202 to 20th May, 2021. The dataset contains the daily confirm cases, death cases, recovery cases, active cases reported on the website. The data an alysis was performed using desolve package in R statistical package.

2.2 Susceptible Infectious and Recovered (SIR) Model

The SIR model is the model that was first used by Kernmack and McKendrick in 1927 and was subsequently used and applied to a variety of diseases particularly airborne childhood disease with lifelong immunity upon recovery such as rubella and measles (Kermack and McKendrick, 1927). In this study, SIR model is used to model and predict the severity of COVID-19 infections in Nigeria. In SIR model, size of population N is divided into three components, known as susceptible (S), as an healthy individual but are at risk of being contracted with the virus, Infectious (I), as an infected individuals, and Recovered (R), as the people that contracted the virus but either died or recovered from the disease. Figure 1 shows the transition process from the susceptible group to the recovered group.

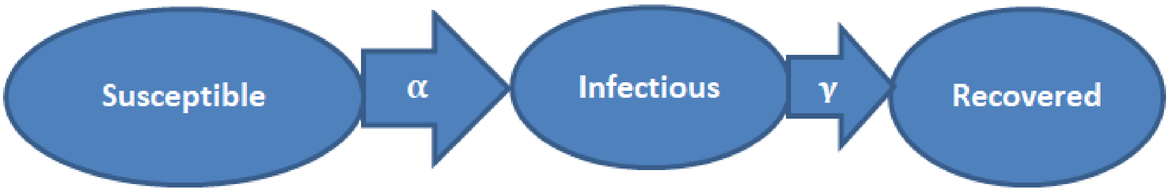


Figure 1. Transition Process from Susceptible Group to the Recovered Group

The susceptible individuals decrease at α when they contract the virus and move to the infectious group, therefore, as the infected individuals recovered or died they move from of the infectious group at the rate γ to the recovered group. Therefore, to model the COVID-19 pandemic in Nigeria, three differential equations have been used to describe the rate of changes in each compartment. The Equation 1, Equation 2 and Equation 3 can be seen as follows:

$$\frac{ds}{dt} = -\frac{\alpha SI}{N}, \quad (1)$$

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

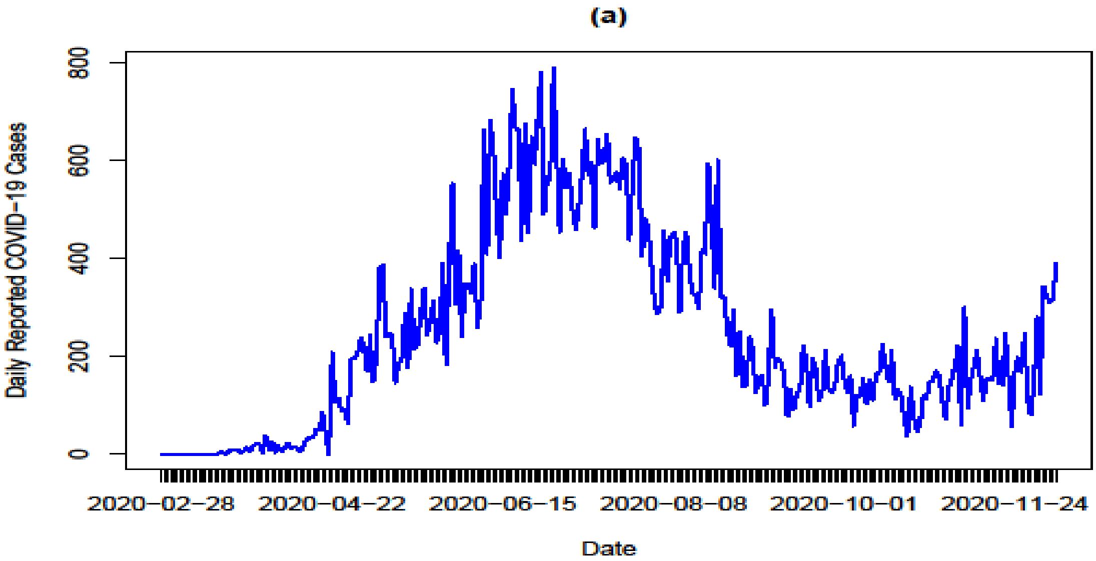
$$\frac{dR}{dt} = \gamma I \quad (3)$$

where α is the infection rate, which controls the transition from the susceptible group to the infectious group, and γ is the removal rate, which controls the transition from the infectious group to recovered group. The assumption of standard SIR model is that the population is fixed, $N = S(t) + I(t) + R(t)$ at time t, no births or deaths. Equation 1 states that the number of susceptible individuals decreases with the number of people infected with the disease. Meanwhile, Equation 2 states that the number of individuals in the infectious group increases with the newly infected individuals (αSI) minus the individuals previously infected but recovered (γI). Equation 3 states that the number of individuals in the recovered group increases with the number of people in the infectious group but either recovered from the disease or died.

The expected duration of recovery from infection, in days, is given by $\frac{1}{\gamma}$, and a significant parameter which shows the speed at which a disease is spreading is the basic reproductive number (R_0). The parameter, R_0, indicates the number of secondary infections arising from the first case in a susceptible population. It is given as $R_0 = \frac{\alpha}{\gamma}$. When $R_0 > 1$, implies that an infected individual will on average spread the disease to more than one person. While, when $R_0 = 1$ indicates that an infected person spread the disease to only one person. The target always we intend to achieve is to obtain $R_0 < 1$, which implies that an infected individual will not spread the disease to another person.

3. Results and Discussion

The daily reported COVID-19 positive cases were obtained from the official website of the NCDC with the data covers 456 days, from 28th February 2020 to 20th May 2021. The data are categorized according to the two Covid-19 waves in Nigeria, first wave, from 28th February 2020 to 7th December 2020, and the second wave, from 8th December 2020 to 20th May 2021. The plotting and model fitting have been analyzed by using Rstudio, deSolve package, and R package version 3.6.3. The daily new and cumulative positive cases for the two waves have been visualized by using Line plots, Figures 2 and 3. During the first wave, the trend of the virus's spread shows stable situation from the first-day infections were discovered until 22nd April 2020, when we started a spike in the number of positive cases. Despite the movement control order (MCO) and other policies imposed by the Nigerian government, the number of cases kept increasing with fluctuations up to date. The increasing trend of number infections might be as a result of inadequate health facilities and other issues in the country. I n addition, for the second wave, the rate of infection increased rapidly and recorded its highest peak on the 23rd January 2021. However, the number of new infections started dropping and remained stable from 18th February 2021 to date.



