Analyzing the Sensitivity of Coronavirus Disparities in Nigeria Using a Mathematical Model

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Abstract

In this paper, we analyzed the sensitivity of coronavirus disparities in Nigeria using a dynamical mathematical model. Due to the government implementing strict measures such as banning public gatherings, closing places of worship and businesses and encouraging social distancing, we looked closely at the statistics and developed a mathematical model that showed the possible control of this virus and thereby preventing an individual getting infected with the virus. The method of solution involves the first and second sensitivities with a fixed population size that is no further births or migration and the only deaths infections are taken due to baby infections with indication on the initial infected population. The first sensitivity is solved using method separation of variables whose COVID-19 profiles were sketched using ODE45. Obtaining the second sensitivity gives a non-linear ordinary differential equation which is used to determine the behavior of the fixed population size. If the second sensitivity greater than zero then the COVID-19 patients steadily decreases to zero while if the second sensitivity less than zero then the COVID-19 patients steadily increases and reach maximum. After this maximum point the number of COVID-19 patients decreases and tends to zero. In either case, the COVID-19 patients tends to extinction. The mathematical model showed that the control of this virus is possible.

Keywords: *COVID-19; NCDC Nigeria; COVID-19 profile; First sensitivity; Initial infected population; Logistic growths; Mathematical modelling; Second sensitivity*

1. Introduction

According to the World Health Organization (WHO), COVID-19 is a novel strain of coronavirus first identified in Wuhan, China in late 2019 that has now spread to more than 200 countries and territories across the globe. On December 31, 2019 in Bogoch et al. (2020), Ge et al. (2020), Guan et al. (2020) and Page et al. (2021), the World Health Organization (WHO) was informed of a typical pneumonia cases in Wuhan. These cases were later identified to be the first official cases of COVID-19, a novel infectious disease caused by a new coronavirus that had not previously been identified. Since then, the virus has gone on to spread to countries around the world and has caused a global pandemic. In NCDC Nigeria (retrieved, 2023), the most recent data from the WHO suggests that over 91 million cases and nearly 2 million deaths have been recorded worldwide as of February 2021. In Naresh et al. (2023), a spread of an infectious diseases has caused tremendous impairment to the human population.

In line with Huang et al. (2020), they carried out epidemiological, clinical, laboratory, and radiological characteristics and treatment and clinical outcomes of the admitted suspected 2019 novel coronavirus (2019-nCoV) in a designated hospital in Wuhan. They reported that by January 2, 2020, most infected patients by the coronavirus were men (30 [73%] of 41). Some common symptoms of this virus by onset of illness were fever (40 [98%] of 41 patients), cough (31 [76%]), and myalgia or fatigue (18 [44%]) while as sputum production (11 [28%] of 39), headache (3 [8%] of 38), hemoptysis (2 [5%] of 39) and diarrhea (1 [3%] of 38) patients were less common symptoms. All the 41 patients had pneumonia.

On 7 January 2020, Ge et al. (2020) identified that a novel coronavirus named as Severe Acute Respiratory Syndrome (SARS) CoronaVirus-2 (SARS-CoV-2) was found in the throat swab sample of one patient. In Yi et al. (2020), COVID-19 caused by SARSCoV-2 has thus far killed over 3,000 people and infected over 80,000 in China and elsewhere in the world, resulting in catastrophe for humans.
Guan et al. (2020) extracted data on the clinical characteristics of the affected patients regarding 1099 patients with laboratory-confirmed COVID-19 from 552 hospital in 30 provinces, autonomous regions and municipalities in mainland China through January 29, 2020. They found out that diarrhea (3.8%) was uncommon symptom of the virus.

COVID-19, caused by the novel coronavirus SARS-CoV-2, has been a major global health concern since its emergence in late 2019. According to the Nigeria Centre for Disease Control (NCDC), the first case of COVID-19 in Nigeria was confirmed on February 27, 2020. Since then, there have been a total of 266,313 confirmed cases of COVID-19, 259,027 recoveries, and 3,155 fatalities as of Epi Week 7 – 8: 13th – 26th February, 2023.

