Original Research Article

Mathematical Model on the Control/Eradication of the Consumption of *Cannabissativa* in Afikpo North Local Government Area of Ebonyi State, Nigeria.

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ABSTRACT

The present work studied the dynamics of the interaction of the susceptible and victims of *Cannabissativa* smoking/consumption using a mathematical model SEIR (Susceptible, Exposed, Infected, and Recovered/Removed) approach with sensitive control parameters introduced accordingly.We strive at developing a set of model equations from a schematic diagram designed as to enable us conduct some necessary analyses for the study.We derive a deterministic model on the control/eradication of *Cannabissativa* smoking/consumption in Afikpo North Local Government Area of Ebonyi State via (a). Developing proper and all-encompassing schematic diagram from where the necessary differential equation will be generated for use for the research analyses, (b). Introducing/employing of ideal control parameters or measures at the right/vital compartments in the schematic diagram, (c). Conducting the three (3) relevant/basic analyses such as (i) Stability, (ii) Endemicity, (iii) Sensitivity analyses of the model equations, (d). Simulating the system using a derived sensitivity index table with the help of R_0, and (e). Interpreting the resulting graphs that will provide the effective control measures on the use of *Cannabissativa*. The results show that, of all the five (5) control parameters, τ (which is the enlightenment control on the dangers and health hazards associated with the use of *Cannabissativa*) is the most effective. The Government is then advised to set up an agency to be saddled with the responsibility of conducting enough sensitization on the dangers as well as the health hazards associated with the use of *Cannabissativa*.

Keywords: Dynamics of interaction; victims of Cannabis sativa; consumption; health hazards; control parameter.

1. INTRODUCTION

Cannabis sativa also known as Indian hemp, is an annual herbaceous flowering plant indigenous to Eastern Asia, but now of cosmopolitan distribution due to widespread cultivation [1]. *Cannabissativa* has been cultivated throughout recorded history, used as a source of industrial fiber, seed oil, food, recreation, religious and spiritual moods and medicine [2]. *Cannabissativa*has also been used in making clothes and in the production of lightening soaps. It has been used to treat many ailments such as pain, insomnia,loss of appetite, depression,etc. Presently, *Cannabis* is most widely used for its ability to intoxicate, as well as for medical reasons [3].

Cannabis contains at least one hundred and twenty (120) active ingredients or cannabinoids [4]. The most abundant ones are cannabidiol (CBD) and delta-9 tetrahydrocannabinol (THC). Some cannabinoids can have euphoric or psychoactive effects. THC produces both effects. Cannabidiol is present in various forms including; (i) Oils toapply on the skin,(ii) Capsules to be taken as supplement and (iii) Gummy candies. *Cannabis* can be used in the following ways; (i) Smoking or vaping it, (ii) Brewing it as tea, (iii) Consuming it in the form of edibles such as brownies or candies, (iv) Eating it raw, (v) Applying it as a topical treatment and (vi) Taking it as capsules or supplements.

Nonetheless, *Cannabis* appear to posess a more demeaning and agonizing effects on victims that smoke or consume this substance. Many victims of *Cannabis* have ended up running mad or being completely deranged as a result of its psychoactive effects in the systems of the victims. It has rendered many of our youths today useless. The side effects of consuming/smoking marijuana/cannabis are too numerous to mention.

In 2018, Food and Drug Administration (FDA) approved a drug named EPIDIOLEX for the treatment of two rare and severe types of epilepsy which is a medication derived from *Cannabis*.According Orrin et al [5], open-space use of highly purified CBD (Epidiolex) deficiency disorder and Aicardi Dup15q, and Doose syndromes was discussed. It is a purified form of CBD that does not contain THC. However, the bad effects of this substance cannot be over emphasized. Quitting the use of this substance after a long duration of use is associated with irritability, mood changes, insomnia, cravings, restlessness, decreased appetite and general discomfort. These symptoms tend to peak within the first week after stopping and last up to two weeks according to research. Research has not found exactly how frequent and long-term use of cannabis/marijuana affects persons' health.

