

COVID-19 outbreak, social distancing and mass testing in Kenya - Insights from a mathematical model

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Abstract

As reported by the World Health Organization (WHO), the world is currently facing a devastating pandemic of a novel coronavirus (COVID-19), which started as an outbreak of pneumonia of unknown cause in the Wuhan city of China in December 2019. Since then, the respiratory disease has exponentially spread to over 210 countries. By the end of April, COVID-19 had caused over three million confirmed cases of infections and over 200,000 fatalities globally. The trend poses a huge threat to global public health. Understanding the early transmission dynamics of the infection and evaluating the effectiveness of control measures is crucial for assessing the potential for sustained transmission to occur in new areas.

We employed a SEIHQRD delay differential mathematical transmission model with reported Kenyan data on cases of COVID-19 to estimate how transmission varies over time and which population to target for mass testing. The model is concise in structure, and successfully captures the course of the COVID-19 outbreak, and thus sheds light on understanding the trends of the outbreak and the vulnerable populations. The results show that, the government should target population in the informal settlement for mass testing and provide affordable sanitizers and clean water to this population. The model results also indicate that people with pre-existing non-communicable diseases (NCDs) should be identified and given special medical care. Given the absence of vaccine at the moment, non-pharmaceutical intervention over a relatively long period is needed to effectively reduce the final epidemic size.

Keywords: : COVID-19; SEIHQRD-model, Social distancing, mass testing, incubation period, delay differential equations, probability of survival, simulations

1 Introduction

The world is currently facing a devastating pandemic of a novel coronavirus (COVID-19), which started as an outbreak of pneumonia of unknown cause in the Wuhan city of China in December 2019. The disease has killed many, altered the definition of normalcy and collapsed economies since it was first reported. It had infected at least 3,150,478 people by April 29, 2020 with the total number of deaths standing at 218,466 and that of recoveries at 964,161 and had affected 213 countries worldwide according world health organization (22). Meanwhile, the number of coronavirus infections in Africa was 35,843 and the deaths 1,530. In Kenya which houses a population of over 47 million, the number of people tested of the virus by April 29, 2020 were 18,597

with 384 cases, 129 recoveries and 15 deaths (22). In February 2020, WHO declared the disease COVID-19, a global pandemic (23). The number of deaths associated with COVID-19 greatly exceed those due to the other two corona viruses (severe acute respiratory syndrome coronavirus; SARS-CoV, and Middle East respiratory syndrome coronavirus; MERS-CoV), and the outbreak is still ongoing, which poses a huge threat to the global public health and economics (13; 18)

Coronaviruses are enveloped single-stranded RNA viruses that are zoonotic in nature (1). The virus is thought to spread mainly from person-to-person. It spreads between people who are in close contact with one another (within about 6 feet of each other). The respiratory droplets produced when an infected person coughs or sneezes can land in the mouths or noses of people who are nearby or possibly be inhaled into the lungs (24). People are thought to be most contagious when they are most symptomatic (the sickest). For some diseases, people start spreading the virus several days before they have any noticeable symptoms; there have been reports of this occurring with SARS-COV-2 (25).

SARS-COV-2 also spreads through contact with contaminated surfaces or objects. Unsuspecting people may become infected by touching these contaminated objects or surfaces, then touching their eyes, noses or mouths before cleaning their hands (25). Recovery from the disease depends on the strength of the immune system. Most people infected with the COVID-19 virus will experience mild to moderate respiratory illness (about 80%) and recover without requiring special treatment (24). However, for older people, and those with underlying medical problems like cardiovascular disease, diabetes, chronic respiratory disease, and cancer are more likely to develop serious illness (9; 28). How easily a virus spreads from person-to-person can vary. Some viruses are highly contagious (spread easily), like measles, while other viruses do not spread as easily. Another factor is whether the spread is sustained, spreading continually without stopping. The virus that causes COVID-19 seems to be spreading easily and sustainably in the community (*community spread*) in some affected geographic areas.

According to the WHO, the four most common symptoms of COVID-19 are fever, fatigue, shortness of breath and a dry cough. Some patients may also have a runny nose, sore throat, nasal congestion and aches and pains or diarrhoea (21). The Kenyan government has adopted extreme measures to mitigate COVID-19 outbreak. On March 15, 2020, the government closed all the schools, banned public gatherings, and closed all inbound and outbound air transportation. The public panic in face of the ongoing COVID-19 outbreak reminds us the history of the 1918 influenza pandemic in London, United Kingdom (14).

In the early stages of a new infectious disease outbreak, it is crucial to understand the transmission dynamics of the infection. Estimation of changes in transmission over time can provide insights into the epidemiological situation and help identify whether outbreak control measures are having a measurable effect. Such analysis can inform predictions about potential future growth, help estimate risk to other counties, and guide the design of alternative interventions. Mathematics, being the universal language of nature/universe and the foundation of all the natural and engineering sciences, has historically been used to gain realistic insight into the transmission dynamics and control of emerging and re-emerging infectious diseases of public health interest (16).

A simple mathematical model was used to trace the temporal course of the South Korea Middle East Respiratory Syndrome Coronavirus (MERS-CoV) outbreak (7). Further, a mathematical model for MERS-CoV transmission dynamics was used to estimate the transmission rates in two

periods due to the implementation of intensive interventions(4; 12). A mathematical model for corona virus incorporating the interaction between bats and humans was developed (11). The model described the interaction among the bats and unknown hosts, then among the peoples and the infections reservoir which was further improved by considering optimal control (19). (17) used an age-structured susceptible-exposed-infected-removed (SEIR) model to predict the trajectory of COVID-19 outbreak in Wuhan, their projections showed that physical distancing measures were most effective if the staggered return to work started at the beginning of April. An improved dynamic SEIR model was developed to predict COVID-19 epidemic peaks and sizes in China (26; 29). Further a mathematical model was suggested taking into account the possibility of transmission of COVID-19 from dead bodies to humans and the effect of lock-down (2).

Other authors used clinical mathematical modeling technique for explaining the disease outbreak (18). In this study, we extended the work of (14) by incorporating the impact of aggressive mass testing and time delay from exposure to onset of symptoms. We note that the governmental action in Kenya, summarizes all measures including school closure, wearing of masks, social distancing, city lockdown, mass testing, hospitalization and quarantine of patients. The parameter values may be improved when more information is available. Nevertheless, our model is a preliminary conceptual model, intending to lay a foundation for further modelling studies, but we can tune our model so that the outcomes of our model are in line with previous studies (3–5; 8; 15; 27).