The current number of active cases in Nigeria stands at 3,567. The states with the highest number of COVID-19 cases are Lagos (104,286), FCT (29,535), Rivers (18,112), Kaduna (11,675), Plateau (10,365), Oyo (10,352) and Edo (7,928) (covid19.ncdc.gov.ng, November, 2023).

The NCDC has been providing real-time updates to citizens and stakeholders on trends in the spread of the virus in Nigeria, including the number of cases, recovery and death rates, as well as advisories and preventive measures to be taken.

This paper analyzed the sensitivity of coronavirus disparity in Nigeria using mathematical model which has not been identified or used in recent papers. The model solved for the first sensitivity. By equalizing it to zero, 0 gives the critical point(s). In line with Okeke et al. (2019), a critical point also called the stationary point is the argument of a function where the derivative is zero. The value of the function at a critical point is a critical/stationary value. If the second sensitivity greater than zero, 0 then the COVID -19 patients steadily decreases to zero, 0 while if the second sensitivity less than zero, 0 then the COVID-19 patients steadily increases and reach maximum. After this maximum point the number of COVID-19 patients decreases and tends to zero, 0. In either case, the COVID-19 patients tends to extinction. The mathematical model shows that the control of this virus is possible. In line with Verma et al., 2023, COVID-19 has significant human-to-human transmission and that maximum cases of COVID-19 infection has minimal symptoms and self-covering.

The risk levels of socio-economic vulnerability for Nigeria's states indicates that there are disparities in socio-economic vulnerability between the different regions of the country. For example, the Northwest region has comparatively more difficulty in improving access to basic services, such as health care, education, and economic opportunity. These disparities can potentially lead to further marginalization of already vulnerable people in areas with higher risk levels. In Odor et al. (2020), controlling infection is used as a primary public healthcare intervention to prevent the spread of SAR-CoV-2.

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2. Methodology and Materials

The data COVID-19 collection sets in Nigerian states were obtained from NCDC (covid19.ncdc.gov.ng, November, 2023) of the distributions of the Nigerian States datasets showing number of: lab confirmed, on admission, discharged and death cases.

The first sensitivity of the modelled problem is solved using Separation of Variables method. Obtaining the second sensitivity gives a non-linear ordinary differential equation which is used to determine the behavior of $P(x)$. If the second sensitivity > 0 then the COVID-19 patients steadily decreases to zero, 0 while if the second sensitivity < 0 then the COVID-19 patients steadily increases and reach maximum.

3. Formulation of Model

Let $P(x)$ be the number of patients infected with COVID-19, $Q(x)$ be the number of patients not infected with COVID-19. If no other number of patients are added to the population, q_0 (represents the initial infected population) then:

$$P(x) + Q(x) = constant = P(0) = q_0 \quad (1)$$

Therefore,

$$Q(x) = q_0 - P(x) \quad (2)$$

Introducing the constant of proportionality, $k > 0$ and $\frac{dP(x)}{dx} \propto P(x)Q(x)$ to get:

$$\frac{dP(x)}{dx} = kP(x)Q(x) \quad (3)$$

Or from the equation (2), equation (3) becomes:

$$\frac{dP(x)}{dx} = kP(x)[q_0 - P(x)] \quad (4)$$

Or

$$\frac{dP(x)}{dx} = kP(q_0 - P) \quad (5)$$

(5) gives the First Sensitivity.