A british doctor conducted a research study on patients in India to determine the medicinal effects of *Cannabis* on some diseases such as tetanus, rabies, and rheumatism. His research led to the popular use of this drug in some notable countries and cities world over [6]. In 1972, a group of researchers carried out a study on the medical effects of *Cannabis* (marijuana) and found out that it could treat glaucoma by reducing the pressure in the eye [7]. Another research study was conducted in 1975 on marijuana as an effective soothing medicine to reduce the nausea and side-effects of AIDS-related medications [8]. Menetrey et al [9] developed a mathemathical model for the prediction of time of *Cannabis* exposure while Chapwanya et al [10] developed a model for *Cannabis* epidemic in a South African province with a non-linear incidence rate. Toben et al [11] looked at the implementation of mathematical models to predict new *Cannabis* use by urine drug testing: it is time to move forward, while Abramson et al [12] considered the importance of mathematical models to explore the effects of marijuana and other plant based products on learning and memory in their respective study. Saini et al [13] discussed a topic entitled'Hempseed (*Cannabis sativa L*) bulk mass modelling based on engineering properties in their study'. The present study is based on a mathematical model on control/eradication of consumption of *Cannabissativa*.

2. MODEL FORMULATION.

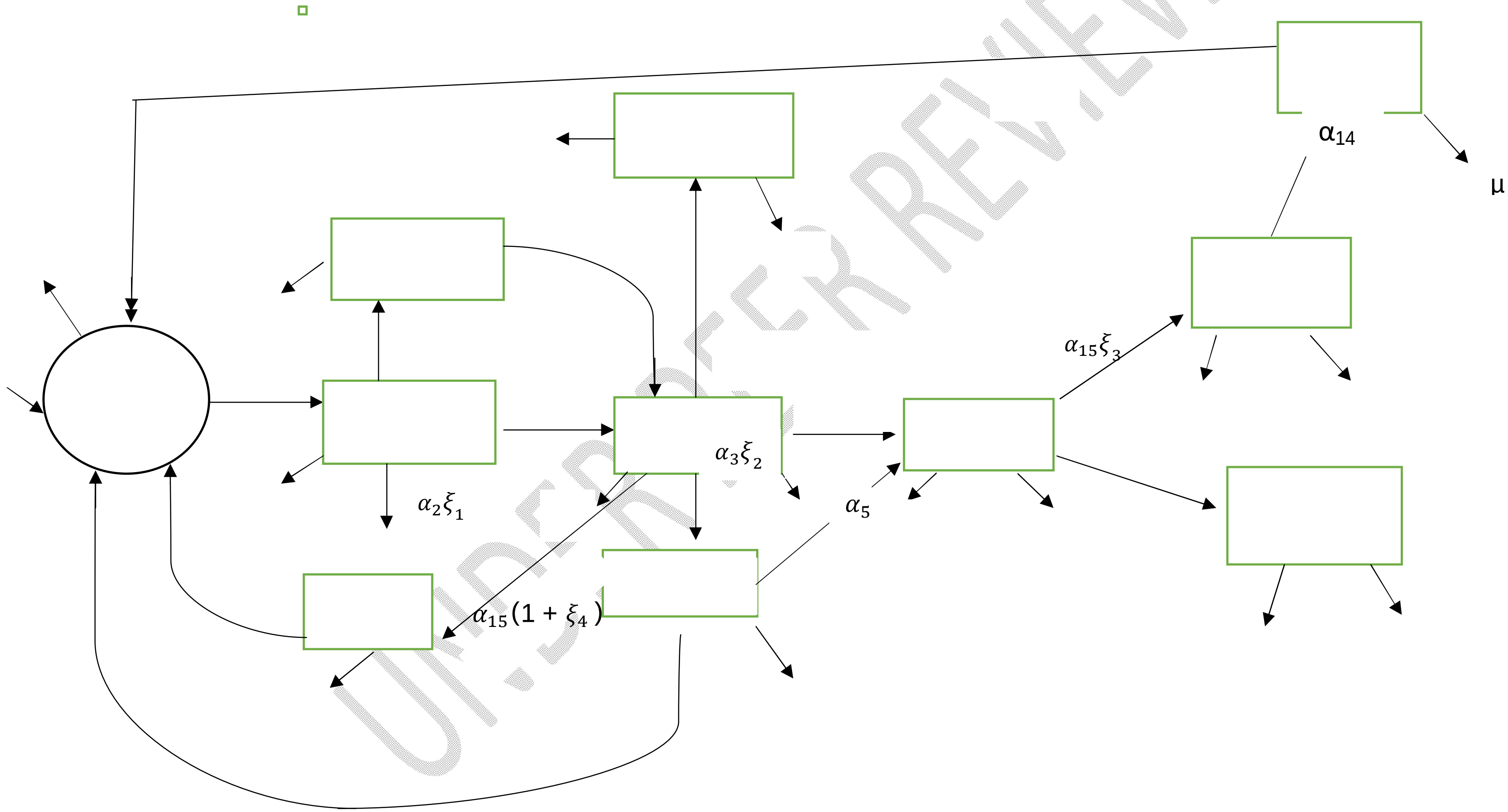

Fig. 1. Schematic diagram of *Cannabissativa* consumption.

