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Dynamical Analysis and Control Strategies for Capturing the Spread of COVID-19

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Abstract

In this paper, a study of preventive measures capable of curbing the spread of COVID 19 pandemic to avoid its second wave was carried out. The existence and uniqueness of the proposed mathematical model is assured, the basic reproduction number is established, the local and global stability of the disease free equilibrium are well obtained and the variational iteration method is applied to solve the mathematical model. Numerical simulation of the included control parameters are carried out. The obtained results and outcomes are presented graphically. It was revealed that enlightenment to vaccination awareness should be encouraged as vaccination is a good strategy of capturing the spread of the disease.

Keywords: Covid-19, Basic Reproduction Number, Local stability, Global Stability, variational Iteration Method

Introduction

The novel virus (2019-nCoV) is highly transmissible. This infection causes a severe acute respiratory syndrome and it has spread across the world. The confirmed cases of COVID-19 are over 10.27 million, and there have been more than 0.5 million deaths till 30 June 2020 globally (WHO 2020). The WHO confirmed that the virus can be contacted via breathing. The incubation period of the disease is 2–14 days and around 97.5 per cent of infected individuals usually show symptoms within 11 to 12 days of infection (Del and Malani 2020, Li et al. 2020, Lai et al. 2020).

To gain understanding of the spread and preventive measures that could be applied to curtail the disease, researchers have presented varieties of mathematical models. Das et al. (2021) established a mathematical model that described COVID-19 transmission dynamics with isolation class. The data acquired from an ongoing event in India was applied and their outcomes recommended how to control the spread of COVID-19, keeping in mind contact and recovery rate. An analysis of the COVID-19 transmission in Lagos Nigeria was also conducted by Okuonghae and Omame (2020); their results revealed that if at least 55% of the population comply with the social distancing regulation with about 55% of the population effectively making use of face masks while in public, the disease will eventually die out in the population. In the same vein, an analysis of the outburst of COVID-19 pandemic was examined in Nigeria by Ajisegiri et al. (2020), their outcome revealed possible evidence of

ongoing and increasing community transmission of COVID-19 infections and inadequate testing capacity and overwhelming of health resources.

Numerical simulations often give realistic impacts of the parameters embedded in mathematical models. To carry out this simulation, numerical methods such as the variational iteration method proposed by He (1999) are often applied to solve the epidemiology models. Peter et al. (2018) applied this method to obtain the solution of a deterministic mathematical model of typhoid fever. The accuracy of the method is confirmed as it shows good agreement with the classical inbuilt RK4 on Maple 18.

In this research, we modified a mathematical model of COVID 19 transmission dynamics proposed by Wusu et al. (2022) by incorporating vaccination and enlightenment to vaccination parameter capable of capturing the spread of COVID-19 to avoid second wave. The qualitative analysis of the model which involves establishing the basic reproduction number, disease free equilibrium and the threshold for local stability and global stability is conducted. The variational iteration method is applied to solve the epidemic model and numerical simulations are carried out with the aid of Maple 18 software.

Materials and Methods

Model formulation and analysis

The coupled differential equations which portray the epidemic model are presented as follows:

$$\left.\begin{aligned}
\frac{dS}{dt} &= \Lambda - (\theta(1+z)+\mu)S + \alpha R - \frac{(1-\mu)\beta SI}{N-D} \\
\frac{dE}{dt} &= \frac{(1-\mu)\beta SI}{N-D} - (\gamma - \delta_1 + \mu)E \\
\frac{dI}{dt} &= \gamma E - (\delta_2 - \sigma + \mu)I \\
\frac{dV}{dt} &= \theta(1+z)S - \mu V \\
\frac{dR}{dt} &= \delta_1 E + \delta_2 I - (\alpha + \mu)R \\
\frac{dD}{dt} &= \sigma I - \mu D
\end{aligned}\right\} \qquad (1)$$

Model description

$S(t)$ represents the individuals prone to contacting the virus, the susceptible class already in contact with the virus showing no clinical symptoms yet are represented by $E(t)$, $I(t)$ represents the infected population, the population that have been vaccinated is represented by $V(t)$, $R(t)$ are recovered individual, $D(t)$ denotes the exited population, and the total population is represented by $N(t)$.