At the Critical Point(s): The equation (5) becomes:

$$\frac{dP(x)}{dx} = 0 = kP(q_0 - P) = 0 \quad (6)$$

Therefore,

$$kP(q_0 - P) = 0, k \neq 0 \quad (7)$$

such that

$$P(q_0 - P) = 0 \quad (8)$$

Therefore,

$$P = 0 \text{ or } P = q_0 \quad (9)$$

The Second Sensitivity becomes:

From equation (5): $\frac{dP(x)}{dx} = kPq_0 - kP^2$

Therefore,

$$\frac{d^2P}{dx^2} = kq_0\frac{dP(x)}{dx} - 2kP\frac{dP(x)}{dx} \tag{10}$$

For the retardation in Sharma et al. (2022), let α denotes the rate of increase of infection and β denotes the retardation of infections with $\lambda = \alpha - \beta$ then the rate of change of number of infected COVID -19 patients in an area is:

$\frac{\Delta P(x)}{\Delta x} = \frac{P(x+\Delta x)-P(x)}{\Delta x}$ so that:

$$\lim_{\Delta x\to 0}\left(\frac{\Delta P(x)}{\Delta x}\right) = \lim_{\Delta x\to 0}\left(\frac{P(x+\Delta x)-P(x)}{\Delta x}\right) \to \frac{dP(x)}{dx} = \lambda P(x) \tag{11}$$

Solving equation (11) with the method of separation of variable to get:

$$\int \frac{dP(x)}{P(x)} = \int \lambda dx$$

$InP(x) = \lambda x + \epsilon, \epsilon$ is the constant of integration.

Or $InP(x) = \lambda x + In\epsilon_1$

Therefore, $\lambda x = In\frac{P(x)}{\epsilon_1}$

$$\frac{P(x)}{\epsilon_1} = e^{\lambda x}$$

Or

$P(x) = \epsilon_1 e^{\lambda x}$ gives an exponential function. (12)

4. Numerical Simulation

From equation (10) at $P = 0$ and $P = q_0$, the second sensitivity gives:

$$\frac{d^2P}{dx^2} = kq_0\frac{dP(x)}{dx} > 0 \tag{13}$$

and

$$\frac{d^2P}{dx^2} = kq_0\frac{dP(x)}{dx} - 2kq_0\frac{dP(x)}{dx} \tag{14}$$

$$\Rightarrow \frac{d^2P}{dx^2} = -kq_0\frac{dP(x)}{dx} < 0 \tag{15}$$

respectively.

This property shows that $P = 0$ gives the minimum point of the infected COVID-19 patients and $P = q_0$ gives the maximum point of the infected COVID-19 patients.

With the initial population, q_0 =1 in NCDC Nigeria (retrieved, 2023), the solution to the model are depicted as shown in Figures 1 – Figure 5 below using ODE45 of 7 days, 10 days, 14 days, 15 days and 28 days at various constants in given time span (days).

