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Modelling the Transmission Dynamics of COVID-19 Incorporating public Enlightenment Campaign

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ABSTRACT: A mathematical model to study the transmission dynamics of COVID-19 incorporating public enlightenment campaign as control is presented. The effective reproduction number (R_c) was computed using the next generation method. Using the Lyapunov method, the global stability of the disease-free equilibrium was found to be globally asymptotically stable whenever $R_c \leq 1$. Sensitivity analysis was conducted on the effective reproduction number in order to determine parameters of the model that are most sensitive and targeted by way of intervention strategies. Numerical simulations of the COVID-19 model shows that if 90% of both treatment and public enlightenment campaign is achieved, the pandemic will be greatly controlled and subsequently eradicated in the population.

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Corona virus disease COVID-19 is an infectious disease which was first identified amid an outbreak of respiratory illness caused in Wuhan City, China (Cennimo, 2021). The corona virus has been responsible for 270,327,277 cases and 5,316,017 deaths globally, European Center for Disease Prevention and Control (ECDC), (2021). In Nigeria, it is on record that 217, 481 cases have been confirmed while 2,981 deaths recorded so far (Nigeria Centre for Disease Control (NCDC), (2021) and World Health Organization, (WHO), 2021). The COVID-19 virus spreads primarily through droplets of saliva or discharge from the nose when an infected person coughs or sneezes (WHO, 2020). Thus, the disease spreads from one person to another as a result of close contact with an infected person. Symptoms of COVID-19 may range from mild symptoms to severe illness. Symptoms may appear within 2-14 days after exposure to the virus and these include: fever, chills, cough, shortness of breath or difficulty in breathing, sore throat, congestion or runny nose, fatigue, headache, muscle pain, loss of taste or smell, nausea, vomiting, and diarrhea (Felman, 2021). A test can detect the infection, even if there are no symptoms (CDC, 2021). Over the last two years, numerous models have been developed in order to understand the spread and control of COVID-19, see for example, Gweryina et al., (2021), William et al., (2021) and Iboi et al., (2021) just to mention a few have all developed mathematical models to study the transmission dynamics, control and prevention of COVID-19 pandemic. In all the papers referenced in this work, none considered public enlightenment campaign as one of the control strategies in curbing further spread of COVID-19. Public enlightenment campaign can help play a key role in educating the public about COVID-19 pandemic stressing the available control/prevention strategies among other steps that could help curb the spread of the pandemic. This could be achieved through the organization of workshops, television adverts and radio jingles to help enlighten the public about COVID-19. In this paper, a mathematical model to study the transmission dynamics of COVID-19 incorporating public

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enlightenment campaign as a control strategy is presented. This research is a modification of the work by Olaniyi et al., (2020) and based on the following assumptions: all successfully treated individuals become susceptible after treatment from the isolation centre, proper COVID-19 protocols are fully observed during burial rites of the dead, hence no need for the dead compartment, the present study incorporates the parameters of birth, death, and control strategies like the public enlightenment campaign, which was not captured in the works of Olaniyi et al., (2020), we neglect immigration of individuals into the country in order to curtain the spread of the pandemic, this study did not incorporate recovery class since individuals who are properly treated from the hospital moved to their various houses (become susceptible). Individuals who are either symptomatic (I) or Isolated (H) can die due to COVID-19 infections.

MATERIALS AND METHOD

The total population at time t, denoted by N is sub-divided into five (5) compartments of the susceptible individuals S , exposed individuals E, symptomatic individuals I , asymptomatic individuals A and isolated individuals H.

Let Λ be the recruitment number into the susceptible into the population, γ be the recovery rate and β be the rate of transmission of the COVID-19 pandemic. μ is the natural death rate associated to all the compartments. α represents the rate at which humans exposed to COVID-19 progress from the exposed state to either the symptomatic or asymptomatic compartments after the incubation period of 14 days. The parameter l_1 represents the rate of individuals with symptoms after the incubation period. As a result, the rate of the individuals that do not show symptoms after incubation period is $(1 - l_1)$.