2.1 Emanating equations from the schematic diagram of *Cannabissativa*

$$\frac{ds}{dt} = \wedge + \alpha_8 E_B + \alpha_9 A_R + \alpha_{12} R - (\beta\tau + \mu)S.$$

$$\frac{dE}{dt} = \beta\tau S - [\alpha_1(1-\xi_1) + \alpha_2\xi_1 + \mu + \alpha_{10}]E$$

$$\frac{dE_{NB}}{dt} = \alpha_1\left(1-\xi_1\right)E - (\mu + \alpha_7)E_{NB}$$

$$\frac{dE_B}{dt} = \alpha_{15}(1+\xi_4)A - (\mu + \alpha_8)E_B$$

$$\frac{dA}{dt} = \alpha_{10}E + \alpha_7 E_{NB} - (\alpha_4[1-\xi_2] + \alpha_3\xi_2 + \alpha_{11} + \mu + \delta_2)A$$

$$\frac{dA_{DP}}{dt} = \alpha_4(1-\xi_2)A - (\mu + \delta_1)A_{DP}$$

$$\frac{dA_R}{dt} = \alpha_3\xi_2 A - (\mu + \alpha_5 + \alpha_9)A_R$$

$$\frac{dM}{dt} = \alpha_5 A_R + \alpha_{11}A - (\mu + \delta_3 + \alpha_{15}\xi_3 + \alpha_{13}[1-\xi_3])M$$

$$\frac{dM_{IT}}{dt} = \alpha_{15}\xi_3 M - (\mu + \delta_5 + \alpha_{14})M_{IT}.$$

$$\frac{dM_{NT}}{dt} = \alpha_{13}(1-\xi_3)M - (\mu + \delta_4)M_{NT}$$

$$\frac{dR}{dt} = \alpha_{14}M_{IT} - (\mu + \alpha_{12})R$$

$$\beta = \frac{\lambda_1 E + \lambda_2 E_{NB} + \lambda_3 E_B + \lambda_4 A + \lambda_5 A_{DP} + \lambda_6 A_R + \lambda_7 M + \lambda_8 M_{IT} + \lambda_9 M_{NT}}{N}$$

Parameter description

β is the interactional force between the susceptible and the victims of *Cannabissativa* while $\lambda_1, \lambda_2, \dots \dots, \lambda_9$ are the contact rates in their respective compartments.

$$N = S + E + E_{NB} + E_B + A + A_{DP} + A_R + M + M_{IT} + M_{NT} + R.$$

E= Exposed to *Cannabissativa*

E_{NB}= Exposed and NOT backed out

E_B= Exposed and backed out

A= Addicted

A_{DP}=Addicted and deranged permanently.