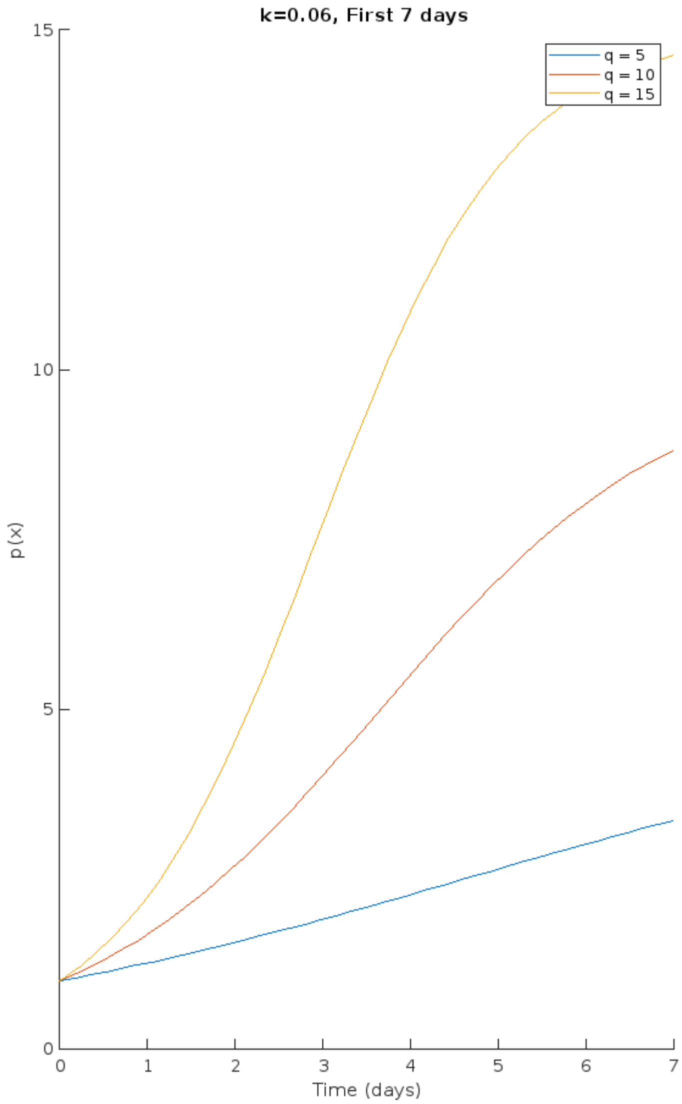

Figure 1: A Covid-19 profile showing the first 7 days on the growth of P(x)

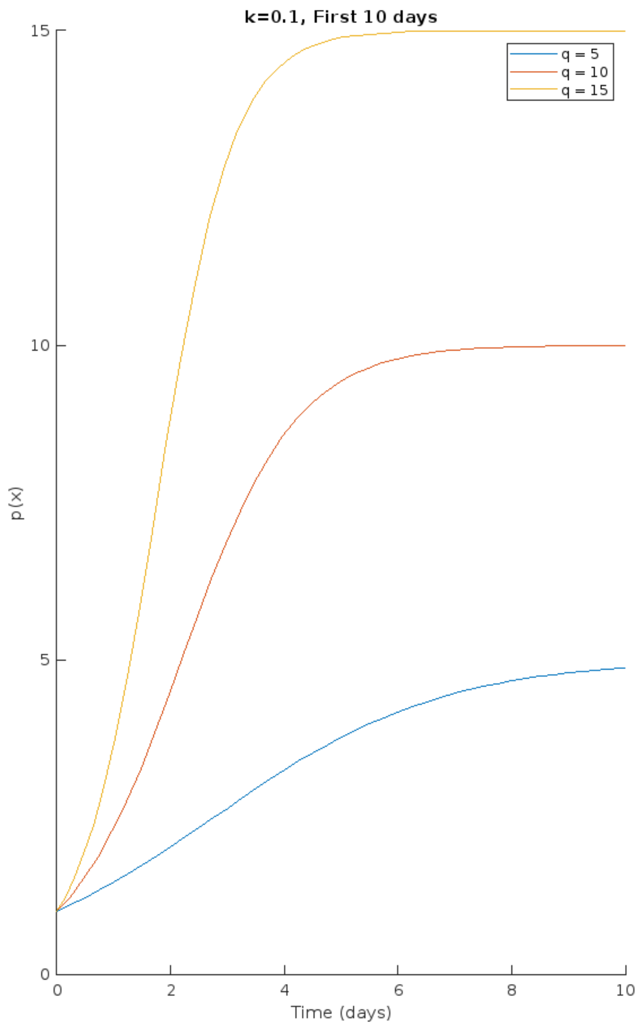

Figure 2: A Covid-19 profile showing the first 10 days on the growth of P(x)

