AN ADJUSTED SIR MODEL FOR COVID-19 TRANSMISSION IN NIGERIA

BY

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Abstract

Background: COVID-19 is in the family of the Coronaviruses. Coronavirus is one of the main pathogens that fundamentally aims at the human respiratory system.

Objectives: This study predicted the COVID-19 transmission in Nigeria via the adjusted SIR model.

Methods: An adjusted SIR model was applied to the NCDC daily data spanning from 27th February 2020 to 7th May 2020.

Results: Susceptible, infective, and recovered individuals were identified with their corresponding trend lines. There were higher occurrences of infected persons, the infective series reached its peak at day 122 with a total of 77,009,941. The infective line began to tail off after day 122 while the recovered began to rise and the susceptible also tailed off gradually. The COVID-19 pandemic was predicted to last for 422 days from the day of its inception in Nigeria.

Conclusion: The findings in the study capitalizes more on the need to adhere strictly to the COVID-19 laid down rules so as to stay safe.

Introduction

Coronavirus is one of the main pathogens that fundamentally aims at the human respiratory system. Past episodes of Coronaviruses (CoVs) include the Middle East Respiratory Syndrome (MERS)-CoV and the Severe Acute Respiratory Syndrome (SARS)-CoV which have been recently portrayed as mediators that constitute major health threat to the public. In 2019, precisely late December, a cluster of sick persons (patients) were admitted to different hospitals and diagnosed with pneumonia of an obscure etiology. These patients were thus connected epidemiologically to seafood and wet animal market located in Wuhan which is in the Hubei area of China[1,2]. Coronavirus was also named COVID-19 by WHO on Feb 11, 2020. Early reports about the disease have it that the beginning of a potential coronavirus episode would have an estimated multiplicative number that was fundamentally bigger than 1 (thus it ranges from 2.24 to 3.58)[3]. Coronavirus disease 2019 is a pandemic that has claimed lives and still claiming lives, thus, apart from the global public health, it has suffered humans globally

bringing in fear and uncertainty in the global business world. As of February 20, 2020, 2130 deaths were confirmed and documented across 5 continents and in 26 countries. Recent studies disclose that the symptoms of COVID-19 are fever, dry cough, and dyspnea (shortness of breath or air hunger) amongst other symptoms are the common signs that are seen at present though these symptoms and signs are similar to the severe acute respiratory syndrome (SARS) and the Middle East respiratory syndrome (MERS) of 2003 and 2012 respectively. Both the SARS and MERS are characterized by droplet and contact transmission although symptoms like nausea, abdominal discomfort, and vomiting are fewer signs that are followed by the typical respiratory symptoms but vary amongst the study population[4]. The SARS, MERS, and COVID-19 are all in the coronavirus family while the coronavirus that causes SARS is referred to as SARS-CoV, that of MERS is the MERS-CoV and the COVID-19 is SARS-CoV-2. The virus SARS-CoV-2 is similar or has a close semblance to that of the SARS-CoV. The SARS and MERS have more fatality cases than the COVID-19 or SARS-CoV-2, yet, what makes the COVID-19 different is its rate of infection and contagion, thus, it is more infectious and contagious than the SARS and MERS. The COVID-19 patients also are seen to also develop intestinal symptoms like diarrhea while MERS and SARS patients have low percentages.