The rest of the paper is organized as follows: in Section 2, we describe the formulated model. In Section 3, we carry-out model analysis including equilibrium analysis. The model is fitted to COVID-19 data in Section 4. The effects of social distancing and mass testing are also investigated in Section 4. In Section 5, we provide dicussions and recommendations.

2 Model Description and Formulation

2.1 Model Assumptions

In this study, an SEIHQRD model is used with the following assumptions:

- We assumed Kenya to be a closed system with a constant population size of 47 million (that is , $S+E+I+Q+H+R+D=47$ million) throughout the course of the epidemic.
- Homogeneous population. Each individual has the same opportunity to make contact with other individuals.
- The spread of the coronavirus only occurs between humans to humans.
- Coronavirus has an incubation period of 14 days.
- Individuals affected by COVID-19 can recover.
- Demographic changes in the population (that is, births, deaths, and ageing) are ignored.

First we present a framework diagram of the COVID-19 infection dynamics.

2.2 Model Framework

Figure 1 shows the flow of COVID-19 infection in a population.

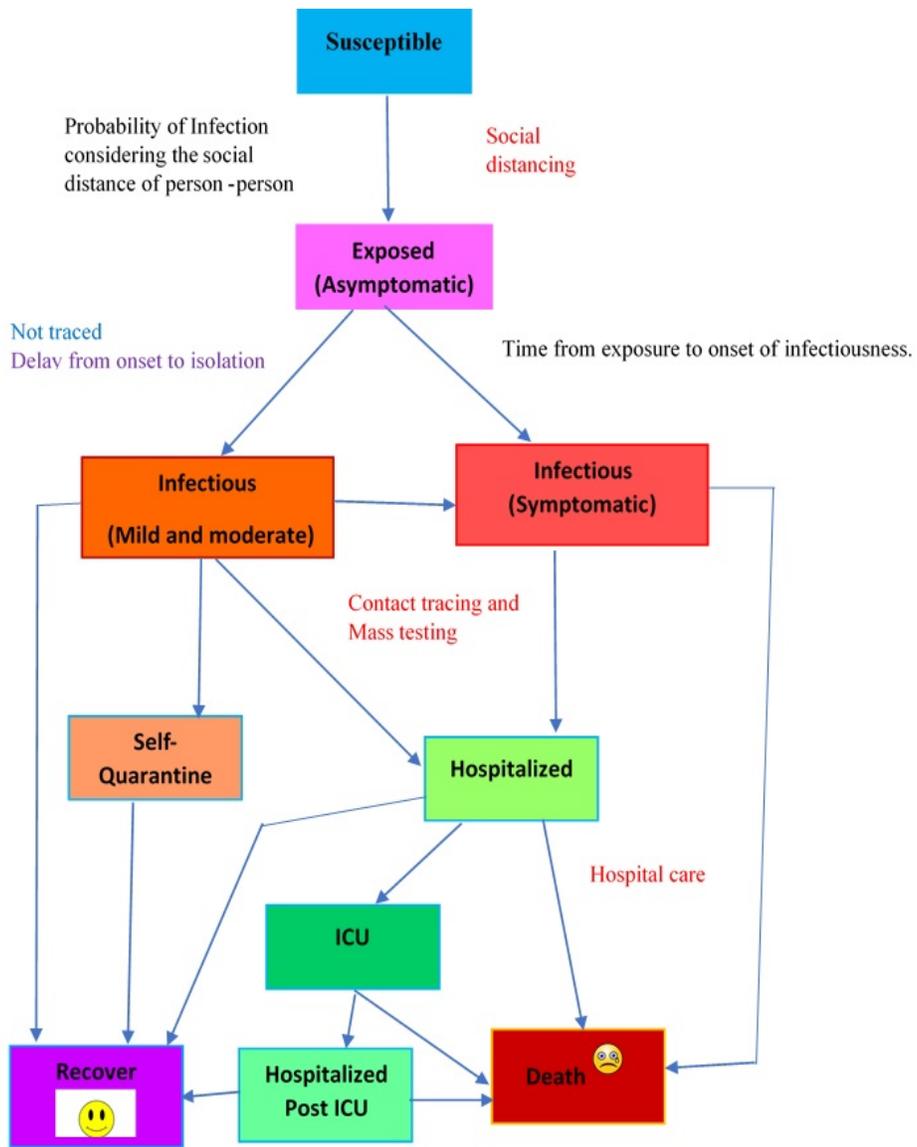


Figure 1: *The Model structure of COVID-19 transmission*

Figure 2 shows the framework of mathematical model

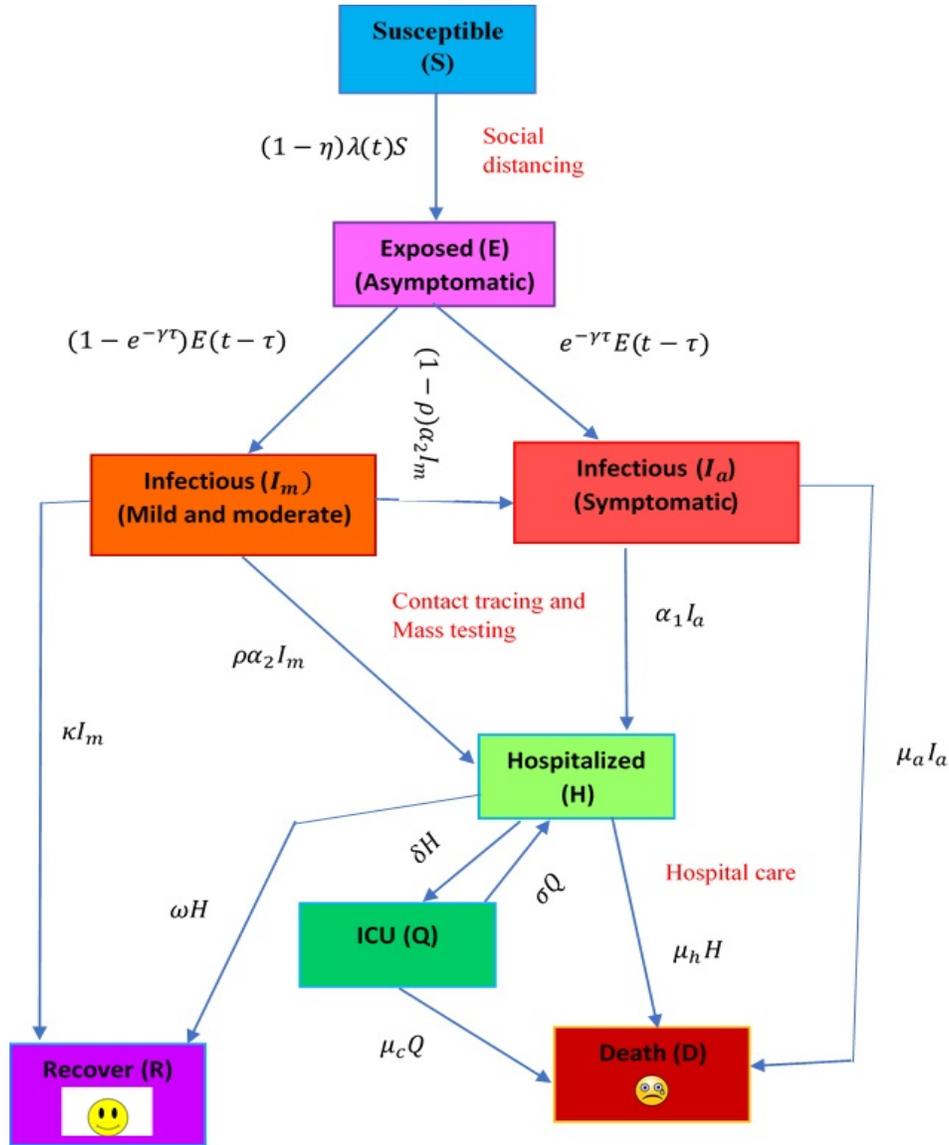


Figure 2: *The Mathematical Model Framework*

2.3 Model Formulation

To describe the dynamics of COVID-19 in Kenya, we develop an eight disease state compartmental SEIHQRD- delay differential model describing the movement of individuals from one state to another starting from the susceptible class S . For the sake of simplicity we assume that, at each time, the population inside a territory is homogeneously distributed (this can be improved by dividing some territories into a set of smaller regions with similar characteristics)(10). Susceptible are all Kenyan population who are at risk of getting the infection, that is, individuals with no history of infection by the disease. When the Susceptible interact with infected individuals they get infected with the virus and move into compartment E , referred to as exposed. Here we let η to be the probability of keeping the desired social distance between individuals. When $(\eta = 1)$, it means the distance between person -person is atleast 1 meter otherwise the probability will be less than 1 $(\eta < 1)$. $\lambda(t)$ represents force of infection from different infectious classes. Exposed are those who have just contracted the disease and are not yet infectious (Asymptomatic), those