We define the initial condition as $S(0) = s_0, E(0) = e_0, I(0) = i_0. V(0) = v_o, R(0) = r_o$, $D(0) = d_o$

The descriptions, parameters, and values are presented in Table 1.

Table 1: Descriptions, parameters and values

Description	Parameters	Values	References
Initial susceptible population	s_0	200	Assumed
Initial exposed population	e_0	120	Assumed
Initial infected population	i_0	80	Assumed
Initial vaccinated population	v_0	60	Assumed
Initial recovered population	r_0	40	Assumed
Exited population	D_0	40	Assumed
Recruitment rate	Λ	500	Fitted
Effective recovery rate	α	0.1	Estimated
Vaccination rate	θ	$0 \le \theta < 1$	incorporated
Acceptance rate of enlightenment for vaccine	z	$0 \le z < 1$	incorporated
Infected recovery rate	δ_1	0.0035	Wusu et al. (2022)
Infected rate	δ_2	0.04539	Wusu et al. (2022)
Natural death rate	μ	0.03	Estimated
Infection contact rate	β	0.655	Wusu et al. (2022)
Progressive rate of infected to susceptible	σ	0.0002931	Wusu et al. (2022)
Incidence rate	λ	0.002	Fitted

Existence and uniqueness of solution

Theorem 1a: Suppose E^1 represents the region $0 \le \omega \le R,$ then the coupled equations in (1) has a unique solution, provided that $\left|\frac{\partial f_i}{\partial x_i}\right|$, $i = 1,2,\cdots,6$ are bounded and continuous**.**

Proof:

From equation (1), let; $f_1 = \Lambda - (\theta(1+z)+\mu)S + \alpha R - \frac{(1-\mu)\beta SI}{N-D}$

$$f_2 = \frac{(1-\mu)\beta SI}{N-D} - (\gamma - \delta_1 + \mu)E$$

$$f_3 = \gamma E - (\delta_2 - \sigma + \mu)I$$

$$f_4 = \theta(1+z)S - \mu V$$

$$f_5 = \delta_1 E + \delta_2 I - (\alpha + \mu)R$$

$$f_6 = \sigma I - \mu D$$

$$\left|\frac{df_1}{dS}\right| = \theta(1+z)+\mu, \left|\frac{df_1}{dE}\right| = 0, \left|\frac{df_1}{dI}\right| = (1-\mu)\Lambda\beta, \left|\frac{df_1}{dV}\right| = 0, \left|\frac{df_1}{dR}\right| = \alpha, \left|\frac{df_1}{dD}\right| = 0$$

$$\left|\frac{df_2}{dS}\right| = 0, \left|\frac{df_2}{dE}\right| = (\gamma + \delta_1 + \mu), \left|\frac{df_2}{dI}\right| = 0, \left|\frac{df_2}{dV}\right| = 0, \left|\frac{df_2}{dR}\right| = 0. \left|\frac{df_2}{dD}\right| = 0$$

$$\left|\frac{df_3}{dS}\right| = 0, \left|\frac{df_3}{dE}\right| = \gamma, \left|\frac{df_3}{dI}\right| = (\delta_2 + \sigma + \mu), \left|\frac{df_3}{dV}\right| = 0, \left|\frac{df_3}{dR}\right| = 0, \left|\frac{df_3}{dD}\right| = 0$$

$$\left|\frac{df_4}{dS}\right| = \theta(1+z), \left|\frac{df_4}{dE}\right| = 0, \left|\frac{df_4}{dI}\right| = 0, \left|\frac{df_4}{dV}\right| = \mu, \left|\frac{df_4}{dR}\right| = 0, \left|\frac{df_4}{dD}\right| = 0$$

$$\left|\frac{df_5}{dS}\right| = 0, \left|\frac{df_5}{dE}\right| = \delta_1, \left|\frac{df_5}{dI}\right| = \delta_2, \left|\frac{df_5}{dV}\right| = 0, \left|\frac{df_5}{dR}\right| = (\alpha+\mu). \left|\frac{df_5}{dD}\right| = 0,$$

$$\left|\frac{df_6}{dS}\right| = 0, \left|\frac{df_6}{dE}\right| = 0, \left|\frac{df_6}{dI}\right| = \sigma, \left|\frac{df_6}{dV}\right| = 0, \left|\frac{df_6}{dR}\right| = 0, \left|\frac{df_6}{dD}\right| = 0.$$

It could be observed that all the partial derivatives are Lipschitz continuous and bounded. Hence, the system of equations (1) has a unique solution.