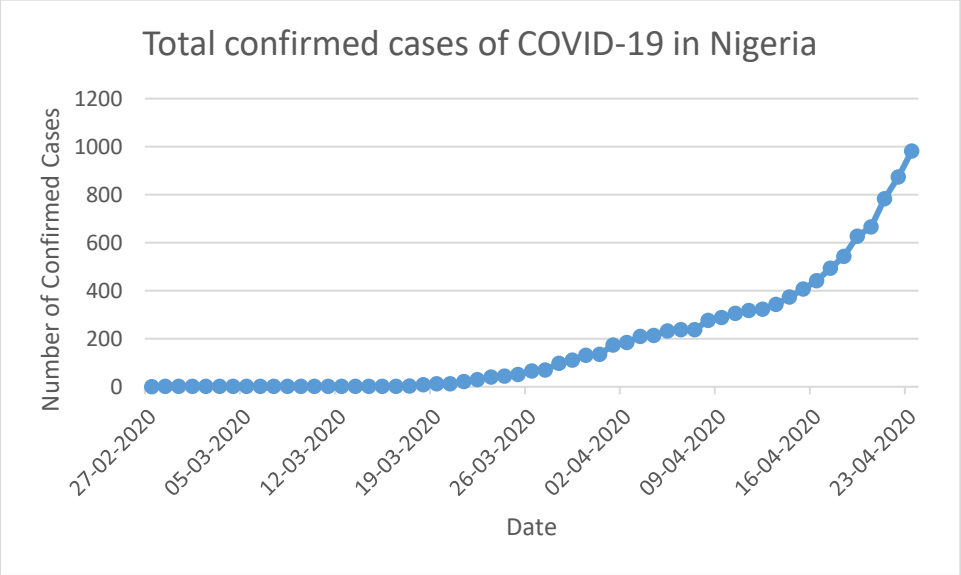
The signs of COVID-19 contagion show up after a gestation period of roughly 5.2 days [5]. The period from the beginning of COVID-19 signs to death of the patients spanned from 6 to 41 days with a median of 14 days[6]. This period is subject to the age of the patient and also the health position of the patient's immune system. In other words, those patients that are over 70 years of age had a shorter immune system than those below 70 years of age[6]. Studies carried out as regards comprehensive and common onset symptoms of COVID-19 disease are fever, dry cough, and tiredness, other symptoms include phlegm or sputum, hemoptysis, headache, dyspnea, diarrhea, and lymphopenia[6–9]. It is, however, important to note that COVID-19 show some clinical characteristics that are unique to it alone and thus makes it totally different from other coronaviruses, its unique characteristic symptom is that it aims at the lower airway as marked by upper respiratory tract symptoms such as sneezing, sore throat, and rhinorrhoea, the newest symptom now is the loss of taste and smell[10–12]. The COVID-19 disease as earlier on stated originated from Wuhan in China and is currently devastating the entire globe with a geometrical increase in people that are infested and also a rising trend in the number of deaths.

The likely mode of transmission of the COVID-19 disease is from human to human although it is suggestive that the large number of persons infected in the wet market in Wuhan points to the direction that COVID-19 originated from a zoological animal. Thus, the primary mode of transmission is by direct contact with an infected person, or by cough and sneezing droplets from infected persons. Sneezing and cough droplets on surfaces can retain the COVID-19 viruses for about 48 hours thus when touched by an uninfected person, he or she needs to wash his or her hands with soap and running water for at least 20 seconds or sanitize with at least 60% alcohol-based sanitizer, if not, he or she becomes infected. It is also important to note that people are advised to wash their hands frequently and avoid hugging, kissing, handshaking by maintaining at least 2 meters of social distancing.

Apart from the reported cases in China, the first reported case outside of China was in Thailand and that was on the 13th of January, 2020[13] and from there, it has spread to 180 countries as of 1st April, 2020. More than 930,000 infections have been reported globally with deaths over 47,000. The United States of America, Italy, and Spain are the most affected as regards the COVID-19 pandemic. The United States of America reported her first case on 21st January

2020 but in March, cases started surging after they expanded their testing points and kits for the virus. The highest number of deaths were reported in Italy with over 13,000 deaths, Italy is ranked the second to the United States, although it can be said that the Italian and Spanish hospitals are slowly beginning to ease. Spain and Italy account for about 40% of the total global COVID-19 deaths with claimed lives of 31,000 in less than 2 months. As of 20th April, the number of cases in Spain rose to 194,000 and deaths passed 20,000. As of 21st April 2020, Spain overtook Italy and became the 2nd while Italy became the 3rd, all are ranked second and third after United States[14–16]. The total confirmed cases as of 21st April 2020 are 2,560,504 and total deaths amounted to 176,926[16].

In Africa, statistics have it that as at April 21st, 2020, 52 countries were affected with 23,517 confirmed cases, 1,160 deaths, and 6.116 recoveries with Lesotho and Comoros as the only unaffected countries in Africa as at that period[17]. Nigeria recorded her first case on 27th February 2020 through an Italian man from Milan, and as of April 21st, 2020, Nigeria had a total of 782 confirmed cases with 197 recoveries and 25 deaths[18]. The graph below shows the trend of COVID-19 pandemic in Nigeria:



As of 23rd of April, 2020, the total confirmed cases of COVID-19 are 981. The trend line shows that the COVID-19 pandemic is on the increase.