at latent stage as shown in Figure 3. After 4-5 days, the exposed start developing symptoms but depending on ones immunity, the development of the symptoms can delay.

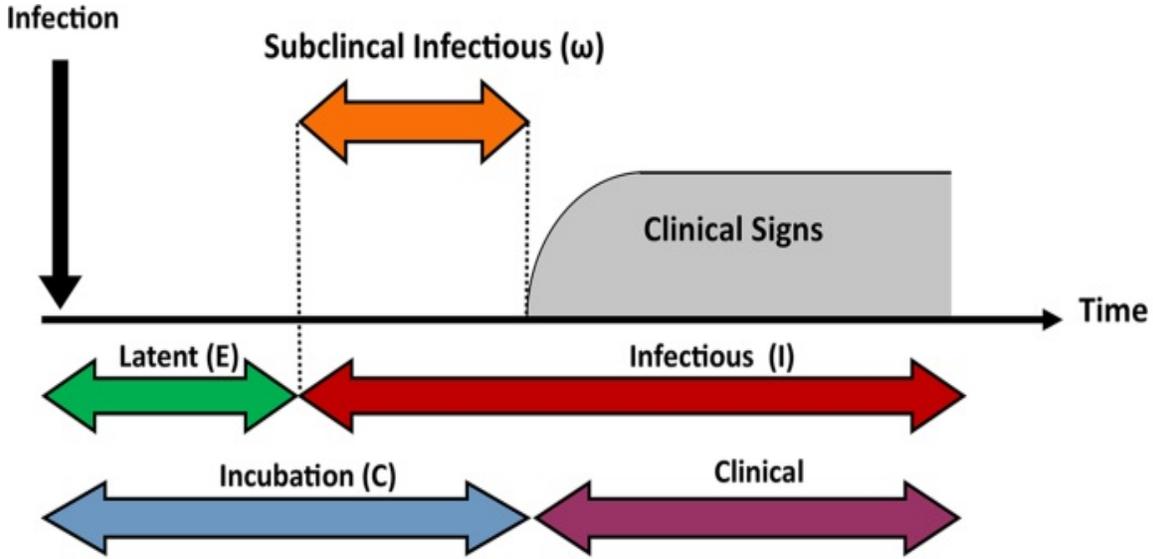


Figure 3: *COVID-19 progression periods*

The term $e^{-\gamma\tau}$ is the probability of an exposed person surviving to being infectious in 4-5 days (latent period). $\frac{1}{\tau}$ is the incubation period that represent the length of time before the infected individuals can become infectious. Those who develop symptoms immediately move to severe infectious class (symptomatic) denoted by compartment I_a . People with pre-existing non-communicable diseases (NCDs) are more vulnerable to becoming severely ill with the virus. These NCDs include: Cardiovascular disease, Chronic respiratory disease, Diabetes, Cancer, and also smokers. Those who have their symptoms delayed due to strong immune system move to mild infectious class (asymptomatic) denoted by I_m . Both individuals in I_a and I_m are infectious though those in I_m have not developed symptoms. The severe individuals are more infectious than the mild ones. The severe individuals can be recognized and taken to hospital /isolation Centres but others die or commit suicide before getting to hospital. The persons with mild infections are the problem and the contact tracing and mass testing should be targeting this population. Depending on ones immunity, some can recover from the disease, others can become severe and move to severe class or others are traced and taken to hospital. Infected cases are traced and effectively tested with probability ρ . Once infected, an individual can be discovered by the detection system either by random screening (mass testing) or by contact-tracing. The infected individuals will take themselves to be hospitalized or quarantine themselves at home. Those who get hospitalized move to class H . The hospitalized can get worse and move to ICU class denoted as Q or recover and move to compartment R . The last class is the Death, represented by compartment D containing those who succumb to COVID-19.