Positivity of solution

All parameters of the modified model are positively represented. We have that;

$N(t) = S(t) + E(t) + I(t) + V(t) + R(t) + D(t).$ (2)

Taking its derivatives,

$$\frac{dN}{dt} = \frac{dS}{dt} + \frac{dE}{dt} + \frac{dI}{dt} + \frac{dV}{dt} + \frac{dR}{dt} + \frac{dD}{dt}$$

$$\frac{dN}{dt} \leq \Lambda - \mu N$$

$N(t)e^{\mu t} = \frac{\Lambda e^{\mu t}}{\mu} + C$, where C is a constant of integration.

Applying the initial condition at t = 0,

$C = N(0) - \frac{\Lambda}{\mu}$.

At time t = 0,

$$\lim_{t\to\infty} N(t) \leq \lim_{t\to\infty}\left[\frac{\Lambda}{\mu} + \left(N(0) - \frac{\Lambda}{\mu}\right)e^{-\mu t}\right] = \frac{\Lambda}{\mu}$$

Hence all terms are positive and the solution is said to be bounded.

Equilibrium analysis

In this section, we discuss the disease free and endemic equilibrium of the model, respectively.

Existence of disease-free equilibrium

At equilibrium point N (t) = 0, i.e. $\frac{dN}{dt} = \frac{dS}{dt} + \frac{dE}{dt} + \frac{dI}{dt} + \frac{dV}{dt} + \frac{dR}{dt} + \frac{dD}{dt} = 0$

From (1), set I = 0 as $S\left((1+z)\theta + \mu\right) = \Lambda$,

This implies $S_0 \frac{\Lambda}{\theta(1+z)+\mu}$

Thus, the disease free equilibrium $E_1 = \left(S_0 E_0 I_0 V_0 R_0 D_0\right)$ where $S_0 \neq 0$ and I = 0,

$$E_1 = \left(S_o = \frac{\Lambda}{\theta(1+z)+\mu}, E = 0, I = 0, V = \frac{\theta(1+z)\Lambda}{\theta(1+z)+\mu}, R = 0, D = 0\right)$$

Existence of endemic equilibrium state

Let $E_e = (S^* E^* I^* V^* R^* D^*)$ as disease endemic equilibrium. Consider the system of equations (1) at equilibrium as obtained from each compartment;

$$D^* = \frac{\sigma I^*}{\mu}; E^* = \frac{(\delta_2 + \sigma + \mu)I^*}{\gamma}; V^* = \frac{\theta(1+z)S^*}{\mu}; R^* = \frac{(\delta_1(\delta_2 + \sigma + \mu) + \gamma\delta_2)I^*}{\gamma(\alpha + \mu)};$$

$$S^* = \frac{(\gamma + \delta_1 + \mu)(\gamma + \delta_2 + \mu)}{\gamma(1-\mu)\beta\lambda} \text{ and } I^* = \frac{\Lambda(\gamma + \delta_1 + \mu)}{\lambda(1-\mu)(\sigma + \delta_2 + \mu)\beta\gamma}$$

Basic reproduction number

From the system of equations (1), consider the disease compartments in the system of equations. $G = F \times V^{-1}$ and $S_0 = \frac{\Lambda}{\theta(1+z) + \mu}$. The transition matrix V and the transmission matrix F are obtained from the partial derivatives of F and V with respect to (E, I), i.e.

$$\frac{dE}{dt} = \frac{(1-\mu)\beta SI}{N - D} - (\gamma - \delta_1 + \mu)E$$

$$\frac{dI}{dt} = \gamma E - (\delta_2 - \sigma + \mu)I$$

Which can be evaluated at the disease free equilibrium E_1 and $\lambda = \frac{I}{N - D}$