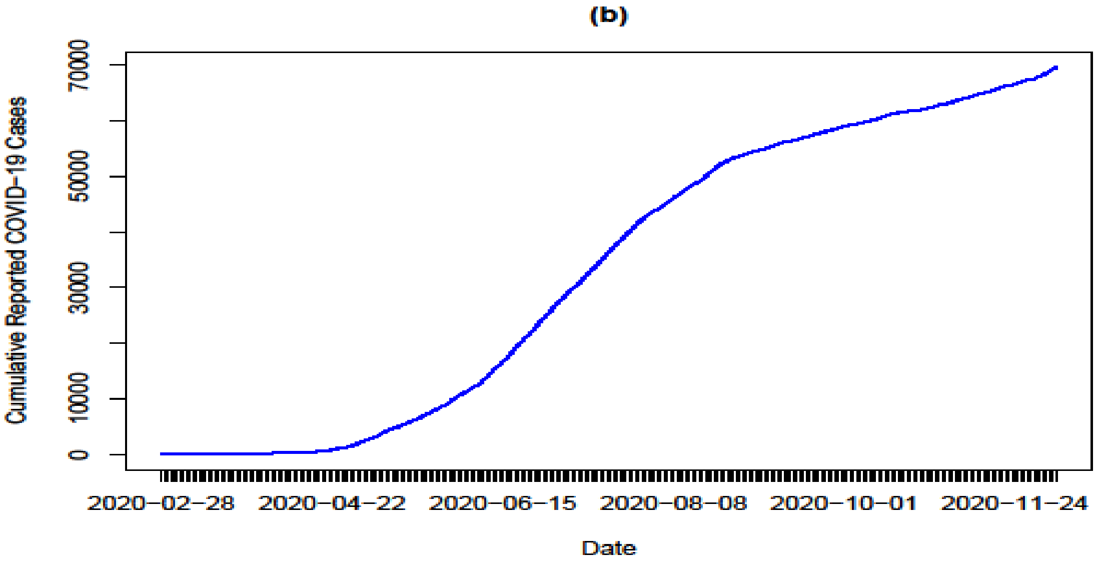


Figure 2. Line Plots of the Nigerian COVID-19 First Wave Reported Positive Cases, (a) for Daily Pos itive and (b) for Cumulative Positive.