The thrust of this paper is to predict the COVID-19 pandemic in Nigeria with the adjusted SIR model. The SIR model was originally developed by Kermack and Mckendrick in 1927[19]. The SIR model is well known for epidemic dynamics, past studies on the SIR methodology [20–23] reflects its suitability as regards infectious diseases and that was the same reason that it was applied for the COVID-19 study in Nigeria but in our case, an adjusted form of the SIR methodology was applied.

Methodology

The Kermack and Mckendrick SIR model was adjusted to study the COVID-19 pandemic in Nigeria, where;

S means susceptible individuals who can contract the disease, at this point, they are not infected yet.

Thus,

$$\frac{dS}{dt} = -\varphi SI \text{ ---------- } (1)$$

Where φ is the infection rate and the susceptible decrease by φSI in proportion to the infection rate φ. In other words, this is the rate at which the susceptible meet the infective and are thus infected.

I mean infected, infectious, or infective, these are individuals that have the disease and can also infect others, and thus, they are the carriers.

Thus,

$$\frac{dI}{dt} = \varphi SI - \delta I \text{ ---------- } (2)$$

The infective I increases by φSI and decreases by δI. Where δ is the rate of immunity acquired. Note that the decrease in δI is in proportion to the rate of δ.

R means removed or recovered individuals. These are individuals that are formerly infectious or infective and no longer considered infectious or infective. In other words, the removed individuals would also include those that are dead or recovered.

Thus,

$$\frac{dR}{dt} = \delta I \text{ ---------- } (3)$$

The removed or recovered individuals will increase by δI

Thus, equations 1, 2, and 3 displays the adjusted SIR model.

If $\frac{dI}{dt} = 0$, a condition which would be referred to as equation (4) then the number of I is regarded as been constant over time.

$\therefore \frac{dI}{dt} = 0$ ----------(4)

Put equation (4) into equation 2

$$I(\varphi S - \delta) = 0 \text{ ---------- } (5)$$

The above equation (5) is derived by simple calculations

Therefore, our interest is to show that infectious individuals actually exist.

Thus,

$$\varphi S - \delta = 0; if\ not, I = 0$$

So that equation (5) will be proven correct

Then, the following conditions stand such that the number of I is constant, that is, constant over time.

Therefore, $\frac{\varphi S}{\delta} = 1 - (6)$

Let the numerator of equation (6) with respect to time t divided by the rate of immunity acquired δ give us the reproduction number with respect to time, that is;

$$\frac{\varphi S(t)}{\delta} = U_t - (7)$$

The following assumptions and conditions will hold for the reproduction number U_t

i. if $U_t > 1$, the COVID-19 pandemic occurs, that is, the disease prevails
ii. if $U_t < 1$, the COVID-19 pandemic dies, that is, the disease will not prevail
iii. $U_t = 1$, is the COVID-19 pandemic threshold.

Let's sum up equations (1) to (3), that is,

$$\frac{dS}{dt} + \frac{dI}{dt} + \frac{dR}{dt} = 0 - (8)$$

Equation (8) transcends to;

S(t) + I(t) + R(t) for all (t), where t = time

But, it is important to note that removed individuals imply death and thus the transition from equation (8) should be better seen as;

$$N(0) = N(t) = S(t) + I(t) + R(t) + \sum_{i=1}^{t-1} d_i - - - - - - - - - - - (9)$$

Where d_i represents the number of deaths due to the COVID-19 pandemic and N equals the total population size. N is also constant over time.

Since we are working with a closed economy, it can be seen from equation (9), that as the number of recovered or removed individuals increases, the susceptible and infectious individuals decreases. Thus, in a long run, the infective becomes zero, and the susceptible and removed or recovered remains. In the course of this paper, the removed or recovered will be referred to as Recovered. Thus, recovered cases include removed cases too.