The parameters h_1 and h_2 represent the rates at which individuals are isolated in both the symptomatic and asymptomatic compartments respectively. COVID-19 is known to have caused several deaths; the parameter δ represents the rate at which people die due to COVID-19 pandemic. The above description of variables and parameters are summarized on Tables 1 and 2 respectively.

While the flow diagram used in the formulation of the COVID-19 model is presented in figure 1. With the descriptions of the variables and parameters on Tables 1 and 2, assumptions and the flow diagram in Figure 1, the following set of non-linear ordinary differential equations were derived:

$$\frac{dS}{dt} = \Lambda - \lambda S + \gamma H - \mu S \tag{1}$$

$$\frac{dE}{dt} = \lambda S - (\alpha + \mu)E \tag{2}$$

$$\frac{dI}{dt} = l_1 \alpha E - (h_1 + \mu + \delta)I \tag{3}$$

$$\frac{dA}{dt} = (1 - l_1)\alpha E - (h_2 + \mu)A \tag{4}$$

$$\frac{dH}{dt} = h_1 I + h_2 A - (\mu + \gamma + \delta)H \tag{5}$$

where,

$$\lambda = \frac{(1-\psi)\beta(I+A+H)}{N}$$
(6)

$$N(t) = S(t) + E(t) + I(t) + A(t) + H(t) \tag{7}$$

Basic Properties of the Model: For Model $(1) - (5)$ to be epidemiologically meaningful, it is important to prove that all its state variables are positive for all time(t).

Positivity and boundedness of solutions: Consider the biologically feasible region

$$\mathcal{M} = \left\{(S, E, I, A, H) \in \mathbb{R}_5^+ : N \leq \frac{\Lambda}{\mu}\right\}$$

It can be shown that the set $\mathcal{M}$ is a positive invariant set.

Lemma 1. The region $\mathcal{M}$ is positively invariant for the system $(1) - (5)$

Proof. The total human population is given by (7) and its rate of change is

$$\frac{dN}{dt} = \Lambda - \mu N - \delta(I + H) \tag{8}$$

Since the right-hand side of (2.8) is bounded by $\Lambda - \mu N$, a standard comparison theorem as outlined in the works of Iboi and Okounghae (2016) was applied here.

$$N(t) \leq N(0)e^{-\mu t} + \frac{\Lambda}{\mu}(1 - e^{-\mu t})$$

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

As $t \to \infty$, the population size $N(t)$ approaches

$$0 \leq N(t) \leq \frac{\Lambda}{\mu}, \Longrightarrow N(t) \leq \frac{\Lambda}{\mu} \tag{9}$$

Thus, $\mathcal{M}$ is positively invariant. In this region, the model $(1) - (5)$ can be considered as being epidemiologically meaningful and mathematically well posed.

Table 1. Description of Variables in the COVID-19 Model

Variables	Interpretation
$S(t)$	Number of susceptible individuals at time, t.
$E(t)$	Number of exposed individuals (though infectious) at time, t.
$I(t)$	Number of symptomatic individuals at time, t.
$A(t)$	Number asymptomatic individuals at time, t
$H(t)$	Number of isolated individuals undergoing treatment at time, t.

Table 2. Description of Parameters in the COVID-19 Model

Parameters	Interpretation
Λ	Recruitment number into the susceptible class
ψ	Public enlightenment campaign
β	Effective transmission coefficient
α	Rate of disease progression from exposed class
l_1	Proportion of exposed with symptoms after the incubation period
$1-l_1$	Proportion of exposed without symptoms after the incubation period
h_1	Isolation rate for symptomatic class
h_2	Isolation rate for asymptomatic class after confirmation
γ	Recovery rate from isolation class
δ	COVID-19 induced mortality rate
μ	Natural death rate