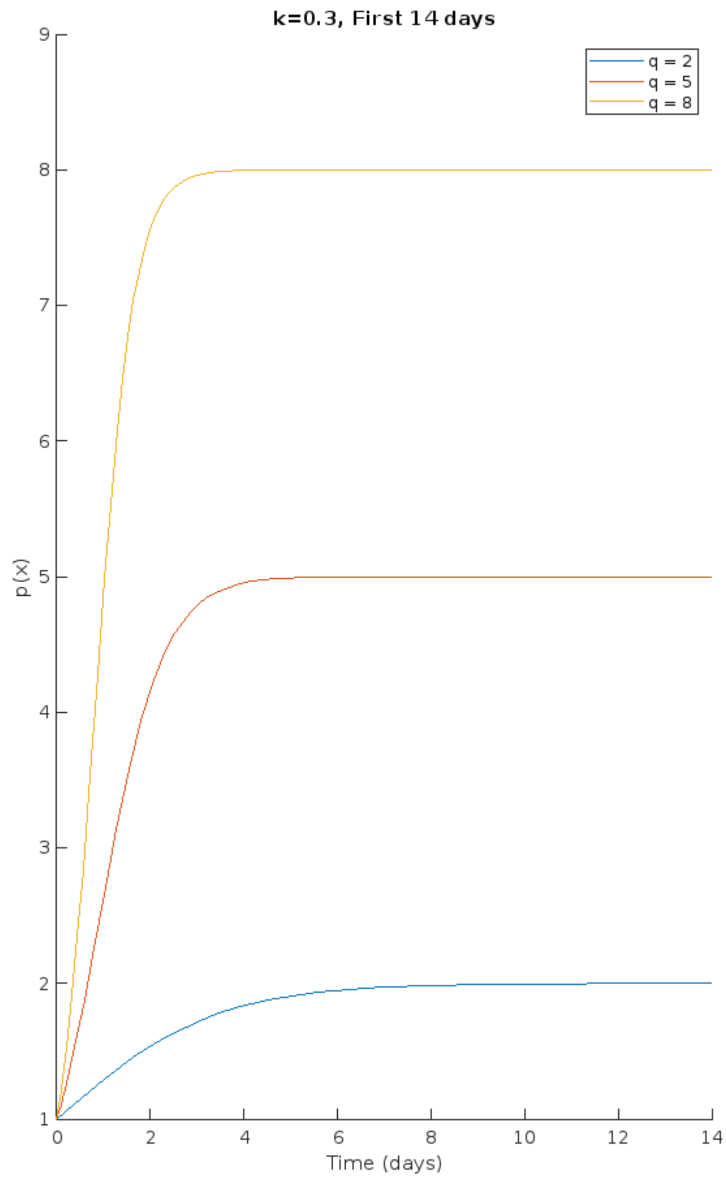

Figure 3: A Covid-19 profile showing the first 14 days on the growth of P(x)