Results

Table 1 The SIR Table for Index case of 27th February 2020

Case	φ	δ	S	I	R	N	Time(days)
Index	0.25	0.07	205218213	1	0	205218214	1

From the table above, Nigeria had her first index case on 27th February 2020, following the total population which is estimated at 205,218, 214. If there had been no index case, there wouldn't be any infection, thus S would be constant but because of the index case, we can see

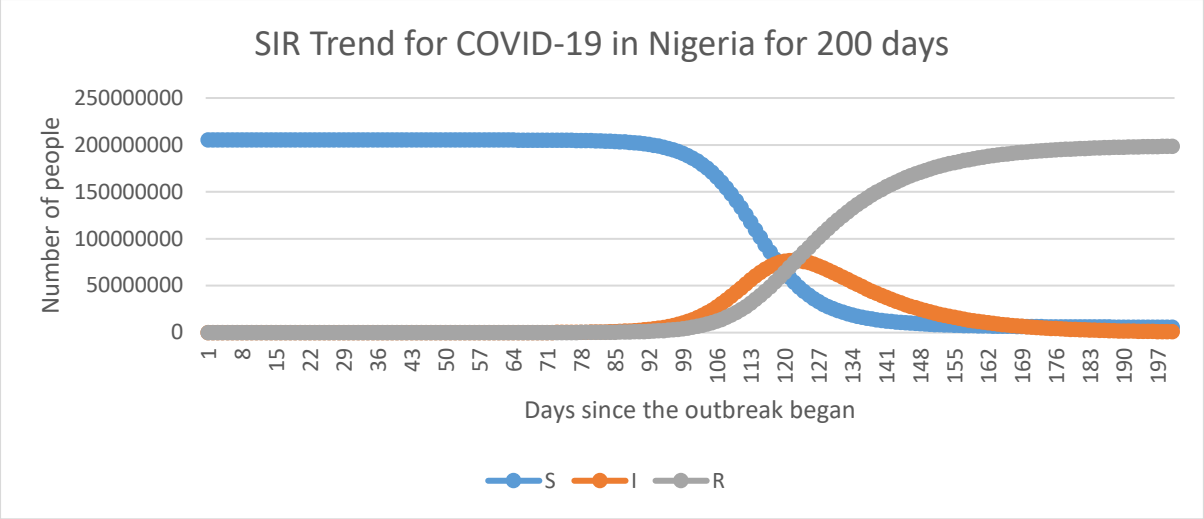
that the recovered equals zero at time t, which we called days. The susceptible becomes 205,218,213 with the fraction of the infection rate at 0.25 and 0.07 for the rate of immunity.

Table 2 SIR for 100 days interval in Nigeria

Time(Days)	Susceptible(S)	Infective (I)	Removed or Recovered (R)	Population Size (N)
1	205218213	1	0	205218214
2	205218213	1.18	0.07	205218214
3	205218212	1.3924	0.1526	205218214
4	205218212	1.643032	0.250068	205218214
5	205218212	1.938778	0.36508024	205218214
6	205218211	2.287758	0.500794683	205218214
7	205218211	2.699554	0.660937725	205218214
8	205218210	3.185474	0.849906515	205218214
9	205218209	3.758859	1.072889687	205218214
10	205218208	4.435454	1.336009828	205218214
20	205218182	23.21443	8.638946843	205218214
30	205218046	121.5004	46.86130244	205218214
40	205217331	635.9107	246.9103811	205218214
50	205213592	3328.181	1293.922108	205218214
60	205194023	17417.19	6773.473334	205218214
70	205091665	91105.21	35443.34169	205218214
80	204557601	475368	185245.1386	205218214
90	201807153	2448600	962461.2329	205218214
100	188544023	11821316	4852874.91	205218214