A_R = Addicted and sent to Rehabilitation Centre

M= Full blown madness

M_{IT} = Mad but isolated and being treated

μ= Natural death rate.

δ_1, δ_2,δ_3, &δ_4 = disease induced death rate.

M_{NT}=Mad but not isolated for treatment.

R= Removed

τ= Information on the dangers of *Cannabissativa*

ξ_1=Abstain from the use of cannabis Sativa (back out)

ξ_2=Go to Rehabilitation centre

ξ_3= Isolate and treat.

$\xi_{4=}$Intensive campaign against the consumption of cannabis.

$\alpha_1, \alpha_2, \dots \dots, \alpha_{15}$= Progression rates

Note: $\xi_1 \leq 1$. If it is equal to 1, then there is 100% control informing/ asking victims to back out. Hence $E_{NB} = 0$.

$\xi_2 \leq 1$. If it is equal to 1, then, there is 100% control insisting that victims should go to Rehabilitation centre, thus $A_D = 0$.

$\xi_3 \leq 1$. If it is equal to 1, then, there is 100% control insisting that victims should be taken to specialists for treatment, thus $M_{NT} = 0$.

The logical thing following the controls $\xi_1, \xi_2$and ξ_3 being equal to 1 each signifies the sensitivity/effectiveness of the control.

The five controls:

1. τ= Information on the dangers of *Cannabissativa*.
2. ξ_1= Abstain from further use (back out).
3. ξ_2= Go to Rehabilitation center.
4. ξ_3=Isolate and go for treatment.
5. ξ_4= Intensive campaign against the consumption of *Cannabis*.

In a society free from the consumption of *Cannabissativa* (SFC) which is the Equilibrium State, the following condition is obtainable

$$E = E_{NB} = E_B = A = A_{DP} = A_R = M = M_{IT} = M_{NT} = 0$$

Thus $\wedge - \mu s = 0$

$\Rightarrow S = \frac{\wedge}{\mu}$.

Hence $E^0 = (\frac{\wedge}{\mu}, 0,0,0,0,0,0,0,0,0,0) \in \mathbb{R}^{11}$

3. STABILITY ANALYSIS OF THE EQUILIBRIUM STATE OF SFC.

The stability of this model can be determined if we can examine the model behaviour near the equilibrium solution. Given the possibility for a total eradication of smoking/consuming *Cannabissativa* in our environment, the condition that will enhance or enable such reality shall be determined as elaborately discussed below:

$$\Lambda + \alpha_8 E_8 + \alpha_9 AR + \alpha_{12} R - (\beta\tau + \mu)S = 0$$

$$\beta\tau S - (\alpha_1(1-\xi_1) + \alpha_2\xi_1 + \mu + \alpha_{10})E = 0$$

$$\alpha_1(1-\xi_1)E - (\mu + \alpha_7)E_{NB} = 0$$

$$\alpha_{15}(1 + \xi_4) - (\mu + \alpha_8)E_B = 0$$

$$\alpha_{10}E + \alpha_7 E_{NB} - (\alpha_4(1-\xi_2) + \alpha_3\xi_2 + \alpha_{11} + \mu + \delta_2)A = 0$$

$$\alpha_4(1-\xi_2)A - (\mu + \delta_1)A_{DP} = 0$$

$$\alpha_3\xi_2 A - (\mu + \alpha_5 + \alpha_9)A_R = 0$$

$$\alpha_5 A_R + \alpha_{11}A - \left(\mu + \delta_3 + \alpha_{15}\xi_3 + \alpha_{13}(1-\xi_3)\right)M = 0$$

$$\alpha_{15}\xi_3 M - (\mu + \delta_5 + \alpha_{14})M_{IT} = 0$$

$$\alpha_{13}(1-\xi_3)M - (\mu + \delta_4)M_{NT} = 0$$

$$\alpha_{14}M_{IT} - (\mu + \alpha_{12})R = 0$$

By Jacobian matrix method to determine the Eigen-values, we shall linearize these systems of equations to get the following:

$$J = \begin{bmatrix} \frac{\partial f_1}{\partial s} & \frac{\partial f_1}{\partial E} & \frac{\partial f_1}{\partial E_{NB}} & \frac{\partial f_1}{\partial E_B} & \frac{\partial f_1}{\partial A} & \frac{\partial f_1}{\partial A_{DP}} & \frac{\partial f_1}{\partial A_R} & \frac{\partial f_1}{\partial M} & \frac{\partial f_1}{\partial M_{IT}} & \frac{\partial f_1}{\partial M_{NT}} & \frac{\partial f_1}{\partial R} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{\partial f_{11}}{\partial s} & \frac{\partial f_{11}}{\partial E} & \frac{\partial f_{11}}{\partial E_{NB}} & \frac{\partial f_{11}}{\partial E_B} & \frac{\partial f_{11}}{\partial A} & \frac{\partial f_{11}}{\partial A_{DP}} & \frac{\partial f_{11}}{\partial A_R} & \frac{\partial f_{11}}{\partial M} & \frac{\partial f_{11}}{\partial M_{IT}} & \frac{\partial f_{11}}{\partial M_{NT}} & \frac{\partial f_{11}}{\partial R} \end{bmatrix}$$

where J is the Jacobian matrix.

On evaluation we shall have the following:

$$J = \begin{bmatrix} -M_1 & 0 & 0 & \alpha_8 & 0 & 0 & \alpha_9 & 0 & 0 & 0 & \alpha_{12} \\ \beta\tau & -M_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\alpha_1\,(1-\xi_1\,) & -M_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \alpha_2\xi_1 & 0 & -M_4 & \alpha_{15}(1+\xi_4\,) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \alpha_{10} & \alpha_7 & 0 & -M_5 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \alpha_4\,(1-\xi_2\,) & -M_6 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \alpha_3\xi_2 & 0 & -M_7 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \alpha_{11} & 0 & \alpha_5 & -M_8 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha_{12}\xi_3 & -M_9 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha_{13}\,(1-\xi_3\,) & 0 & -M_{10} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha_{14} & 0 & -M_{11} \end{bmatrix}$$

Where, $M_1 = -(\beta_\tau + \mu)$, $M_2 = -[\alpha_1(1-\xi_1) + \alpha_2\xi_1 + \mu + \alpha_{10}]$, $M_3 = -(\mu + \alpha_7)$, $M_4 = -(\mu + \alpha_8)$, $M_5 = -\left(\alpha_4[1-\xi_2] + \alpha_3\xi_2 + \alpha_{11} + \mu + \delta_2\right)$, $M_6 = -(\mu + \delta_1)$, $M_7 = -(\mu + \alpha_5 + \alpha_9)$,

$$M_8 = -(\mu + \delta_3 + \alpha_{15}\xi_3 + \alpha_{13}[1-\xi_3]),\; M_9 = -(\mu + \delta_5 + \alpha_{14}),\; M_{10} = -(\mu + \delta_4),$$
$$M_{11} = -(\mu + \alpha_{12})$$

3.1 **Stability analysis of the equilibrium of a society free from the consumption of *Cannabissativa*(SFC) state.**

$$J(f_1, f_2, f_3, f_4, f_5, f_6, f_7, f_8, f_9, f_{10}, f_1, f_{11}) = \begin{bmatrix} \frac{\partial f_1}{\partial s} & \frac{\partial f_1}{\partial E} & \frac{\partial f_1}{\partial E_{NB}} & \frac{\partial f_1}{\partial E_B} & \frac{\partial f_1}{\partial A} & \frac{\partial f_1}{\partial A_{DP}} & \frac{\partial f_1}{\partial A_R} & \frac{\partial f_1}{\partial M} & \frac{\partial f_1}{\partial M_{IT}} & \frac{\partial f_1}{\partial M_{NT}} & \frac{\partial f_1}{\partial R} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{\partial f_{11}}{\partial s} & \frac{\partial f_{11}}{\partial E} & \frac{\partial f_{11}}{\partial E_{NB}} & \frac{\partial f_{11}}{\partial E_B} & \frac{\partial f_{11}}{\partial A} & \frac{\partial f_{11}}{\partial A_{DP}} & \frac{\partial f_{11}}{\partial A_R} & \frac{\partial f_{11}}{\partial M} & \frac{\partial f_{11}}{\partial M_{IT}} & \frac{\partial f_{11}}{\partial M_{NT}} & \frac{\partial f_{11}}{\partial R} \end{bmatrix},$$

where f_1 to f_{11} represent equations 1 to 11 respectively.