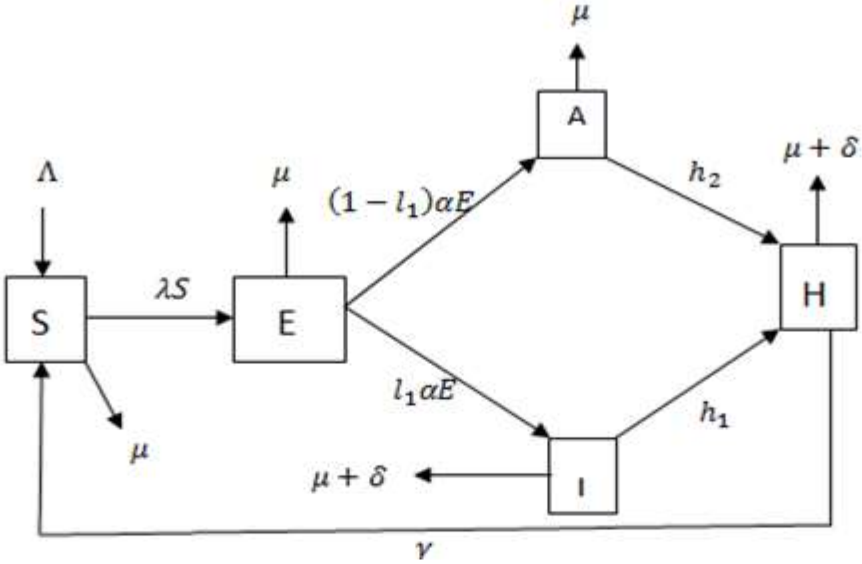

Fig 1. Flow diagram for the model (1)-(5) where $\lambda = \frac{(1-\psi)\beta(I+A+H)}{N}$

RESULTS AND DISCUSSION

The disease-free equilibrium (DFE) of the model $(1)-(5)$ is given by

$$E_0 = (S^0, E^0, A^0, I^0, H^0) = (\frac{\Lambda}{\mu}, 0,0,0,0) \quad (10)$$

Effective Reproduction Number R_c: Local Stability of Disease-Free- Equilibrium: The linear stability of E_0 can be established using the next generation method on the model $(1)-(5)$. Thus, it follows that the matrices F and V which represents new infection and rate of transfer of individuals respectively are given by

$$F = \begin{pmatrix} 0 & \beta(1-\psi) & \beta\varepsilon_1(1-\psi) & \beta\varepsilon_2(1-\psi) \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \quad (11)$$

and

$$V = \begin{pmatrix} k_1 & 0 & 0 & 0 \\ -l_1\alpha & k_2 & 0 & 0 \\ -(1-l_1)\alpha & 0 & k_3 & 0 \\ 0 & -h_1 & -h_2 & k_4 \end{pmatrix} \quad (12)$$

$k_1 = \alpha+\mu$, $k_2 = h_1+\mu+\delta$, $k_3 = h_2+\mu$, $k_4 = \mu+\gamma+\delta$

It follows that the effective reproduction number R_c of the model (1)-(5) is given by

$$R_c = \rho(FV^{-1}) = \frac{\beta(1-\psi)l_1\alpha}{k_1k_2} + \frac{\beta(1-\psi)(1-l_1)\alpha}{k_1k_3} + \frac{\beta(1-\psi)[l_1h_1k_3+(1-l_1)h_2k_2]\alpha}{k_1k_2k_3k_4} \quad (13)$$

Where $\rho(FV^{-1})$ is the spectral radius of the matrix FV^{-1}. Equation (13) is the effective reproduction number R_c of the COVID-19 model (1)-(5). By definition, it is the average number of secondary COVID-19 cases generated by an infected COVID-19 individual in a completely susceptible population.

The results below follows from Theorem 2 in van den Driessche and Watmough (2002).

Lemma 2. The disease-free equilibrium E_0 is locally asymptotically stable when $R_c < 1$ and unstable when $R_c > 1$.

Global Stability of the Disease-Free Equilibrium State

Lemma 3. If $R_c \le 1$, the disease-free equilibrium E_0 of the model (2.1) - (2.5) is globally asymptotically stable.