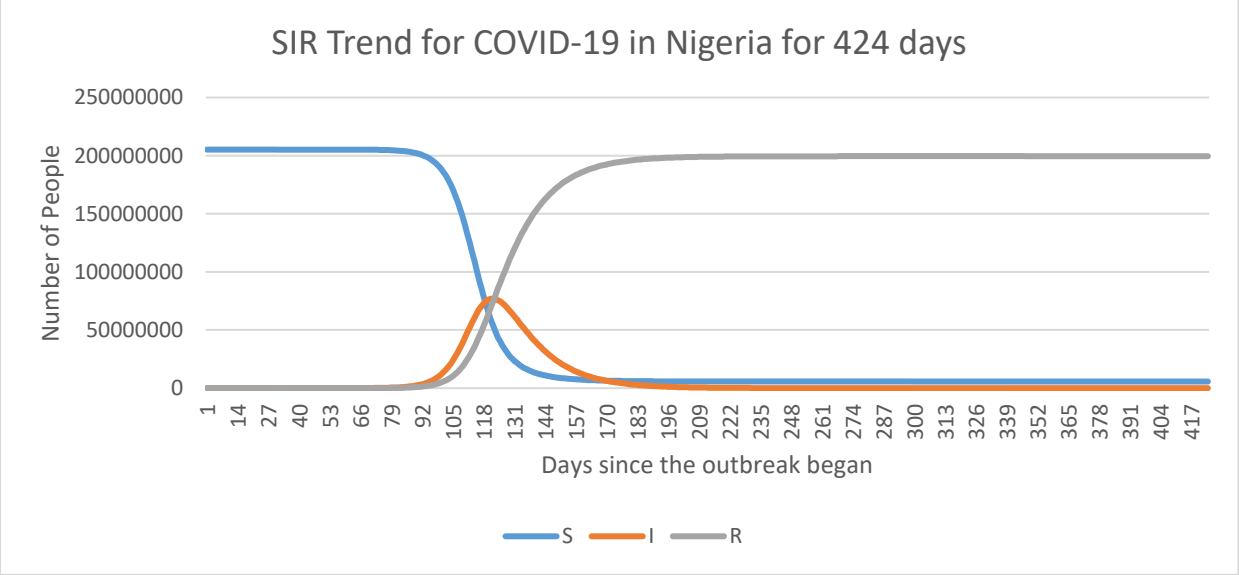
From the table above, one can see that from day 1, only one person was infected and zero (0) recovered, the susceptible decreases as the infective increases. Days 2 and 3 had 1.18 and 1.3924 infected cases which are approximately 1 for days 2 and 3 respectively but from the 4th day, approximately 2 persons tested positive and thus infected with the COVID-19 disease. On the 20th day, it had 23 infected persons, and approximately 7 (8.638946843) persons recovered. As on day 40, it can be seen that those that recovered are still not up to half of the infected persons and the susceptible is still on the decrease. Day 100 had 11,821,316 infected persons and the recovered is still less than half of the infected and the susceptible is fast decreasing in size. It is of utmost importance that the population size remains constant since, at any point, the addition of the susceptible, the infective, and the removed or recovered must equal the population size N. it is expected that as the days increase, the infective increases and so also the recovered. The graphs below show what the SIR trend would look like from day 1 to day 200 and day 1 to 424

Graph 2: The SIR Trend for COVID-19 in Nigeria



Source: Authors compilation

Graph 3



Source: Authors compilation

The X-axis on the graph shows the number of days since the COVID-19 outbreak in Nigeria while the Y-axis shows the number of people in each compartment. Our model started with a total population size of 205,218,214 but one (1) person was infected and thus the infective trend continues. The blue line indicates the susceptible, see day 103, there was a drastic and visible change with a susceptible figure of 179196548.8 approximately 179,196,549. From graph 2, one can see that the I and R series on day 103 is almost interwoven. Thus the trend line for a less infective disease can be seen slowly sloping to the right. The daily number of infected persons is depicted by the red line. The infected trend has a gradual growth, very slowly. It is actually the pandemic curve for the COVID-19 disease.

The Infective series reached its peak on day 122 with a total of 77,009,941 infected persons. At that point, the total number of infective was much more than the susceptible and the recovered was also greater than the susceptible, that is, 74,772,474.81. After day 122, the

infective series began to tail off while the R began to rise. Thus, it is natural that at a certain point, the number of recovered should exceed the infected and susceptible. Although from our graph, the first recovery occurred on day 6 which is approximately 1 person (0.500794683). The ash line represents the recovered. The R trend at day 125 with 90,832,629.81 persons recovered exceeded the infectious trend. The R trend increased until it was seen that the infective persons were far less than those that recovered. The recovered trend kept rising till it was almost the total population N. At day 198, with a total number of recovered persons at 198,375,562, susceptible persons at 5,818, 323, and infected at 1,024,328 approximately. The infected persons are much lower than the susceptible and the recovered.

From graph 3, the infective line kept tailing off till there wasn't any other case or cases recorded, thus, it became zero (0) at days 422, 423, and 424 respectively with values at 0.474042, 0.444153 and 0.416149 which approximately is zero (0). So at day 422, there are zero (0) infected persons, the recovered and susceptible are approximately 199,514,074 and 5,704,139 respectively. It can be seen that since there is no more COVID-19 infection, the susceptible are no longer going to be infected. From the graphs above, the COVID-19 pandemic will last 422 days from 27th February 2020, which is the day of inception in Nigeria and that means that the COVID-19 pandemic will record zero cases from on April 23, 2021. In a nutshell, the pandemic will no longer record any new cases from April 23rd, 2021.