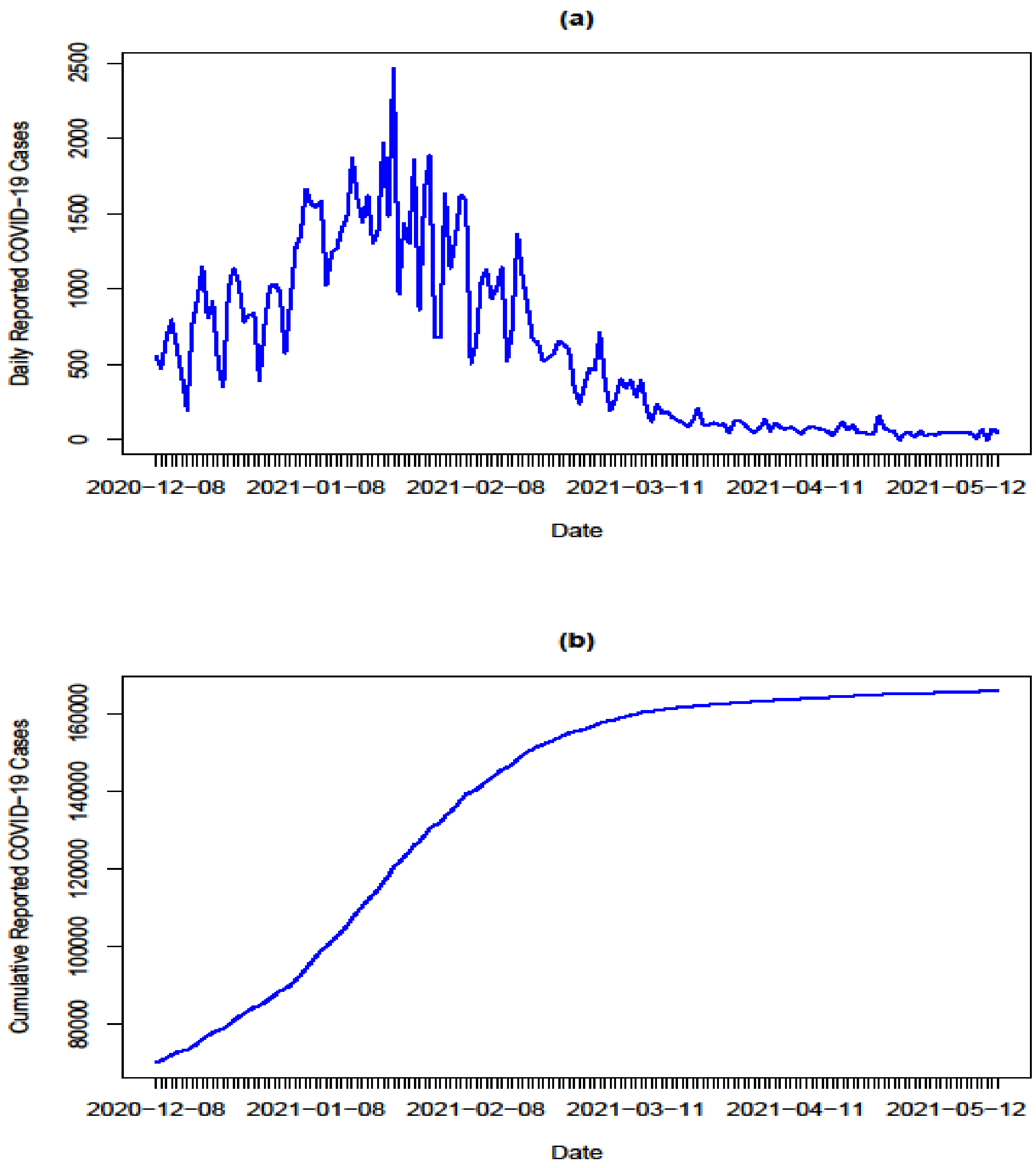


Figure 3. Line Plots of the Nigerian COVID-19 Second Wave Reported Positive Cases, (a) for Daily Positive and (b) for Cumulative Positive.

4. Model Simulation

In this study, using the initial values, $N = 1000$, $S(0) = N - 1$, $I(0) = 1$, and $R(0) = 0$ for SIR model, for the first wave infections, we obtained the values of the infection and removal rates as 0.1793670 and 0.1169329. Thus, R_0 is 1.533931, and the expected number of days of recovery from the infection is 9 days. The value of R_0 obtained indicates that an infected individual will on average spread the virus to 2 susceptible individuals. The fitted SIR model satisfactorily mimics the trend of the actual reported cases. It can be seen in first wave, Figures 4 and 6, at the initial stage of the outbreak, the fitted infection cases are close to the observed cases, from day 1 to day 60, but there are discrepancies afterward, due to sudden spikes in the number of actual cases. The trend of the simulated individuals in the susceptible compartment started declining after day 60 meanwhile, the simulated infected individuals started inclining from day 50. The trend of the simulated recovered compartment also increases after day 60. Similar trend is obtained during the second wave, but with high number of infections (see Figures 5 and 7).

A similar study, though it was aimed at stimulating the propagation dynamics of COVID-19 on the Cape Verde Islands, Da Silva (2021) obtained the values for the infection and removal rates, β and α, to be 0.7555025 and 0.6977990, and the basic reproductive number, R_0 = 1.08269. A related research by Lounis & Bagal (2020) who fitted the classical SIR model to COVID-19 epidemic in Algeria using data from February 25th, 2020 to August 12th, 2020 obtained the values for the infection and removal rates, β and α, to be 0.0561215 and 0.0455331, and the basic reproductive number, R_0 = 1.23254. And also predicted that the peak of the epidemic in Algeria will be reached on September 8th, 2021. Using a different model parameters optimization approach, maximum likelihood estimation using the Nelder-Mead algorithm, Yimeng (2021) predicted that the epidemic peak of Coronavirus cases in Nigeria to be reached around 20th May 2020. Alshomrani et al. (2021) study compared classical SIR model and the Caputo SIR model in modeling the Pakistan covid-19 cases and found that the Caputo SIR model better fits the data. A research by Roberto et al. (2021) described the mathematical asymmetric patterns of susceptible, infectious, and recovered (SIR) model equation application in the light of coronavirus disease 2019 (COVID-19) skewness patterns worldwide. In estimating the time-varying infection rate, Shapiro et al. (2021) fitted the adaptive SIR (aSIR) model for United states covid-19 cases. The aSIR model showed an excellent fit for the number of reported COVID-19 cases.