Proof: Here, we follow a similar approach as outlined in the works of Iboi and Okounghae (2016) to establish the global stability of the disease-free- equilibrium.

From the model $(1)-(5)$, we construct the linear Lyapunov function as follows:

$$V = B_1E + B_2I + B_3A + B_4H$$

With Lyapunov derivative

$$\frac{dV}{dt} = B_1\frac{dE}{dt} + B_2\frac{dI}{dt} + B_3\frac{dA}{dt} + B_4\frac{dH}{dt}$$

$$= \frac{\beta(1-\psi)(I+A+H)S}{N}[l_1\alpha k_3k_4 + (1-l_1)\alpha k_2k_4 + l_1h_1k_3\alpha + (1-l_1)h_2k_2\alpha] - I[k_1k_2k_3(k_4 + h_1) - k_1k_2k_3h_1] - A[k_1k_2k_3(k_4+h_2) - k_1k_2k_3h_2] - H[k_1k_2k_3k_4]$$

$$= k_1k_2k_3k_4\left[\frac{\beta(1-\psi)[l_1\alpha k_3k_4+(1-l_1)\alpha k_2k_4+l_1h_1k_3\alpha+(1-l_1)h_2k_2\alpha}{k_1k_2k_3k_4} - 1\right][I+A+H] \quad (14)$$

It follows from (14) that since $S(t) \le N(t)$ and $N(t) \le \frac{\Lambda}{\mu}$ in μ for all $t > 0$

$$\frac{dV}{dt} \le k_1k_2k_3k_4(R_c - 1)(I+A+H)$$

Hence, $\frac{dV}{dt} \le 0$ if $R_c \le 1$ with $\frac{dV}{dt} = 0$ if and only $I = A = H = 0$.

Therefore, $\frac{dV}{dt}$ is a Lyapunov function in $\mathcal{M}$ and it follows from Lasalle's invariance principle (Lasalle and Lefschete, 1976) that every solution of the equations in $(1)-(5)$ with initial conditions in $\mathcal{M}$ converges to E_0 as $t \to \infty$, that is $(E(t), I(t), A(t), H(t)) \to (0,0,0,0)$ as $t \to \infty$.

Substituting $E = I = A = H = 0$ into (1) gives $S(t) \to \frac{\Lambda}{\mu}$ as $t \to \infty$.

Thus, $(S, E, I, A, H) \to (\frac{\Lambda}{\mu}, 0,0,0,0)$ as $t \to \infty$ for $R_c \le 1$, so the DFE, E_0, is globally asymptotically stable in $\mathcal{M}$ if $R_c \le 1$. Hence the proof.

Having established the proof for local and global stability of the disease-free equilibrium state, it is extremely important to establish the bounds for both the COVID-19 transmission rate and the public enlightenment campaign.

From (13), we obtain,

$$\beta < \frac{1}{C+D+E} \quad (15)$$

Where $C = \frac{(1-\psi)l_1\alpha}{k_1k_2}$, $D = \frac{(1-\psi)(1-l_1)\alpha}{k_1k_3}$ and $E = \frac{(1-\psi)[l_1h_1k_3+(1-l_1)h_2k_2]\alpha}{k_1k_2k_3k_4}$

and

$$\psi < \frac{F+G+J+1}{F+G+J} \quad (16)$$

Where $F = \frac{l_1\alpha}{k_1k_2}$, $G = \frac{(1-l_1)\alpha}{k_1k_3}$

and $J = \frac{[l_1h_1k_3+(1-l_1)h_2k_2]\alpha}{k_1k_2k_3k_4}$

From (15) an upper bound for the infection rate β was obtained.

This suggests that for COVID-19 to be put under control in the population, the infection rate β should not exceed the value given by the right-hand side of (15) while equation (16) suggests that for public enlightenment campaign about COVID-19 to be effective, the campaign rate should target a value greater that the right hand of (16).