Thus, $F_i = \left[\frac{\partial f_i(x_i)}{\partial x_j}\right]$ and $V_i = \left[\frac{\partial v_i(x_i)}{\partial x_j}\right]$ such that

$$F = \begin{bmatrix} 0 & \frac{\beta(1-\mu)\mu}{\theta(1+z)+\mu} \\ 0 & 0 \end{bmatrix}, \text{ and } V^{-1} = \begin{bmatrix} \frac{1}{(\gamma + \delta_1 + \mu)} & 0 \\ \frac{\gamma}{(\delta_2 + \sigma + \mu)(\gamma + \delta_1 + \mu)} & \frac{1}{(\delta_2 + \sigma + \mu)} \end{bmatrix}$$

Since R_0 is the spectral radius of $G = F \times V^{-1}$

Therefore,

$$R_0 = \frac{\beta(1-\mu)\mu\gamma}{(\theta(1+z) + \mu)(\delta_2 + \sigma + \mu)(\gamma + \delta_1 + \mu)}$$

Stability analysis

Local stability analysis of diseases-free equilibrium

The local stability of the disease free equilibrium is determined by computing $\left|J_{E_1} - \lambda_i I\right| = 0$ and evaluating using

$$E_1 = \left(S_0 = \frac{\Lambda}{\theta(1+z) + \mu}, E = 0, I = 0, V = \frac{\theta(1+z)\Lambda}{\theta(1+z) + \mu}, R = 0, D = 0\right)$$

To obtain the eigenvalues λ_i for $i = 1, 2, 3, 4, 5, 6$.

Therefore:

$$J_{E_i} = \begin{vmatrix} \theta(1+z)+\mu+(1-\mu)\beta I & 0 & -\frac{(1-\mu)\beta S}{N-D} & 0 & \alpha & 0 \\ (1-\mu)\beta I & -(\gamma+\delta_1+\mu) & \frac{(1-\mu)\beta S}{N-D} & 0 & 0 & 0 \\ 0 & \gamma & -(\delta_2+\sigma+\mu) & 0 & 0 & 0 \\ \theta(1+z) & 0 & 0 & \mu & 0 & 0 \\ 0 & \delta_1 & \delta_2 & 0 & -(\alpha+\mu) & 0 \\ 0 & 0 & \sigma & 0 & 0 & -\mu \end{vmatrix}$$

Determining the eigenvalues,

$$J_{E_i} = \begin{vmatrix} \theta(1+z)+\mu+(1-\mu)\beta I-\lambda_1 & 0 & -\frac{(1-\mu)\beta S^0}{N-D} & 0 & \alpha & 0 \\ (1-\mu)\beta I & -(\gamma+\delta_1+\mu)-\lambda_2 & \frac{(1-\mu)\beta S}{N-D} & 0 & 0 & 0 \\ 0 & \gamma & -(\delta_2+\sigma+\mu)-\lambda_3 & 0 & 0 & 0 \\ \theta(1+z) & 0 & 0 & \mu-\lambda_4 & 0 & 0 \\ 0 & \delta_1 & \delta_2 & 0 & -(\alpha+\mu)-\lambda_5 & 0 \\ 0 & 0 & \sigma & 0 & 0 & -\mu-\lambda_6 \end{vmatrix}$$

Computing for $\lambda_1, \lambda_2 \cdots \lambda_6$

$\lambda_1 = -(\theta(1+z)+\mu)$, $\lambda_2 = -(\alpha+\mu)$, $\lambda_3 = -\mu$, $\lambda_4 = -\mu$

$$\begin{vmatrix} -(\gamma+d_1+\mu)-\lambda & -\frac{(1-\mu)\beta S^0}{N-D} \\ \gamma & -(d_2+\sigma+\mu)-\lambda \end{vmatrix} = 0$$

$\lambda^2 + (\gamma+d_1+\mu+d_2+\sigma+\mu)\lambda + (\gamma+d_1+\mu)(d_2+\sigma+\mu) - \frac{(1-\mu)\beta\mu}{(\mu+\theta(1+z))} = 0$ Recall that

$$\beta(1-\mu)\mu\gamma = R_0(\theta(1+z)+\mu)(\delta_2+\sigma+\mu)(\gamma+\delta_1+\mu)$$

Then the quadratic equation becomes:

$\lambda^2 + (\gamma+d_1+d_2+\sigma+2\mu)\lambda + (\gamma+d_1+\mu)(d_2+\sigma+\mu)(1-R_0) = 0$

Using Descartes' rule of sign; the equation will have negative roots when $R_0 < 1$ because there will be no sign change.