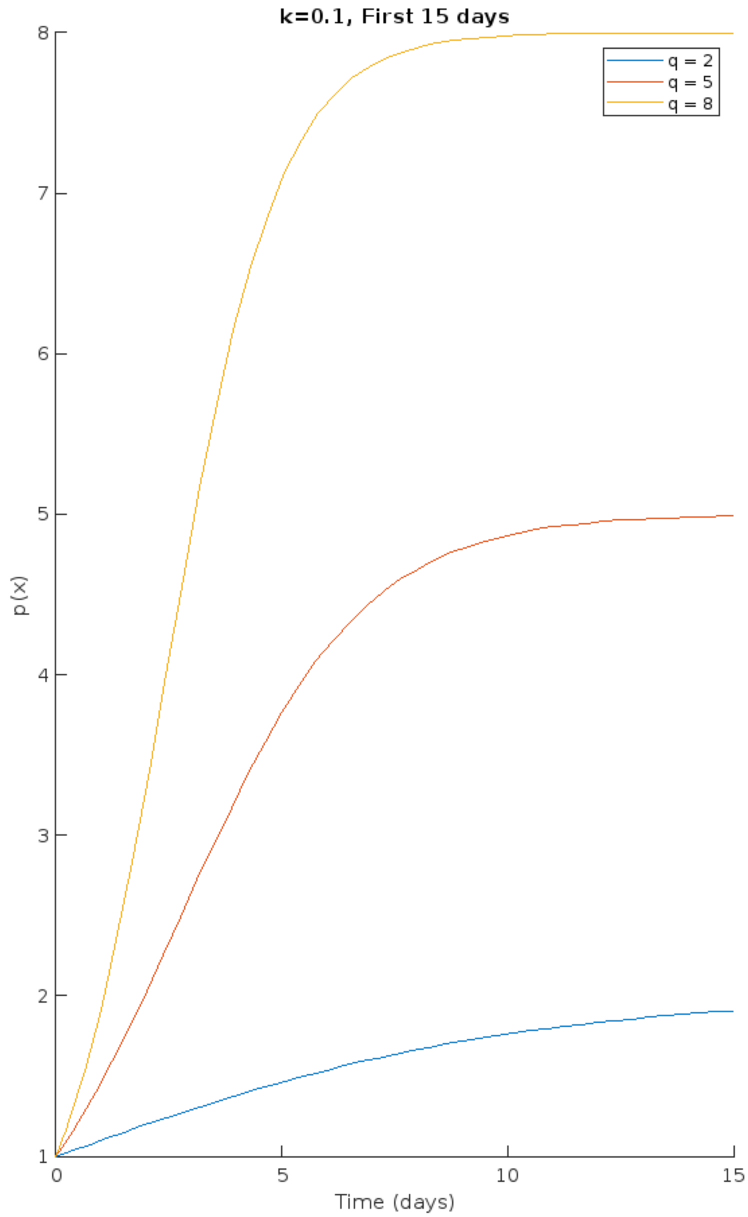

Figure 4: A Covid-19 profile showing the first 15 days on the growth of P(x)

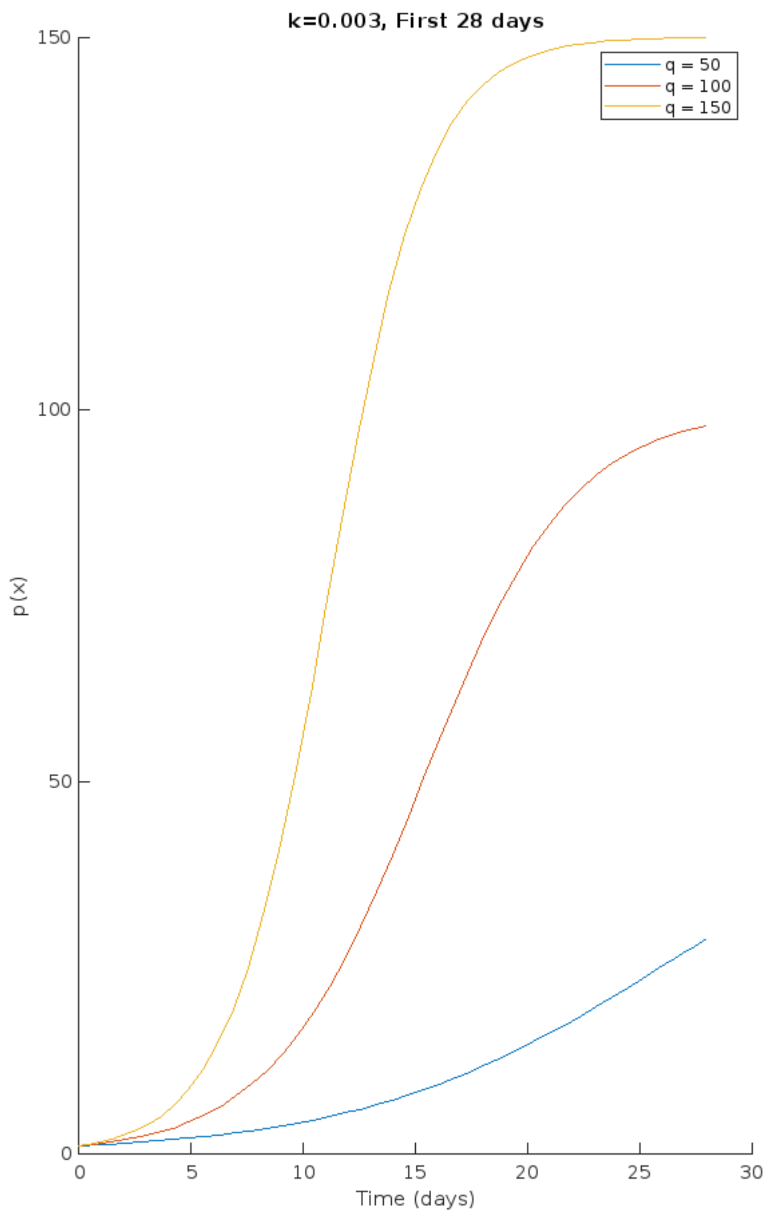

Figure 5: A Covid-19 profile showing the first 28 days on the growth of P(x)