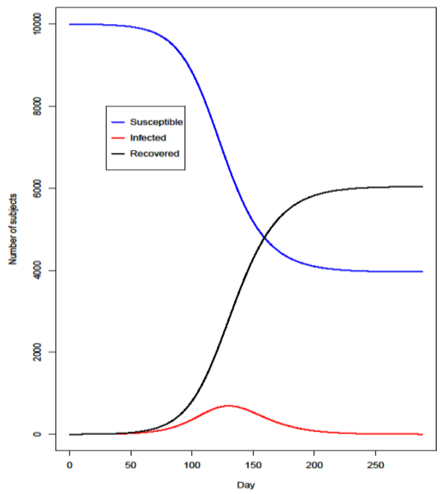


Figure 4. The Simulation of SIR Model for the Nigerian COVID-19 First Wave Cases of three Population Size, Susceptible, Infected and Recovered Present by Line Blue, Red and Black

Respectively.

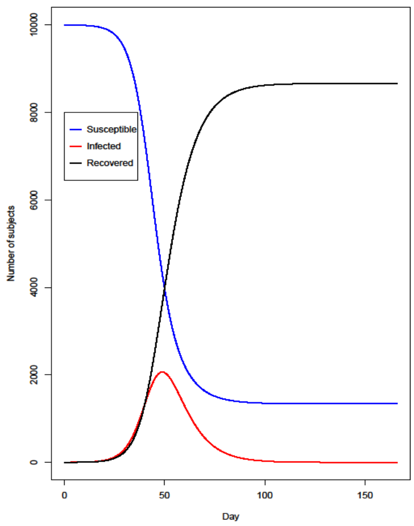


Figure 5. The Simulation of SIR Model for the Nigerian COVID-19 Second Wave Cases of three Population Size, Susceptible, Infected and Recovered Present by Line Blue, Red and Black Respectively.

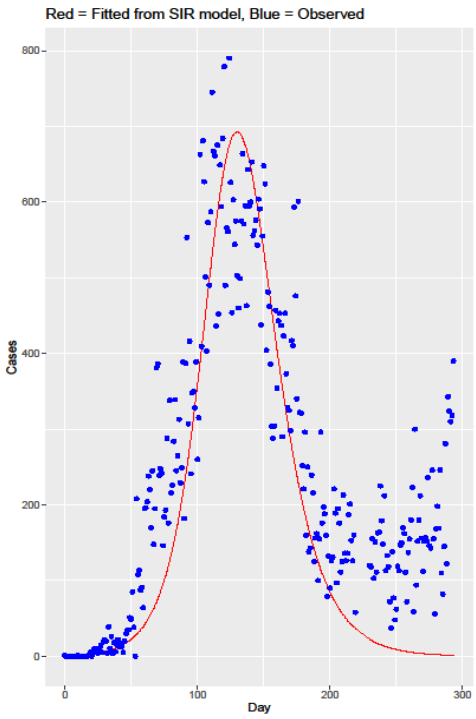


Figure 6. The Fitted and the Observed Nigerian First Wave COVID-19 Cases, Red: Cases Obtained Using the Fitted Model and Blue: Observed Cases.

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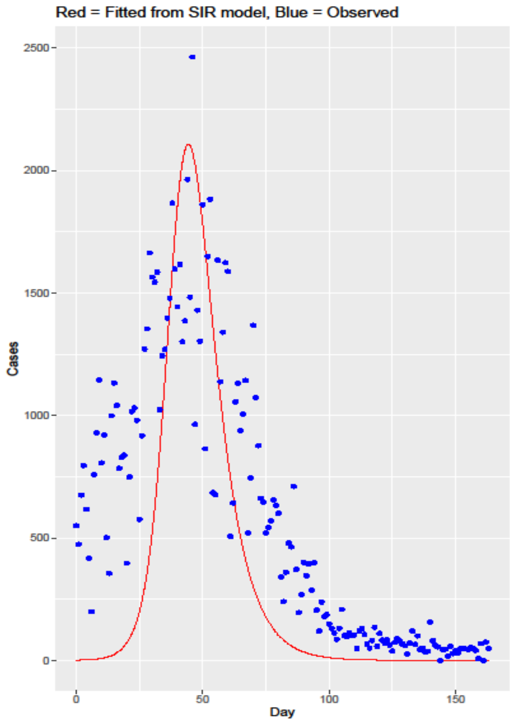

Figure 7. The Fitted and the Observed Nigerian Second Wave COVID-19 Cases, Red: Cases Obtained Using the Fitted Model and Blue: Observed Cases.