Global stability at disease free equilibrium

Applying Lyapunov function approach to proceed for the result for the global stability of the model at disease free equilibrium state.

$V(t,S,E,I,V,R,D) = C_1E + C_2I$

$$\frac{dV}{dt} = C_1\dot{E} + C_2\dot{I}$$

$$= C_1\left(\frac{(1-\mu)\beta SI}{N-D} - (\gamma+\delta_1+\mu)E\right) + C_2\left(\gamma I(\delta_2+\sigma+\mu)\right)$$

$$= \left(C_2\gamma - C_1(\gamma+\delta_1+\mu)\right)E + \left(C_1\frac{(1-\mu)\beta SI}{N-D} - C_2(\delta_2+\sigma+\mu)\right)I$$

$$\leq \left(C_2\gamma - C_1(\gamma+\delta_1+\mu)\right)I_1 + \left(C_1\frac{(1-\mu)\beta\mu}{(\theta(1+z)+\mu)} - C_2(\delta_2+\sigma+\mu)\right)I_2$$

$$\frac{\gamma}{(\delta_1+\gamma+\mu)(\delta_2+\sigma+\mu)}\left(\frac{(1-\mu)\beta\mu}{(\theta(1+z)+\mu)}-(\gamma+\delta_1+\mu)I\right)+\frac{1}{\delta_2+\sigma+\mu}(\gamma E-(\delta_2+\sigma+\mu)I)$$

$$\frac{\gamma(1-\mu)\beta\mu}{(\delta_1+\gamma+\mu)(\delta_2+\sigma+\mu)}I-\frac{\gamma E}{\delta_2+\sigma+\mu}+-\frac{\gamma E}{\delta_2+\sigma+\mu}-I \quad \Rightarrow \quad \frac{\gamma(1-\mu)\beta\mu}{(\delta_1+\gamma+\mu)(\delta_2+\sigma+\mu)}I-I$$

Since $R_0=\frac{\gamma(1-\mu)\beta\mu}{(\delta_1+\gamma+\mu)(\delta_2+\sigma+\mu)}$,

Therefore we have, $R_0I-I=(R_0-1)I$

Let $C_1=\frac{\gamma}{(\delta_1+\gamma+\mu)(\delta_2+\sigma+\mu)}$ and $C_2=\frac{1}{(\delta_2+\sigma+\mu)}$

$V^{'}\le(\delta_2+\sigma+\mu)(R_o-1)I$

It is imperative to note that $V^{'}=0$ only when E = 0, the substitution of E = 0 into the model system of equations (1) shows that $S=\frac{\Lambda}{(\theta(1+z)+\mu)}$ at $t\to\infty$. Based on LaSalle's invariance principle. Hence E_0 = 0 is globally asymptotically stable whenever R_0 < 1.

Numerical simulation

Here we apply the variational iteration method to obtain the numerical solution of the epidemiology model. For easy computation, we let $\lambda=\frac{1}{N-D}$ and with and constructing an iteration formula for each compartments of the model;

$$S_{n+1}(t)=S_n(t)-\int_0^t\frac{d}{d\tau}S_n(\tau)-\Lambda+\theta(1+z)S_n(\tau)-\alpha R_n(\tau)+(1-\mu)\beta S_n(\tau)I_n(\tau)\lambda d\tau$$

$$E_{n+1}(t)=E_n(t)-\int_0^t\frac{d}{d\tau}E_n(\tau)-(1-\mu)\beta S_n(\tau)I_n(\tau)\lambda-(\gamma+\delta_1+\mu)E_n(\tau)d\tau$$

$$I_{n+1}(t)=I_n(t)-\int_0^t\frac{d}{d\tau}I_n(\tau)-\gamma E_n(\tau)+(\delta_2-\sigma+\mu)I_n(\tau)d\tau$$

$$V_{n+1}(t)=V_n(t)-\int_0^t\frac{d}{d\tau}V_n(\tau)-\theta(1+z)S_n(\tau)-\mu V_n(t)d\tau$$

$$R_{n+1}(t)=R_n(t)-\int_0^t\frac{d}{d\tau}R_n(\tau)-\delta_1E_n(\tau)-\delta_2I_n(\tau)+(\alpha+\mu)R_n(\tau)d\tau$$

$$D_{n+1}(t)=D_n(t)-\int_0^t\frac{d}{d\tau}D_n(\tau)-\sigma I_n(\tau)-\mu D_n(\tau))d\tau\ ;$$