Table 3 Comparison Table for the COVID-19 Pandemic in Nigeria

Date	Actual R values	Predicted R values	Date	Actual I values	Predicted I values
27/2/2020	0	0	28/2/2020	1	1
7/3/2020	0	1	8/3/2020	1	5
17/3/2020	1	9	18/3/2020	7	27
27/3/2020	3	47	28/3/2020	93	143
6/4/2020	35	247	7/4/2020	204	750
16/4/2020	153	1294	17/4/2020	317	3,927
26/4/2020	239	6773	27/4/2020	1,046	20,552
6/5/2020	534	35,443	7/5/2020	2,508	107,490

From Table 3 above, one can see the disparities that exist between the actual Recovered values and the predicted recovered values so also the actual infective values and its corresponding predicted values. From the table above, the disparities could imply that the values predicted by the Nigeria Centre for Disease Control may not actually be true values and this may be as a result of the NCDC not been able to possess and acquire enough testing kits that could be used to test more people. The idea is that their results are mainly based on samples tested. For day 27th February 2020, both actual and predicted values for both recovered and infective were the same, that is, zeros (0) and ones (1). As of 8/3/2020, the infective case was one (1) while predicted were 5 cases.

Discussion

In this study, the adjusted SIR model was applied to the COVID-19 pandemic ravaging the world today with special emphasis on Nigeria. The results showed that many people along the line will get infected if they don't adhere to the COVID-19 laid down rules. The Infective trend showed a gradual and slow movement. The recovered trend at some point exceeded the

infective and susceptible. It would actually take 422 days for the Nigeria Centre for Disease Control (NCDC) to cease recording any new case(s) of COVID-19 in Nigeria. Disparities also exist between the predicted and actual values but it is still on record that to be able to surmount this pandemic, the laid down COVID-19 rules of social distancing, use of face masks amongst others should be strictly adhered to. Several studies depict the effective nature of the SIR model, studies like [10,20,21] looked at the SIR parameters they were included in the model, they believed that the solution provided was an opening window in the area of epidemiology since it was difficult in achieving exact solution[20] while[21], though similar to the first study used a 2-dimensional grid with standard weighted least squares optimization problem to identify susceptible, infective and recovered individuals. The study by[10] also looked at the characteristics of 47 cases of MERS-CoV disease, their results showed that 46 adults and 1 child were infected although 45 of the adults had underlying diseases, only 2 were previously healthy. Thus, their findings show that most people that eventually died from the disease were a result of their underlying sickness.

Conclusion

The adjusted SIR model revealed that more people were infested over time than what the NCDC data portrayed. However, persons infected at a point were far less than those persons that recovered. The recovered trend kept rising though as the infective trend kept tailing off till days 422, 423, and 424 all recorded zero cases for infective. From the results, we were able to identify how many people were prone to be infected, how many were susceptible, and how many recovered at each point in time, referring to the time as days. We were able to also predict how long the pandemic will last if and only if the rules are followed strictly. It could also be seen that the COVID-19 pandemic will last for 422 days which is 1 year and 58 days, thus, from the day of inception in Nigeria. The findings from our work should assist the Nigerian government especially the NCDC in managing the COVID-19 outbreak properly by not totally relaxing the lockdown. Hospitals, markets, churches, banks, streets amongst others should be fumigated regularly. Surveillance should be more on the defaulters of the COVID-19 rules and due punishment should be melted out on them.

Conflict of Interest

None declared

References

1. Bogoch A, Watts A, Thomas-Bachli C, Huber MUG, Kraemer KK. Pneumonia of unknown etiology in Wuhan, China: Potential for International Spread via commercial air travel. *J Trav Med*. 2020. http://doi.org/10.1093/jtm/taaa008.

2. Lu H, Stratton CW, Tang YW. Outbreak of pneumonia of unknown etiology in Wuhan China: the mystery and the miracle. *J Med Virol*. 2020;92(4):401-402. http://doi.org/10.1002/jmv.25678.

3. Zhao S, Lin Q, Ran J, et al. Preliminary estimation of the basic reproduction number of

novel coronavirus (2019-nCoV) in China, from 2019 to 2020: a data-driven analysis in the early phase of the outbreak. *Int J Infect Dis*. 2020;92(Mar):214-217. doi:10.1016/i.ijid.2020.01.050

4. Wang D, Hu B, Hu C, et al. Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus-infected pneumonia in Wuhan, China. *JAMA*. 2020;323(11):1061-1069. doi:10.1001/jama.2020.1585

5. Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. *N Engl J Med*. 2020. https://doi.org/10.1056/NEJMoa2001316.