5. Conclusion

In conclusion, the SIR model for the transmission of the COVID-19 pandemic in Nigeria was developed. The basic reproductive number, R_0, obtained indicates that the pandemic is under control but, the government needs to urgently come up with new measures to curb the spread of the virus. The COVID-19 pandemic, which is now becoming endemic, might live longer than expected and affect many people in Nigeria. Therefore, documenting the knowledge of the severity of the COVID-19 pandemic in Nigeria will guide the stakeholders, especially the government of various levels, to dramatically plan effective control strategies for policymaking.

Research should be set up in the future to study the propagation dynamics of COVID-19 in Nigeria, like Da Silva's (2021) work. Also, only the classical SIR model is developed in this research other advanced models should be considered in the future.

6. References

Algehyne, E. A., Jibril, M. L., Algehainy, N. A et. al. (2022), fuzzy neural network expert system with an improved gini index random forest-based feature importance measure algorithm for early diagnosis of breast cancer in Saudi Arabia. *Big Data Cogn. Comput*., 6(13).

Alsayed, O., Rahim, M. S. M., Bidewi, I. A. et al. (2022). selection of the right undergraduate major by students using supervised learning techniques. *Appl. Sci.* 11(10639);

Adegboye OA, Adekunle AI, Gayawan E (2020). early transmission dynamics of novel coronavirus

(COVID-19) in Nigeria. *Int. J. Environ. Res. Public Health* 17.

Abdul RJ, Chinmay C, Celestine W. (2021). exploratory data analysis, classification, comparative analysis, case severity detection, and internet of things in COVID-19 telemonitoring for smart hospitals. *Journal of Experimental & Theoretical Artificial Intelligence*. 1-24; 2021. 0.1080/0952813X.2021.1960634.

Anastassopoulou C, Russo L, Tsakris A & Siettos C (2020). Data-based analysis, modelling and forecasting of the COVID-19 outbreak. *PLOS One*. 15(3): e0230405.

Anichur R, Chinmay C, Adnan A, Md. R, Md. JI, Dipanjali K, Ziaur R, Shahab SB (2021). SDN-IoT Empowered Intelligent Framework for Industry 4.0 Applications during COVID-19 Pandemic, *Cluster Computing*. 25:2351–2368.

Bassey E, Akaninyene O (2020). Can Nigeria contain the COVID-19 outbreak using lessons from recent epidemics? *THE LANCET, Global Health*. 8(6): e770.

BBC: Coronavirus (2020). Nigeria confirms first case in sub-Saharan Africa. BBC. 2020. https://www.bbc.com/news/world-africa-51671834 Accessed 3rd June, 2020.

Casella F (2020). Can the COVID-19 epidemic be managed on the basis of daily data? Preprint at https://arxiv.org/abs/2003.06967.

Casella, F (2021). Can the COVID-19 Epidemic Be Controlled on the Basis of Daily Test Reports? *IEEE Control Systems Letters.* 5(3):1079-1084.

Da Silva A (2021). Modeling COVID-19 in Cape Verde Islands - An application of SIR model. *Computational and Mathematical Biophysics*. 9(1): 1-13. https://doi.org/10.1515/cmb-2020-0114.

Giuseppe G (2021). A simple SIR model with a large set of asymptomatic infectives. *Mathematics in Engineering*. 3(2): 1-39. doi: 10.3934/mine.2021013

Hemanta KB, Chinmay C, Yogesh S, Suvendu KP (2021). COVID-19 diagnosis system by deep learning approaches. *Expert Systems*. 1-18, e12776; 2021. https://doi.org/10.1111/exsy.12776.