This produces an 11 x 11 Jacobian matrix as shown above.

Evaluating the Jacobian Matrix at the free *Cannabis* smoking Equilibrium (SFC) point, we shall obtain the following: In fact, at the SFC $E = E_{NB} = E_B = A = A_{DP} = A_R = M = M_{IT} = M_{NT} = R = 0$.

It will be pertinent to note that at the SFC, there is no interaction between the consumers of *Cannabissativa* and the susceptible class, hence the nullity of the interactional force β which is defined to be $\beta = \frac{\lambda_1 E+\lambda_2 E_{NB}+\lambda_3 E_B+\lambda_4 A+\lambda_5 A_{DP}+\lambda_6 A_R+\lambda_7 M+\lambda_8 M_{IT}+\lambda_9 M_{NT}}{N}$

At this point, and with the deductions above, we need to source for the characteristic equation of the Jacobian matrix evaluated at the SFC point.

Hence

$|J - \lambda I| =$

$$
\begin{vmatrix}
-M_1-\lambda_1 & 0 & 0 & \alpha_8 & 0 & 0 & \alpha_9 & 0 & 0 & 0 & \alpha_{12} \\
0 & -M_2-\lambda_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -\alpha_1(1-\xi_1) & -M_3-\lambda_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \alpha_2\xi_1 & 0 & -M_4-\lambda_4 & -\alpha_{15}(1+\xi_4) & 00 & 0 & 0 & 0 & 0 & 0 \\
0 & \alpha_{10} & \alpha_7 & 0 & -M_5-\lambda_5 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \alpha_4(1-\xi_2) & -M_6-\lambda_6 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \alpha_3\xi_2 & 0 & -M_7-\lambda_7 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \alpha_{11} & 0 & \alpha_5 & -M_8-\lambda_8 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha_{12}\xi_3 & -M_9-\lambda_9 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha_{13}(1-\xi_3) & 0 & -M_{10}-\lambda_{10} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha_{14} & 0 & -M_{11}-\lambda_{11}
\end{vmatrix}
$$

The characteristic equation of J* is given by

$$f(\lambda i) = [\lambda_1 + M_1][\lambda_2 + M_2][\lambda_3 + M_3][\lambda_4 + M_4][\lambda_5 + M_5][\lambda_6 + M_6][\lambda_7 + M_7][\lambda_8 + M_8][\lambda_9 + M_9][\lambda_{10} + M_{10}][\lambda_{11} + M_{11}]$$

Where $\lambda_1 = \mu$ since $\beta\tau = 0$ at SFC.

$\lambda_2 = -[\alpha_1(1-\xi_1) + \alpha_2\xi_1 + \mu + \alpha_{10}]$

$$\lambda_3 = -(\mu + \alpha_7)$$

$\lambda_4 = -(\mu + \alpha_8)$

$\lambda_5 = -(\alpha_4[1-\xi_2] + \alpha_3 E_2 + \alpha_{11} + \mu + \delta_2)$

$\lambda_6 = -(\mu + \delta_1 + \alpha_5)$

$\lambda_7 = -(\mu + \alpha_9)$,

$\lambda_8 = -(\mu + \delta_3 + \alpha_{12}\xi_3 + \alpha_{13}[1-\xi_3])$

$\lambda_9 = -(\mu + \delta_5 + \alpha_{12})$

$\lambda_{10} = -(\mu + \delta_4 + \alpha_{14})$

$\lambda_{11} = -(\mu + \alpha_{12})$.