5. Conclusion

The figures showed the logistic population growths which occurred when the growth rates decreased as the population reaching their carrying capacity. The mathematical model has showed that the control of this COVID-19 virus is possible. The paper has also assessed the available data on coronavirus-related cases of COVID-19 in Nigeria and investigated ways to reduce the occurrence of COVID-19 cases by using a mathematical model. The mathematical model is beneficial and create positive impact to all people. The first sensitivity being equal to zero, 0 gives the critical point(s). If the second sensitivity evaluated at this critical point, P equals 0 gives a quantity greater than zero, 0 then the COVID-19 patients steadily decreases to zero, 0 while if the second sensitivity evaluated at this critical point, P equals q_0 gives a quantity less than zero, 0 then the COVID-19 patients steadily increases and reach maximum. After this maximum point the number of COVID-19 patients decreases and tends to zero, 0. In either case, the COVID-19 patients tends to extinction.

Due to the potential disparities among the vulnerable people in areas with higher risk levels, it is important to reduce the risk levels of socio-economic vulnerability for all of Nigeria's states.

1. To accomplish this, Nigeria's government and other organizations should invest in initiatives to support social and economic development in areas with higher risk levels (with percentage mean greater than or equal to 1.860, especially in the 18 states).

2. Government and other organizations should incentivize businesses to invest in the areas.

3. Additionally, it is important to ensure proper representation in government so that those especially vulnerable people have their voices heard.

4. Overall, their risk levels of socio-economic vulnerability shows an inequality between the different regions of the country. It is important to recognize this and work to reduce the risk levels of socio-economic vulnerability for all of Nigeria's states.

5. By identifying the wards with the highest risk levels of socio-economic vulnerability, policy makers and local governments can better target resources in order to improve the quality of life in these wards.

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Table 1: Percentage of number of discharged and death cases in Nigerian States

S/No.	States Affected	% No. Discharged	% No. of Deaths
1	Lagos	99.25249411	0.74750589
2	FCT	99.15667547	0.843324528
3	Rivers	99.14435551	0.855644494
4	Kaduna	99.23749143	0.762508568
5	Plateau	99.27613165	0.723868352
6	Oyo	98.04868624	1.951313756
7	Edo	95.93844601	4.061553986
8	Delta	97.87959106	2.120408936
9	Ogun	98.5859631	1.414036903
10	Kano	97.65596161	2.344038391
11	Ondo	97.7562783	2.243721696
12	Akwa Ibom	99.12070344	0.879296563
13	Kwara	98.49020996	1.509790045
14	Gombe	98.00302572	1.996974281
15	Osun	97.1968312	2.8031688
16	Enugu	99.01326982	0.98673018
17	Nasarawa	98.36409396	1.63590604
18	Anambra	99.31630083	0.683699172
19	Imo	97.8422619	2.157738095
20	Ekiti	98.86455799	1.135442011
21	Kastina	98.46980976	1.53019024
22	Benue	98.87842082	1.121579183
23	Abia	98.4975696	1.502430402
24	Ebonyi	98.42829077	1.571709234
25	Bauchi	98.8153998	1.184600197
26	Borno	97.29064039	2.709359606
27	Taraba	97.71043771	2.28956229
28	Bayelsa	97.95769511	2.042304887
29	Adamawa	96.77419355	3.225806452
30	Niger	98.03536346	1.964636542

31	Cross River	97.36008448	2.639915523
32	Sokoto	96.59367397	3.406326034
33	Jigawa	97.30134933	2.698650675
34	Yobe	98.58044164	1.41955836
35	Kebbi	96.59574468	3.404255319
36	Zamfara	97.6	2.4