The total population at any time t , is denoted by $N(t)$ and is given by

$$N(t) = S(t) + E(t) + I_m(t) + I_a(t) + H(t) + Q(t) + R(t) + D(t). \quad (1)$$

The rate of generation of new COVID-19 cases is modelled by $\lambda(t)S$, where $\lambda(t)$ is the force of

infection given by

$$\lambda(t) = \frac{(\beta_1 I_m(t) + \beta_2 I_a + \beta_3 H(t) + \beta_4 Q(t))}{N(t)}. \quad (2)$$

2.4 Description of the variables and parameters used in the model

The variables and parameters description for the model are summarized in Tables 1 and 2 :

Table 1: Summary of variables in the concept model

Variable	Description
S	Susceptible population
E	Exposed population
I_a	Infective population with COVID-19 symptoms
I_m	Mild symptomatic population
H	Hospitalized population
Q	Population in ICU
R	Recovered population
D	Dead people

Table 2: Description of Parameters for the model

Parameter	Description
ρ	probability of effective and aggressive mass testing
κ	rate of recovery of the mild infected individuals
β_1	Effective contact rate between susceptible and severe infected individuals .
β_2	Effective contact rate between susceptible and mild infected individuals .
β_3	Effective contact rate between susceptible and hospitalized individuals
β_4	Effective contact rate between susceptible and those in ICU
γ	transition rate from exposed to infectious individuals
α_1	hospitalization rate of the severe infected individuals
α_2	transition rate from the mild infections to severe infections
ω	recovery rate after treatment
δ	transfer rate to ICU
σ	recovery rate from ICU
η	probability of keeping the desired social distance
μ_a	death rate of non-hospitalized severe infected due to COVID-19
μ_h	death rate of the hospitalized due to COVID-19.
μ_q	death rate of those in ICU due to COVID-19.
$\frac{1}{\tau}$	the incubation period

Given the flow diagram in Figure 1, the parameter description in Table 2, and using Equation (2), we have the following system of non-linear ordinary differential equations:

$$\begin{aligned}
\frac{dS(t)}{dt} &= -(1 - \eta)\lambda(t)S(t), \\
\frac{dE(t)}{dt} &= (1 - \eta)\lambda(t)S(t) - \gamma E(t), \\
\frac{dI_a(t)}{dt} &= (1 - \rho)\alpha_2 I_m(t) + e^{-\gamma\tau} E(t - \tau) - \alpha_1 I_a(t) - \mu_a I_a(t), \\
\frac{dI_m(t)}{dt} &= (1 - e^{-\gamma\tau}) E(t - \tau) - \alpha_2 I_m(t) - \kappa I_m(t), \\
\frac{dH(t)}{dt} &= \alpha_1 I_a(t) + \rho\alpha_2 I_m(t) + \sigma Q(t) - (\omega + \delta + \mu_h) H(t), \\
\frac{dQ(t)}{dt} &= \delta H(t) - (\sigma + \mu_q) Q(t), \\
\frac{dR(t)}{dt} &= \kappa I_m(t) + \omega H(t), \\
\frac{dD(t)}{dt} &= \mu_q Q(t) + \mu_h H(t) + \mu_a I_a(t),
\end{aligned} \tag{3}$$

subject to the following initial conditions

$$S(0) > 0, E(0) \geq 0, I_a(0) \geq 0, I_m(0) \geq 0, H(0) \geq 0, Q(0) \geq 0, R(0) \geq 0, D(0) \geq 0.$$

2.5 Equilibria analysis of the model

The basic reproduction number R_0 , is defined as the number of secondary infections produced by one infective that is introduced into an entirely susceptible population at the disease free equilibrium (6). The next generation matrix approach is frequently used to compute R_0 , see (20).

Normalizing the model variables by considering the percentage of the total population to be 1 at each instant, then system (3) has a disease-free equilibrium (DFE) given by

$$E_0 = (1, 0, 0, 0, 0, 0, 0, 0).$$

To compute R_0 , the next generation method was used. The next generation matrix is denoted by FV^{-1} . The model reproduction number, R_0 , which is defined as the spectral radius of FV^{-1} , and denoted by $\rho(FV^{-1})$ was derived after thorough algebraic manipulations and represented

as:

$$\begin{aligned}
R_0 &= \frac{(1-\eta)e^{-\gamma\tau}(\alpha_2\beta_1(-\rho e^{\gamma\tau} + e^{\gamma\tau} + \rho)(\sigma(\mu_h + \omega) + \mu_q(\delta + \mu_h + \omega)) + \kappa)}{\gamma(\alpha_2 + \kappa)(\mu_a + \alpha_1)(\sigma(\mu_h + \omega) + \mu_q(\delta + \mu_h + \omega))} \\
&\quad + \frac{\beta_2(1-\eta)(1-e^{-\gamma\tau})}{\gamma(\alpha_2 + \kappa)} \\
&\quad + \frac{(1-\eta)e^{-\gamma\tau}(\beta_4\delta + \beta_3(\mu_q + \sigma))(\rho\alpha_2\mu_a(e^{\gamma\tau} - 1) + \alpha_1(\alpha_2(-\rho e^{\gamma\tau} + e^{\gamma\tau} + \rho) + \rho\alpha_2(e^{\gamma\tau} - 1) + \kappa))}{\gamma(\alpha_2 + \kappa)(\mu_a + \alpha_1)(\sigma(\mu_h + \omega) + \mu_q(\delta + \mu_h + \omega))}
\end{aligned} \tag{4}$$