At $n=0$

$S_1(t)=((\Lambda-(\theta(1+z)+\mu)s_0+\alpha r_0-(1-\mu)\beta s_0i_0)t$ $E_1(t)=((1-\mu)\beta s_0i_0-(\gamma-\delta_1+\mu)e_0)t$

$I_1(t)=(\gamma e_0-(\delta_2-\sigma+\mu)i_0)t$

$V_1(t)=(\theta(1+z)s_0-\mu v_0)t$

$R_1(t)=(\delta_1e_0+\delta_2i_0-(\alpha+\mu)r_0)t$

$D_1(t)=(\sigma i_0-\mu D_0)t$

Subsequent iterations such as $n = 1,2,\cdots k$ can computed using the following maple 18 codes;

Restart:

$ic := \{S_1(t) = ((\Lambda - (\theta(1+z) + \mu)s_0 + \alpha r_0 - (1-\mu)\beta s_0 i_0)t,$

$S_1(\tau) = ((\Lambda - (\theta(1+z) + \mu)s_0 + \alpha r_0 - (1-\mu)\beta s_0 i_0)\tau$

$E_1(t) = ((1-\mu)\beta s_0 i_0 - (\gamma - \delta_1 + \mu)e_0)t, E_1(\tau) = ((1-\mu)\beta s_0 i_0 - (\gamma - \delta_1 + \mu)e_0)\tau$

$I_1(t) = (\gamma e_0 - (\delta_2 - \sigma + \mu)i_0)t, I_1(\tau) = (\gamma e_0 - (\delta_2 - \sigma + \mu)i_0)\tau, V_1(t) = (\theta(1+z)s_0 - \mu v_0)t,$

$V_1(\tau) = (\theta(1+z)s_0 - \mu v_0)\tau, R_1(t) = (\delta_1 e_0 + \delta_2 i_0 - (\alpha + \mu)r_0)t, R_1(\tau) = (\delta_1 e_0 + \delta_2 i_0 - (\alpha + \mu)r_0)\tau,$

$D_1(t) = (\sigma i_0 - \mu D_0)t,\ D_1(\tau) = (\sigma i_0 - \mu D_0)\tau\}$

#second iteration

$S_2(t) = collect(eval(S_{n+1}, \{n = 1, ic\}), t)$

$E_2(t) = collect(eval(E_{n+1}, \{n = 1, ic\}), t)$

$I_2(t) = collect(eval(I_{n+1}, \{n = 1, ic\}), t)$

$V_2(t) = collect(eval(V_{n+1}, \{n = 1, ic\}), t)$

$R_2(t) = collect(eval(R_{n+1}, \{n = 1, ic\}), t)$

$D_2(t) = collect(eval(D_{n+1}, \{n = 1, ic\}), t)$

Thus, the solution of each class evaluated using the parameters defined on Table 1 are

$$S(t) = \left\{ \begin{array}{l} 200 + (487.1008000 - 200\theta(1+z))t - 0.0005797992927\left((487.1008000 - 200(\theta(1+z))\right)t^3 \\ + t^2\left(8.449600000\theta(1+z) - 20.97381839 - \frac{1}{2}\theta(1+z)\left(487.1008000 - 200(\theta(1+z))\right)\right) \end{array} \right\}$$

$$E(t) = \left\{ \begin{array}{l} 120 + 1.53920000\mathrm{t} + \left(13.38643359 - 5.449600000\theta(1+z)\right)t^2 \\ + 0.0005797992927\left(487.1008000 - 200\theta(1+z)\right)t^3 \end{array} \right\}$$