Islam M. et al.(2020). Wearable Technology to Assist the Patients Infected with Novel Coronavirus (COVID-19). *SN Comput. Sci.* 1(6): 320.

Kermack WO & McKendrick, A. G. (1927). A contribution to the mathematical theory of epidemics. *Proc. R. Soc. Lond.* A. 115: 700–721.

Lin Q et al. (2020). A conceptual model for the coronavirus disease 2019 (COVID-19) outbreak in Wuhan, China with individual reaction and governmental action. *Int. J. Inf. Dis.* 93: 211–216.

Li Q, Guan X, Wu P, et al. (2020). Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus-Infected Pneumonia. *N Engl J Med*. 382:1199-1207.

Li Y et al. (2020). A machine learning-based model for survival prediction in patients with severe COVID-19 infection. *MedRxiv*.

Ling H, Shaoqiu C, Yuanyuan F et al. (2020). risk factors associated with clinical outcomes in 323

COVID-19 hospitalized patients in Wuhan, China, *Clinical Infectious Diseases*, ciaa539. https://doi.org/10.1093/cid/ciaa539.

Lounis M & Bagal, DK (2021). Estimation of SIR model's parameters of COVID-19 in Algeria. *Bulletin of the National Research Centre*. 44(1): 180. https://doi.org/10.1186/s42269-020-00434-5.

Marius G, Giulia P, Francesco P et al. (2020). Preparedness and vulnerability of African countries against importations of COVID-19: A modelling study. *The Lancet*. 395(10227): 871-877.

Muhammad LJ, Usman SS (2020). Power of Artificial Intelligence to Diagnose and Prevent Further COVID-19 Outbreak: A Short Communication, arXiv:2004.12463 [cs.CY].

Muhammad LJ. et al. (2021). Deep learning models for classification and localization of COVID-19 abnormalities on chest radiographs. *4th International Conference on Computing & Information Sciences (ICCIS)*. 1-6.

Muhammad L.J. et al. (2022) Deep Learning Models for Predicting COVID-19 Using Chest X-Ray Images. In: Johri P., Diván M.J., Khanam R., Marciszack M., Will A. (eds) Trends and Advancements of Image Processing and Its Applications. EAI/Springer Innovations in Communication and Computing. Springer, Cham. https://doi.org/10.1007/978-3-030-75945-2_6

Nigeria Centre for Disease Control. COVID-19 Outbreak in Nigeria Situation Report; NCDC: Abuja, Nigeria, 2020.

Roberto TC, Lopes H, Franco D (2021). SARS-COV-2: SIR model limitations and predictive constraints. *Symmetry*. 13(4):676. https://doi.org/10.3390/sym13040676.

Sarumi, O. A. et al. (2022). potential of deep learning algorithms in mitigating the spread of COVID-19. In: J. Nayak, B. Naik, A. Abraham (eds) Understanding COVID-19: The Role of Computational Intelligence. Studies in Computational Intelligence,963.

Shapiro MB, Karim F, Muscioni G, Augustine AS (2021). adaptive susceptible - infectious - removed model for continuous estimation of the COVID-19 infection rate and reproduction number in the United States: Modeling study. *Journal of Medical Internet Research*; 23(4): e24389.

THE QUARANTINE ACT (CAP Q2 LFN 2004) for COVID-19 Regulation; 2020.

Wu J, et al. (2020). Estimating clinical severity of COVID-19 from the transmission dynamics in Wuhan, China. *Nat. Med*. 26: 506–510.

Worldometer (2020). COVID-19 Coronavirus Outbreak, Retrieved from https://www.worldometers.info/coronavirus/coronavirus-cases/ Accessed 3rd June, 2020.

Yimeng D (2021). Simulations of the COVID-19 epidemic in Nigeria using SIR model. (2020). *Journal of Physics: Conference Series*, 1893: 012016.

Zhu N, Zhang D, Wang W, et al. (2020). A novel coronavirus from patients with pneumonia in China, 2019. *N Engl J Med*. 382: 727-33.