Hence,

$$R_0 = R_I + R_H$$

where

$$\begin{aligned}
R_I &= \frac{(1-\eta)e^{-\gamma\tau}(\alpha_2\beta_1(-\rho e^{\gamma\tau} + e^{\gamma\tau} + \rho)(\sigma(\mu_h + \omega) + \mu_q(\delta + \mu_h + \omega)) + \kappa)}{\gamma(\alpha_2 + \kappa)(\mu_a + \alpha_1)(\sigma(\mu_h + \omega) + \mu_q(\delta + \mu_h + \omega))} + \frac{\beta_2(1-\eta)(1-e^{-\gamma\tau})}{\gamma(\alpha_2 + \kappa)} \\
R_H &= \frac{(1-\eta)e^{-\gamma\tau}(\beta_4\delta + \beta_3(\mu_q + \sigma))(\rho\alpha_2\mu_a(e^{\gamma\tau} - 1) + \alpha_1(\alpha_2(-\rho e^{\gamma\tau} + e^{\gamma\tau} + \rho) + \rho\alpha_2(e^{\gamma\tau} - 1) + \kappa))}{\gamma(\alpha_2 + \kappa)(\mu_a + \alpha_1)(\sigma(\mu_h + \omega) + \mu_q(\delta + \mu_h + \omega))}
\end{aligned}$$

Here R_0 represents the number of new cases a COVID-19 infected individual generates during their infectious period. It is the sum of two terms each representing the average new infections contributed by an infected individual while in the four infectious classes. R_I represents the new cases generated by infected individuals in compartments I_a and I_m , R_H represents new cases generated by patients hospitalized (H and Q classes).

From R_0 in equation(4), each term is multiplied by $(1-\eta)$ and $e^{-\gamma\tau}$ which represents the probability of keeping the desired social distance and the effect of individual immune response. Hence, if social distance is kept (individual behavioral change), or lock-down measures are maintained, then the emergency of new corona cases is reduced. Therefore the government campaign of “social distancing” and “personal nutrition” is very important in preventing the development of new cases.

It is therefore evident from R_0 that an increase in adherence to government measures and patient recovery rate would reduce the severity of COVID-19 in Kenya. To improve the rates of recovery, good care for COVID-19 patients is warranted. Infected individuals should be taken to isolation centres for proper treatment and care.

From Theorem 2 in (20), we have the following result:

Theorem 1. *The DFE, E_0 of the system of equations (3) is locally asymptotically stable when $R_0 < 1$ and unstable otherwise.*

3 Numerical Simulations

In this section, we present a series of numerical results of system (3) using COVID-19 reported cumulative cases in Kenya to predict and estimate the incidence of the virus in the country considering the laid down intervention measures.

3.1 Application of the model to COVID-19 data in Kenya

COVID-19 cases in Kenya were collected from March 13, 2020 when the first imported case was registered to June 25, 2020 from the Ministry of Health (MoH) as shown in Table 3.

COVID-19 cases in Figure 4.

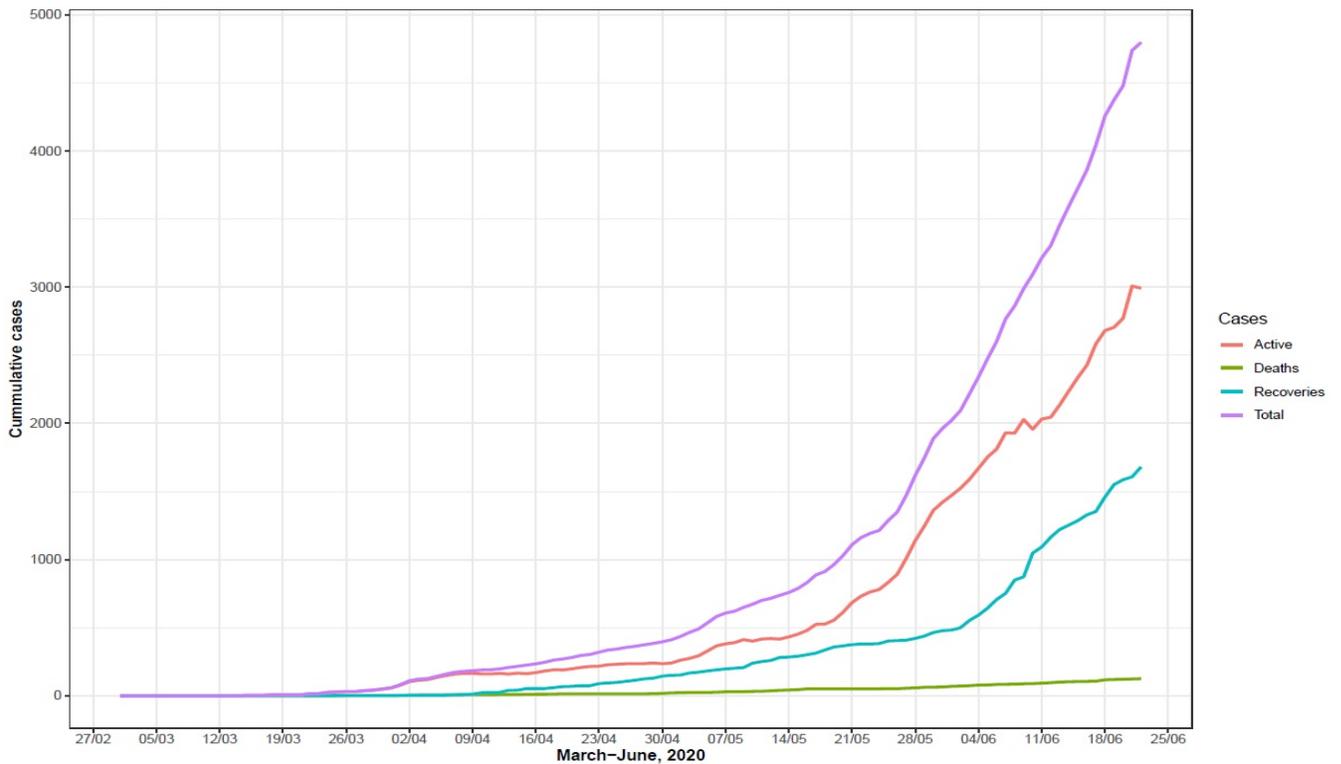


Figure 4: *COVID-19 reported cases data in Kenya*

The least squares curve fitting routine in matlab with optimization was used to estimate the parameter values as well as predict future population of new infections. The estimation process attempts to find the best concordance between computed and observed data. The parameter values which are calculated from the given data in Figure 4 are displayed in Table 3 and the initial conditions for the populations are as given in Table 4,