It is asymptotically stable, which implies/ensures the convergence of the solution to this deterministic model.

4. SENSITIVITY ANALYSIS

4.1 Basic reproduction number of *Cannabissativa* consumption:

We study the sensitivity analysis of the parameters of the model by considering the basic reproduction number, $R_0 = \rho(FV^{-1})$. The spectral radius is represented by ρ which is the most dominant eigen-value of FV^{-1}. R_0 can be thought of as the number of cases one case of cannabis consumer generates on average over the course of his consumption period in a given area that is not used to it before. This metric is useful because it helps to determine whether or not a victim of cannabis (a consumer) can spread the use of cannabis through a population.

In general, if the individual who become addicted early may be more likely to introduce the idea of cannabis consumption randomly in a given population, then our computation of R_0 must account for this tendency. We will judge this by considering the fact that,when $R_0 < 1$, the contact rate will be very low. But if $R_0 > 1$, the contact rate will be very high leading to fast spread of cannabis consumption in the population. The higher the value of R_0 the harder it will be to control the escalation of consumers in the population. It is established that when $R_0 < 1$, then the SFC is locally asymptotically stable and consumers cannot invade the population but if $R_0 > 1$, the SFC is unstable and invasion is always possible.

With the basic Reproduction Number (R_0) of cannabis consumer at the SFC equilibrium state of this model, it is found that $E^0(S^0, E^0, E^0_{NB}, E^0_B, \ldots\ldots) = (\frac{\wedge}{\mu}, 0,0,0,0,0,0,0,0,0,0)\epsilon\mathbb{R}^{11}$.

Hence, for us to calculate the reproduction number R_0, the method of next generation matrix G which consists of F and V^{-1} shall apply.

In fact, $F = [\frac{\partial f_i}{\partial x_i}]$ and $V = \left[\frac{\partial v_j}{\partial x_j}\right]$, where F_i are the new consumers into compartments and V_i are the transfer of consumers from one compartment to another while R_0 is simply the SFC (society free from the consumption of cannabis).

And the following computations follow: at the SFC, the susceptible and the Recovered/ Removed compartments are excluded: Thus, we obtain the following for (f_i)'s Exposed class $(E) = \beta\tau S$.

$E_{NB} = 0$

$E_B = 0$

$A = 0$

$A_{DP} = 0$

$A_R = 0$

$M = 0$

$M_{IT} = 0$

$M_{NT} = 0$

$(v_j)'^s$ are deduced as follow: Exposed class $(E) = +[\alpha_1(1-\zeta_1) + \alpha_2\zeta_1 + \mu + \alpha_{10}]E$

$E_{NB} = (\mu + \alpha_7)E_{NB} - \alpha_1(1-\xi_1)E$

$E_B = (\mu + \alpha_8)E_B - (\alpha_2\xi_1 E + \alpha_{15}(1+\xi_4)A$

$A = (\alpha_4[1-\xi_2] + \alpha_3\xi_2 + \alpha_{11} + \alpha_{15}(1+\xi_4) + \mu + \delta_2)A - (\alpha_{10}E + \alpha_7 E_{NB})$

$A_{DP} = (\mu + \delta_1)A_{DP} - \alpha_4(1-\xi_2)A$

$A_R = (\mu + \alpha_5 + \alpha_9)A_R - \alpha_3\xi_2 A$

$M = (\mu + \delta_3 + \alpha_{12}\xi_3 + \alpha_{13}[1-\xi_3]M - (\alpha_5 A_R + \alpha_{11}A$

$M_{IT} = (\mu + \delta_5 \alpha_{14}) M_{IT} - \alpha_{12} \xi_3 M$

$M_{NT} = (\mu + \delta_4) M_{NT} - \alpha_{13}(1 - \xi_3) M$

At the SFC , τ is 1 implying the information on the dangers of cannabis consumption is 100% effective which implies that $\beta \tau S = \beta S = \beta \frac{\wedge}{\mu} = \frac{\wedge \lambda_1}{\mu N} + \frac{\wedge \lambda_2}{\mu N} + \cdots + \frac{\wedge \lambda_9}{\mu N}$