$$I(t) = 80 + 2.5534320\mathrm{t} + \left(-0.01022349938\right)t^2$$

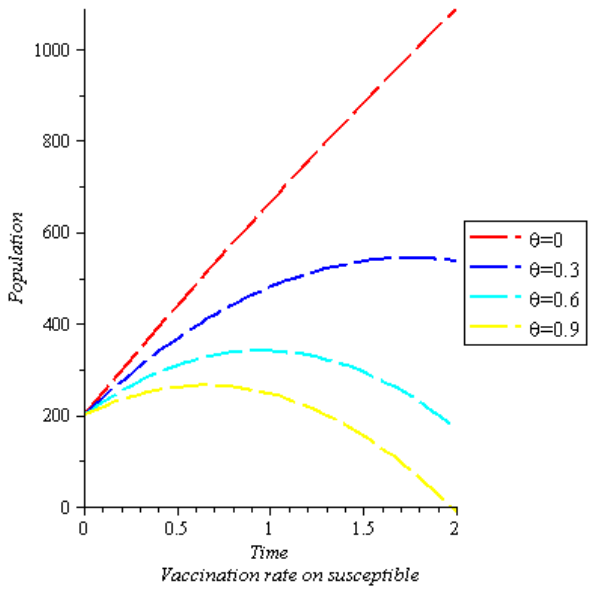
$$V(t) = \left\{ \begin{array}{l} 60 + (-1.8 + 200\theta(1+z))\mathrm{t} \\ + \left(0.02700000000 - 3\theta(1+z) - \frac{1}{2}\left(\theta(1+\mathrm{z}) - 487.1008000 - 200\theta(1+\mathrm{z})\right)\right)t^2 \end{array} \right\}$$

$$R(t) = 40 - 4.416880\mathrm{t} + 0.2955858139t^2 \quad D(t) = 40 - 1.1765520\mathrm{t} + 0.01802248546t^2$$

Results and Discussions

Results

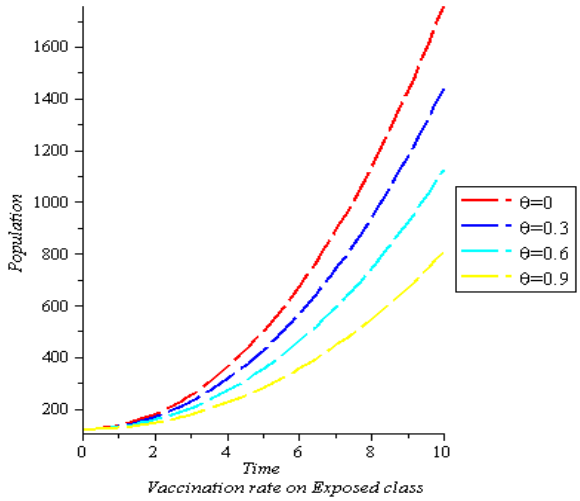
The acquired results for the numerical simulation are presented in Figures 1 to 4.



$s_0 = 200, e_0 = 120, i_0 = 80, v_0 = 60, r_0 = 40, D_0 = 40, \beta = 0.655, \gamma = 0.0445, \Lambda = 500$

$\delta_1 = 0.0035, \delta_2 = 0.04539, \alpha = 0.1, \rho = 0.48, \lambda = 0.002, \mu = 0.03, \sigma = 0.0002931, z = 0.5$

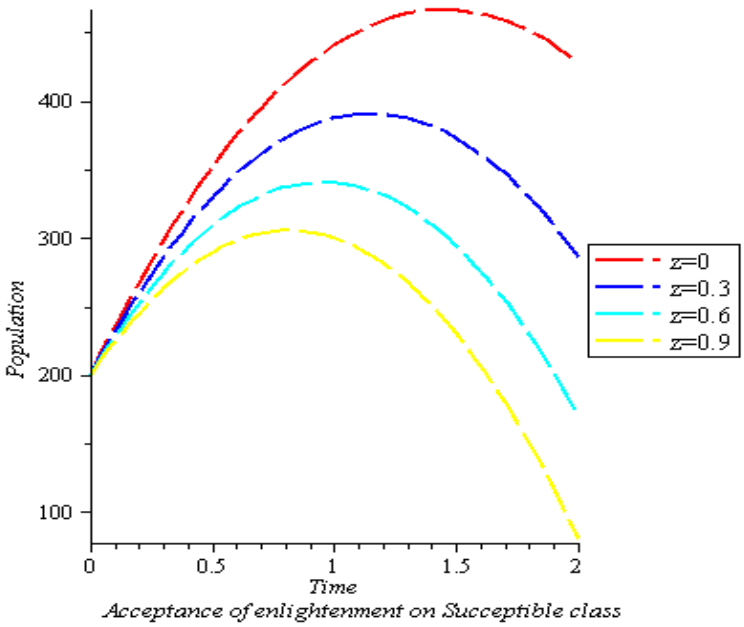
Figure 1: Effects of vaccination rate on susceptible individuals.