Table 3: *Model parameters values*

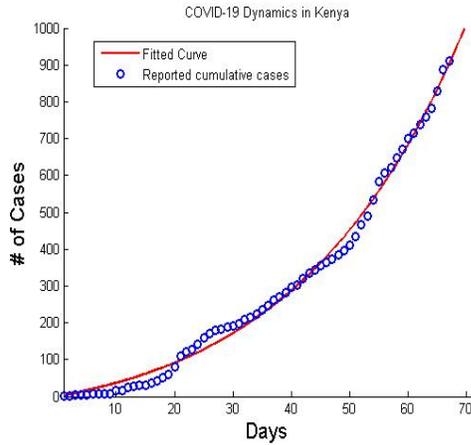
Parameter	Value
β_1	0.05
β_2	0.021
β_3	0.0016
β_4	0.001
ρ	0.0005
κ	0.01
α_1	0.01
α_2	0.09
γ	0.1
ω	0.027
δ	0.00002
σ	0.0009
η	0.001
μ_a	0.0001
μ_h	0.003
μ_q	0.0003
$\frac{1}{\tau}$	5

Table 4: *Initial conditions*

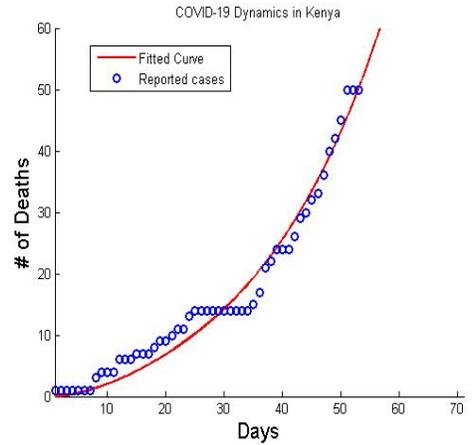
Variable	$S(0)$	$E(0)$	$I_a(0)$	$I_m(0)$	$H(0)$	$Q(0)$	$R(0)$	$D(0)$
Values	$4.4 * 10^7$	10	1	1	0	0	0	0

3.2 Data fitting and model predictions

Using the parameter values and initial values as given in Tables 3 and 4 respectively, and applying them on system (3), we have the fitted curves as displayed in Figure 5.



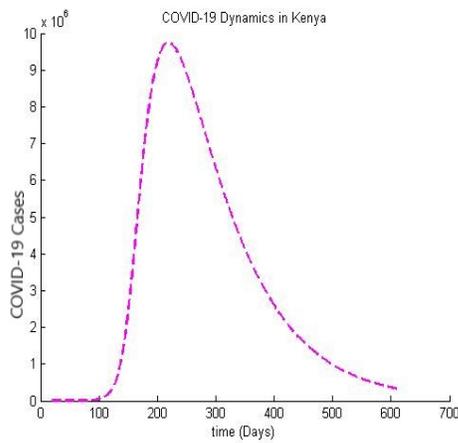
(a) *COVID-19 cases with actual Kenyan Data*



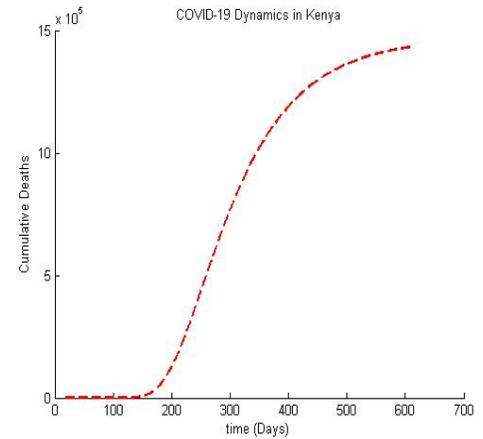
(b) *COVID-19 Deaths with actual Kenyan data*

Figure 5: *Curve fitting with reported Kenyan data*

The model is used to first reproduce the observed trajectory of COVID-19 in Kenya. The model is validated by showing that it reasonably mimics the observed data, that is the reported cases in Kenya and the disease-induced death as shown in Figures 5a and 5b respectively, and hence used to make predictions on the likely course of the disease.



(a) *COVID-19 projected cases in Kenya*

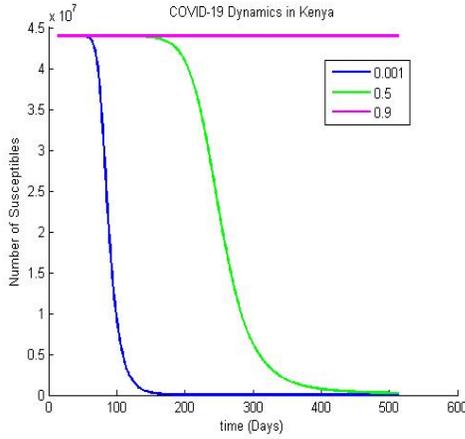


(b) *COVID-19 projected Deaths in Kenya*

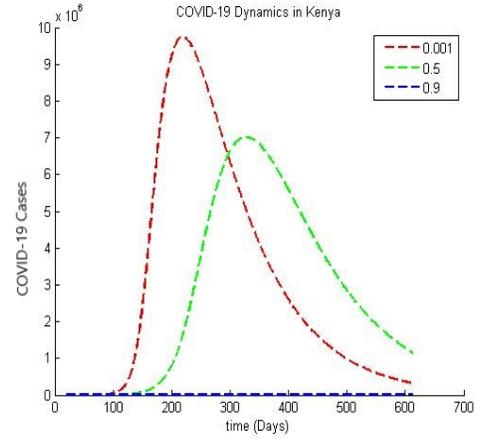
Figure 6: *COVID-19 projections for disease cases and deaths*

Figure 6a and 6b show the projected COVID-19 cases in Kenya and projected deaths if no intervention is applied. We observe that model system (3) fits well the COVID-19 data from Kenya (see Figures 5a and 5b respectively). Moreover, in the absence of interventions, Kenya is likely to experience exponential growth in the number of COVID-19 cases and deaths(see Figures 6a and 6b respectively). The Kenyan government should therefore strictly deploy and implement existing control measures against COVID-19 in every county.