Sensitivity Analysis: Sensitivity analysis is conducted on the effective reproduction number using the normalized forward sensitivity index in order to determine the parameters that are most sensitive and that should be targeted by way of intervention strategies.

Mathematically, the normalized forward sensitivity index of a parameter (α) that depends on differentiable (R_c) (Williams *et al*, 2020) is expressed as:

$$X_{\alpha}^{R_c} = \frac{\partial R_c}{\partial x} \times \frac{\alpha}{R_c} \qquad (17)$$

The results obtained from the analysis are presented in Table 3. The table shows that parameters with positive index will increase the endemicity of the pandemic while those with negative index will reduce the endemicity of the pandemic.

Table 3. Numerical Value of the Sensitivity Index

S/NO	Parameter	Sensitivity index
1	β	$+1.00000$
2	α	$+0.02534$
3	h_1	-0.01074
4	γ	-0.06352
5	l_1	-0.34187
6	h_2	-0.35016
7	δ	-0.54515
8	ψ	-1.00000

Numerical Simulations: In this section, numerical simulation of the COVID-19 model (1)-(5) is performed using a set of reasonable estimated parameter values and initial conditions for the variables presented on Table 1. Some parameter values were assumed while others were gotten from other published articles as acknowledged in this paper. The simulation of the model (1)-(5) was done using Maple 17 mathematical software.

Table 4. Initial Conditions for the Variables

S/NO	Variable at Initial Condition	Value	Source
1	S(0)	1000	Assumed
2	E(0)	500	Assumed
3	I(0)	250	Assumed
4	A(0)	200	Assumed
5	H(0)	159	Assumed

Table 5. Parameter Values

Parameter	Value	Source
Λ	20	Assumed
ψ	0.001-0.9	Assumed
β	0.5	Assumed
δ	0.2	Williams *et al* (2020)
α	0.1923	Olaniyi *et al* (2020)
l_1	0.5	Olaniyi *et al* (2020)
h_1	0.33604	Olaniyi *et al* (2020)
h_2	0.19466	Olaniyi *et al* (2020)
γ	0.03	Assumed
μ	0.005	Williams *et al* (2020)

Figure 2 shows that strengthening public enlightenment campaign at 90% level among the susceptible population will greatly reduce the number of persons who will be exposed or infected with COVID-19 pandemic. Figure 3 reveals that, administering proper treatment at 90% level will lead to the prompt recovery of individuals in the isolation centres.

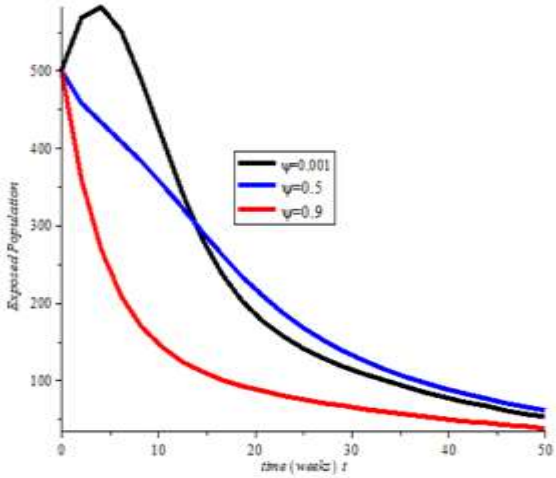

Fig 2. Impact of public enlightenment campaign on the susceptible population

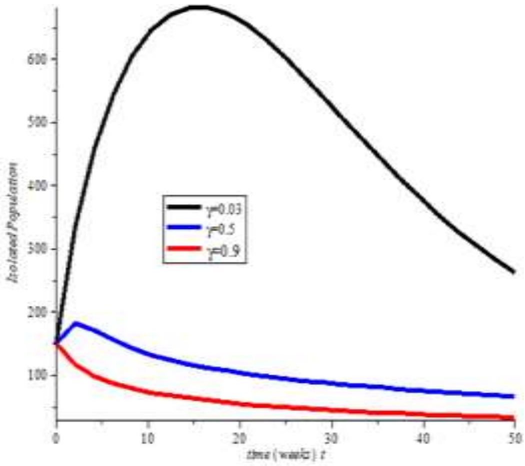

Fig 3. Impact of increasing the recovery rate through treatment of individuals at the isolation centres