6. Wang W, Tang J, Wei F. Updated understanding of the outbreak of 2019 novel coronavirus (2019-nCoV) in Wuhan, China. *J Med Virol*. 2020;92(4):441-447. https://doi.org/10.1002/jmv.25689.

7. Ren LL, Wang YM, Wu ZQ, Xiang ZC, Guo L, Xu T. Identification of a novel coronavirus causing severe pneumonia in human: a descriptive study. *Chinese Med J*. 2020. https://doi.org/10.1097/CM9.0000000000000722.

8. Huang C, Wang Y, Li X, et al. Articles Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet*. 2020;395:497-506. doi:10.1016/S0140-6736(20)30183-5

9. Carlos WG, Dela Cruz CS, Cao B, Pasnick S, Jamil S. Novel Wuhan (2019-nCoV) Coronavirus. *Am J Respir Crit Care Med*. 2020;201:7-8. doi:10.1164/rccm.2014P7

10. Assiri A, Al-Tawfik JA, Al-rabeeah AA, et al. Epidemiological, demographic, and clinical characteristics of 47 cases of Middle East respiratory syndrome coronavirus disease from Saudi Arabia : a descriptive study. *Lancet Infect Dis*. 2013;13(September):752-761. doi:10.1016/S1473-3099(13)70204-4

11. Lee N, Hui D, Wu A, et al. A Major Outbreak of Severe Acute Respiratory Syndrome in Hong Kong. *N Engl J Med*. 2003;348(20):1986-1994. https://www.nejm.org/doi/pdf/10.1056/NEJMoa030685?articleTools=true.

12. NCIRD. Symptoms of Coronavirus. Centers for Disease Control and Prevention. https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/symptoms.html. Published 2020.

13. Amira F, Hamzah B, Lau CH, et al. CoronaTracker : Worldwide COVID-19 Outbreak Data Analysis and Prediction. *Bull World Heal Organ*. 2020;(March):1-32. doi:http://dx.doi.org/10.2471/BLT.20.255695

14. McMurtry A, Zampano G. COVID-19: What went wrong in Italy ad Spain? *AA News Broadcasting System*. https://www.aa.com.tr/en/europe/covid-19-what-went-wrong-in-italy-and-spain/1797461. Published April 8, 2020.

15. Rourke A. Coronavirus Outbreak: Trump warns China over COVID-19 outbreak as Europe approaches 100,000 deaths. *The Guardian*. https://www.theguardian.com/world/2020/apr/19/trump-warns-china-over-covid-19-outbreak-as-europe-approaches-100000-deaths. Published April 20, 2020.

16. JHU. COVID-19. *John Hopkins University*. https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6. Published April 21, 2020.

17. Abdur RAS. Coronavirus across Africa: 23,517 cases; 1,160 deaths; 6,116 recoveries. *Africanews.* https://www.africanews.com/2020/04/21/coronavirus-in-africa-breakdown-of-infected-virus-free-countries/. Published April 22, 2020.

18. NCDC. Updates on COVID-19. Nigeria Centre for Disease Control. https://covid19.ncdc.gov.ng/. Published 2020.

19. Kermack WO, Mckendrick AG. A contribution to the mathematical theory of epidemics. *R Soc*. 1927;115(772). https://doi.org/10.1098/rspa.1927.0118.

20. Shabbir G, Khan H, Sciences E, Sadiq MA. A note on Exact solution of SIR and SIS epidemic models. *arXiv*. 2010;(January 2014):1-6.

21. Calafiore GC, Novara C, Possieri C. A Modified SIR Model for the COVID-19 Contagion in Italy. *Physics.soc-ph*. 2020:1-6.

22. Diaz P, Constantine P, Kalmbach K, Jones E, Pankavich S. A modified SEIR model for the spread of Ebola in Western Africa and metrics for resource allocation R. *Appl Math Comput*. 2018;324:141-155. doi:10.1016/j.amc.2017.11.039

23. Sajid M, Abbas Z, Ali N, Javed T. A Note on Solutions of the SIR Models of Epidemics Using HAM. *ISRN Appl Math*. 2013;2013(1):1-5.