3.3 Impact of social distancing on the populations



(a) Effects of social distancing on susceptible population



(b) Effects of social distancing on cumulative COVID-19 cases

Figure 7: Model prediction considering the impact of social or physical distancing on the populations

Figure 7a shows the impact of following government control measures and guidelines on the population at risk of contracting the virus (susceptible population). The simulation shows that ignoring safety guidelines such as social distancing and unchanged individual behavior has a devastating effect on the susceptible individuals denoted by the blue line in Figure 7a.

Figure 7b shows the impact of Government directive measures on COVID-19 new cases in Kenya. If by beginning of May, 2020, all the government directive measures were adhered to, then we would not have significant new infections hence no deaths. With no intervention, the COVID-19 case peak will be 9.8 million and achieved after 250 days since the first reported case in Kenya as shown by the red line in Figure 7b. With 50% adherence to social distancing, the peak is achieved after 350 days and it will be 6.5 million, indicated by line green in Figure 7b. With 90% observation of the social distance directive, we shall have very insignificant number of cases as depicted by line blue in Figure 7b. In many of the informal settlements the social distance from person to person is less than one meter hence if an infection is introduced in such settlements, the disease dynamics will resemble the dynamics depicted by the red or green lines in Figure 7b. Hence the Government should target these populations for mass testing and provision of affordable masks, sanitizers, clean water and soap. The informal settlements in Nairobi that would be of greatest interest including Kibera, Mukuru kwa Njenga, Mathare and Korogocho slums.

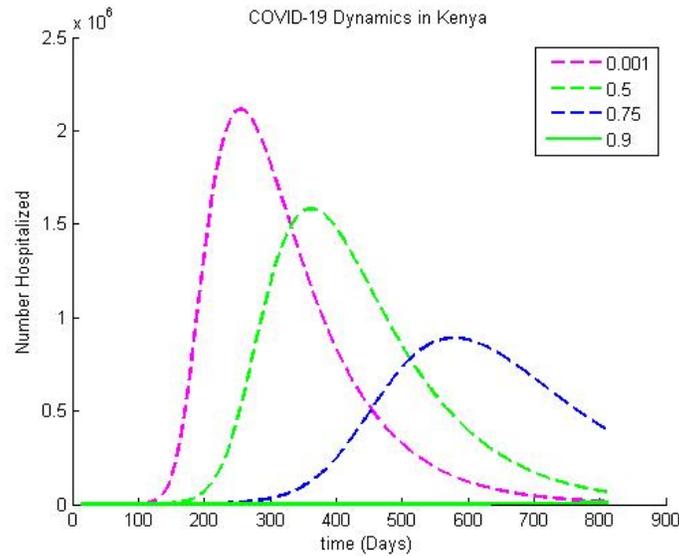


Figure 8: *Model prediction of the number hospitalized considering the impact of social distancing on the population denoted by η in our model.*

Figure 8 shows the projections of the number of COVID-19 cases hospitalized and the impact of social distancing and personal hygiene intervention measures. With no interventions at all, depicted by the red line in Figure 8, the model suggests we would rapidly run out of available hospital beds, but with 90% implementation of intervention measures, the hospitals will be free of COVID-19 patients as depicted by the solid green line in Figure 8. As shown by the solid green line, a combination of adherence to existing government control measures and improved medical environment is likely to yield most recoveries from COVID-19 infections and hence flattening the hospitalized peak curves. The medical practitioners should understand the patients comorbid conditions to tailor the management of critical illness during intensive care management of COVID-19. They should determine which medications should be continued and which should be stopped temporarily.

3.4 Impact of mass testing on the populations

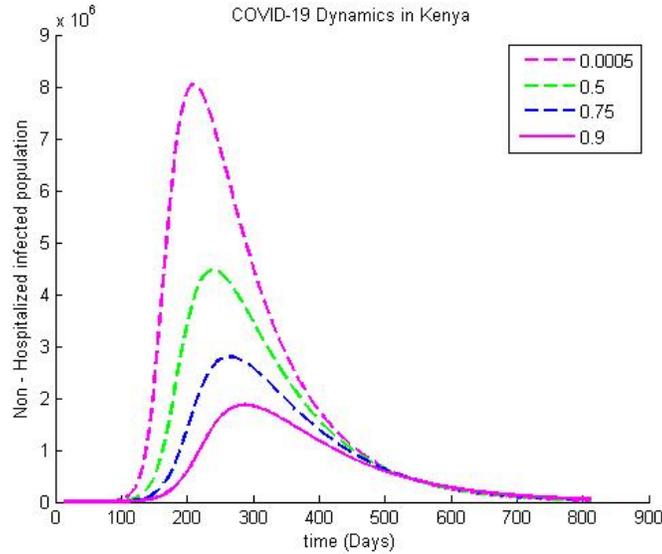
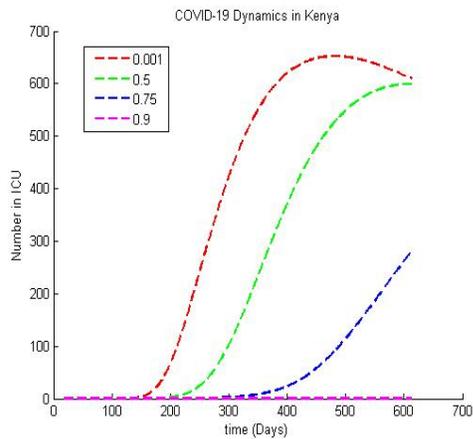


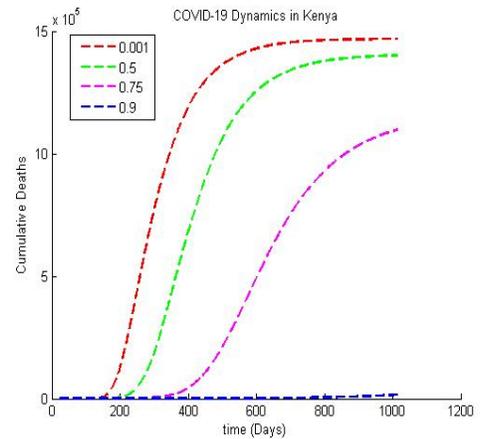
Figure 9: *The impact of mass testing on non-hospitalized infected population denoted by ρ in our model*

Figure 9 presents the projections and the impact of mass testing on the non-hospitalized COVID-19 cases. From Figure 9, it is shown that with mass testing, the asymptomatic and symptomatic patients who are not yet in hospital will be identified and either hospitalized or quarantined hence preventing further transmission. The asymptomatic persons(those with mild infections) are the problem and the contact tracing and mass testing should be targeting this population. With 90% effective and aggressive mass testing, there will be very few individuals in the community with the virus as depicted by the solid purple line. Therefore the Government should increase the the mass testing exercise and target the most vulnerable populations first.