Conclusion: A mathematical model to study the transmission dynamics of COVID-19 incorporating public enlightenment campaign is presented. The model was found to be locally asymptotically stable when $R_c < 1$ and globally asymptotically stable whenever $R_c \leq 1$. A bound for COVID-19 transmission rate and that of public enlightenment campaign was obtained. Finally, numerical simulations conducted on the model reveal that, 90% of treatment and public enlightenment campaign must be attained for COVID-19 to be put under control in the population.

REFERENCES

Cennimo, D J (2021). Coronavirus Disease 2019 (COVID-19): Practice Essentials, Background, Route of Transmission. Emedicine.Medscape.Com. https://emedicine.medscape.com/article/2500114-overview#a1

Centre for Disease Control. (2020). Coronavirus Disease 2019 (COVID-19). Centers for Disease Control and Prevention. https://www.cdc.gov/coronavirus/2019-ncov/science/science briefs/scientific-brief-sars-cov-2.html.

Centers for Disease Control. (2021). Different COVID-19 Vaccines. Centers for Disease Control and Prevention. https://www.cdc.gov/coronavirus/2019-ncov/vaccines/different-vaccines.html

Centre for Disease Control. (2020). COVID-19 and Your Health. Centers for Disease Control and Prevention. https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html

European Center for Disease Prevention and Control (2021). COVID – 19 Situation Update Worldwide, as of week 49, updated 16 December 2021. Retrieved on December 20, 2021 from https://www.ecdc.europa.eu>giographic-distribution-world-wide.

Felman, A. (2021). What to know about coronaviruses. Medicalnewstoday.Com. Retrieved on December 18, 2021 from https://www.medicalnewstoday.com/articles/256521#covid-19

Gweryina, RI; Madubueze, CE; Kaduna, FS (2021). Mathematical assessment of the role of denial on COVID-19 transmission with non-linear incidence and treatment functions. Scientific African, 12: e00811, doi; 10.1016/j.sciaf. 2021. e00811.

Iboi, E; Sharomi, O; Ngonghala, CN; Gumel, AB (2020). Mathematical modelling and analysis of COVID-19 pandemic in Nigeria. *Math. Bios. Eng.*, *17*(6), 7193–7221.

Iboi, E; Okuonghae, D (2016). Population dynamics of a mathematical model for syphilis. *Appl. Math. Modelling*, 40: 3573-3590.

Mumbu, ARJ; Hugo, AK (2020). Mathematical modelling on COVID-19 transmission impacts with preventive measures: a case study of Tanzania. *J. Biol. Dyn.*, *14*(1), 748–766.

Nigeria Centre for Disease Control. (2021). NCDC CoronavirusCOVID-19 Microsite. Retrieved on December 10, 2021 from https://covid19.ncdc.gov.ng/.

Olaniyi, S; Obabiyi, O; Okosun, K; Oladipo, A; Adewale S (2020). Mathematical modelling and optimal cost-effective control of COVID-19 transmission dynamics. *Eur. Phys. Journal Plus.* 135. 938. 10.1140/epjp/s13360-020-00954-z.

Van den Driessche, P; Watmough, J (2002). Reproduction numbers and sub-threshold endemic equilibria for compartmental models of disease transmission. *Math. Bios.*, 180 : 29-48.

William, A; David, O; Tenuche, BS; Samuel, OK; Alih, DM; Johnson, A (2021). Mathematical Model of the Transmission Dynamics of Corona Virus Disease (COVID-19) and Its Control. *Asian Res. J. Math*, *16*(11): 69-88.

World Health Organisation. (2021). WHO Coronavirus (COVID-19) Dashboard. With Vaccination Data. Retrieved on December 7, 2021 from https://covid19.who.int/.