$s_0 = 200, e_0 = 120, i_0 = 80, v_0 = 60, r_0 = 40, D_0 = 40, \beta = 0.655, \gamma = 0.0445, \Lambda = 500$

$\delta_1 = 0.0035, \delta_2 = 0.04539, \alpha = 0.1, \rho = 0.48, \lambda = 0.002, \mu = 0.03, \sigma = 0.0002931, z = 0.5$

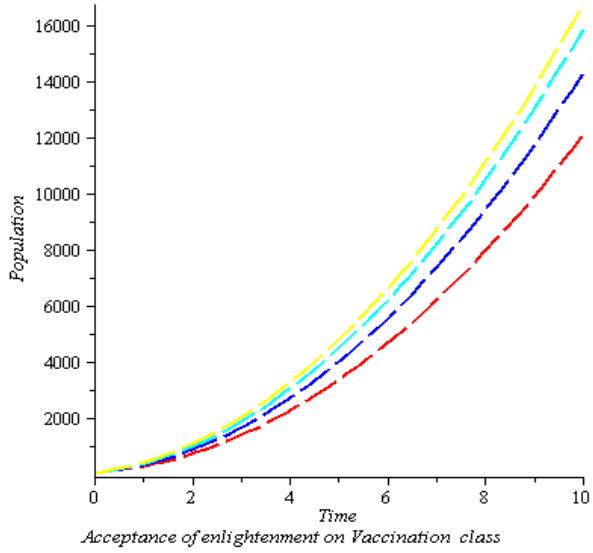
Figure 2: Effects of vaccination rate on exposed individuals.



$s_0 = 200, e_0 = 120, i_0 = 80, v_0 = 60, r_0 = 40, D_0 = 40, \beta = 0.655, \gamma = 0.0445, \Lambda = 500$

$\delta_1 = 0.0035, \delta_2 = 0.04539, \alpha = 0.1, \rho = 0.48, \lambda = 0.002, \mu = 0.03, \sigma = 0.0002931, \theta = 0.6$

Figure 3: Impacts of acceptance rate of enlightenment z on susceptible class.



$s_0 = 200, e_0 = 120, i_0 = 80, v_0 = 60, r_0 = 40, D_0 = 40, \beta = 0.655, \gamma = 0.0445, \Lambda = 500$

$\delta_1 = 0.0035, \delta_2 = 0.04539, \alpha = 0.1, \rho = 0.48, \lambda = 0.002, \mu = 0.03, \sigma = 0.0002931, \theta = 0.6$

Figure 4: Impacts of acceptance rate of enlightenment z on vaccination class.

Discussion

The graphs (Figures 1–4) reveal the impacts of vaccination and acceptance of enlightenment rate in the prevalence of COVID-19. It could be observed that vaccination is a good control factor that

should be implemented by health care workers to reduce the disease outburst. Figure 1 particularly indicates that high rate of vaccination tends to reduce the number of individuals prone to contacting the disease. In fact, this correlates with the simulation outcome presented in Figure 2 where a drastic reduction in the number of exposed population is observed. Figures 3 and 4 show that the rate of prevalence of COVID-19 is dependent on the rate at which people accept the enlightenment to be vaccinated. An observation from the presented graph in Figure 4 shows that more people tend to be vaccinated if the rate at which the populations embrace enlightenment to be vaccinated is high. Figure 3 confirms a transitive property of the enlightenment parameter on the vaccination and susceptible class of the model, respectively. It signifies that the higher the enlightenment rate, the more people tend to be vaccinated and the less people tend to be prone to contact the disease.

Conclusion and recommendation

The analysis, simulation and results obtained from this research work showed that effective vaccination should be implemented to curb the spread of COVID-19 pandemic. It is advised that the media and health care workers should enlighten the masses to go for awareness programs as it will boost the rate at which people see positivity in taking vaccine.

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Declaration

The authors declare that there are no conflicts of interest concerning the publication of this paper.

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