3.5 Other predictions



(a) *ICU predictions*



(b) *Death predictions*

Figure 10: *Model prediction on the number in ICU and deaths from COVID-19*

Figure 10a shows the number of COVID-19 hospitalized patients and in ICU. With 90% implementation of the non-pharmaceutical interventions and hospital patient management, we shall have no ICU cases of COVID-19 as indicated by the dotted purple line in Figure 10a.

Figure 10b shows the COVID-19 death predictions. Without or with partial interventions, about half of the Kenyan population die of COVID-19, otherwise with at least 90% adherence to the government directives and guidelines and with good hospital and ICU care, the country will experience insignificant deaths due to COVID-19 as depicted by the dotted blue line in Figure 10b.

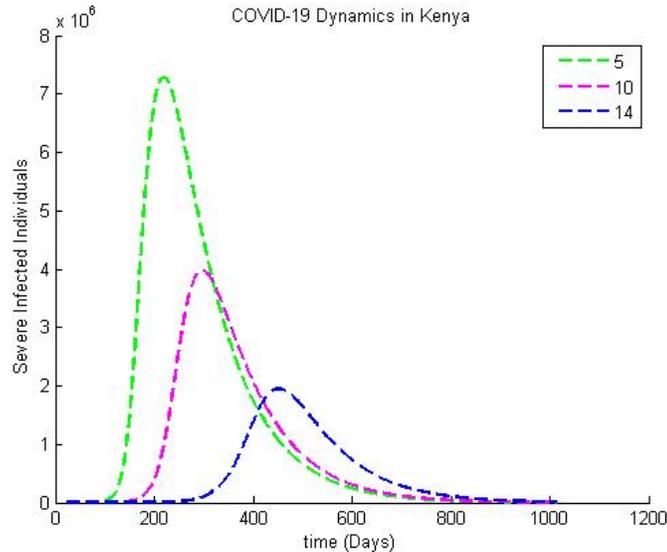


Figure 11: *Model prediction on COVID-19 severe infected population given the incubation period*

Figure 11 shows the dynamics of the symptomatic infected population given the period taken before a patient shows symptoms. Once infected, individuals with low immunity develop the COVID-19 symptoms faster and become severely infected, such individuals are either above 60 years of age, smokers or they have other underlying pre-existing medical conditions. From the graph in Figure 11, these population is indicated by the dotted green line. With improved immunity represented by the time one takes to develop COVID-19 symptoms, the number with severe infection reduce as depicted by the dotted purple and blue lines in Figure 11. Hence another group of concern for the government to target for special care is the individuals with pre-existing medical or non-medical conditions. Separate medical facility and medical attention should be set aside for such individuals. Many individuals in the community are scared to visit medical facilities with the fear of COVID-19 hence they remain in their homes without their medication. Also the government should consider providing medication for these population for free during the pandemic period.

4 Discussion and recommendation

In this study, we applied the SEIHCRD compartmental delay differential model to the daily reported cases of COVID-19 to estimate the transmission dynamics of COVID-19 and determine which population to target for mass testing in Kenyan population. The model Simulation shows that ignoring safety guidelines such as social distancing, wearing of masks, frequent washing of hands with water and soap or using alcohol-based hand sanitizers and cutting down on travel

has devastating effect on the disease dynamics. The model results also give insights to health policy-makers and Government on the effective approaches and implementable actions that can enhance the prevention, preparedness and readiness for future emergencies of COVID-19 and similar diseases.

The study results also show that unless there is a dedicated effort from government, decision makers and individual Kenyans, the rate of COVID-19 infection will continue to increase despite the increased rate of recovery. Given the absence of vaccine at the moment, non-pharmaceutical intervention over a relatively long period is needed to effectively reduce the final epidemic size.

In many of the informal settlement the social or physical distance kept from person to person is less than the required social distance hence if an infection is introduced in such settlements, the disease infections will be very high and therefore, the Government should target these populations for mass testing and provision of affordable masks, sanitizers, clean water and soap. From the model simulations, it is shown that with aggressive and effective mass testing, the asymptomatic and symptomatic patients who are not yet in hospital will be identified and either hospitalized or quarantined in isolation centres hence preventing further transmission. The asymptomatic persons(those with mild infections) are the problem and the contact tracing and mass testing should be targeting this population. With 90% aggressive and effective mass testing, there will be very few individuals in the community with the virus as depicted by the solid purple line.

Once infected, individuals with low immunity develop the COVID-19 symptoms faster and become severely infected, such individuals are either above 60 years of age, smokers or they have other underlying pre-existing medical conditions. Our model results suggest that, the individuals in these populations, when infected with COVID-19 become severe immediately and therefore another group of concern for the government to target for special care is the individuals with pre-existing medical and non-medical conditions. Separate medical facility and medical attention should be set aside for such individuals. The medical practitioners should understand the patients co-morbid conditions to tailor the management of critical illness during intensive care management of COVID-19. They should determine which medications should be continued and which should be stopped temporarily.

Many individuals in the community are scared to visit medical facilities with the fear of COVID-19 hence they remain in their homes without their medication. Therefore, the government should consider providing medication for these population for free during the pandemic period.

Our study suggests that aggressive targeted mass testing is required to identify and isolate the asymptomatic patients in the community. Moreover, our analysis reveals that , adherence to the Government intervention measure, effective mass testing and improved hospital and ICU care will see Kenya free of COVID-19 new cases, deaths and improved recoveries from the disease.

One of the limitations of the study is availability of data. We would request the Ministry of health to plan on how house the data to be publicly available for research.

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Availability of data and materials

All data used in this study are included in this manuscript.

Authors' contributions

All authors contributed to all sections of this manuscript.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article

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