Note that at SFC, τ is 100%, that is, τ=1; thus βτs = βs, but

$s = \frac{\wedge}{\mu} \Longrightarrow \beta s = \frac{(\lambda_1 E + \lambda_2 E_{NB} + \lambda_3 E_B + \lambda_4 A + \lambda_5 A_{DP} + \lambda_6 A_R \lambda_7 M + \lambda_8 M_{IT} + \lambda_9 M_{NT}) S}{N}$

This implies that $\beta s = \beta \frac{\wedge}{\mu} = \frac{(\lambda_1 E + \lambda_2 E_{NB} + \lambda_3 E_B + \lambda_4 A + \lambda_5 A_{DP} + \lambda_6 A_R + \lambda_7 M + \lambda_8 M_{IT} + \lambda_9 M_{NT}) \frac{\wedge}{\mu}}{N}$

$$\beta s = \lambda_1 K_1 + \lambda_2 K_2 + \lambda_3 K_3 + \lambda_4 K_4 + \lambda_5 K_5 + \lambda_6 K_6 + \lambda_7 K_7 + \lambda_8 K_8 + \lambda_9 K_9 \; where \; K_1 = \frac{\lambda_1 \wedge}{\mu N}, K_2 = \frac{\lambda_2 \wedge}{\mu N} \ldots \ldots, K_9 = \frac{\lambda_9 \wedge}{\mu N}.$$

$$F_i = \begin{pmatrix} \beta S \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

$$\therefore F = \begin{pmatrix} \lambda_1 K_1 & \lambda_2 K_2 & \lambda_3 K_3 & \lambda_4 K_4 & \lambda_5 K_5 & \lambda_6 K_6 & \lambda_7 K_7 & \lambda_8 K_8 & \lambda_9 K_9 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$V_j = \begin{pmatrix} M_2 E \\ M_3 E_{NB} - \alpha_1(1 - \xi_1) E \\ M_4 E_B - (\alpha_{10} E + \alpha_{15}(1 + \xi_4) A \\ M_5 A - (\alpha_{10} E + \alpha_7 E_{NB}) \\ M_6 A_{DP} - \alpha_4 (1 - \xi_2) A \\ M_7 A_R - \alpha_3 \xi_2 A \\ M_8 M - (\alpha_5 A_R + \alpha_{11} A) \\ M_9 M_{IT} - \alpha_{12} \xi_3 M \\ M_{10} M_{NT} - \alpha_{13}(1 - \xi_3) M \end{pmatrix}$$

$$\therefore V = \begin{pmatrix} M_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -\alpha_1(1-\xi_1) & M_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -\alpha_2\xi_1 & 0 & M_4 & -\alpha_{15}(1+\xi_4) & 0 & 0 & 0 & 0 & 0 \\ -\alpha_{10} & \alpha_7 & 0 & M_5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\alpha_4(1-\xi_2) & M_6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\alpha_3\xi_2 & 0 & M_7 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\alpha_{11} & 0 & -\alpha_5 & M_8 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -\alpha_{12}\xi_3 & M_9 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -\alpha_{13}(1-\xi_3) & 0 & M_{10} \end{pmatrix}$$

We used Maple software to obtain the next generation matrix given as $G = FV^{-1}$. It is with this that we obtained the most dominant eigen-value $R_0 = \rho(FV^{-1})$, where ρ is the widest spectral radius which ensures that the R_0 is the basic reproductive number of the next generation matrix. This normalized forward sensitivity index R_0 that depends differentiably on a parameter say χ is defined by

$\gamma_\chi^{R_0} = \frac{\partial R_0}{\partial \chi}\frac{\chi}{R_0}$ and this was used to derive the analytical expressions with respect to each parameter in the model and hence the deduction of section 5.1.

5. RESULTSANDDISCUSSION

We discuss the findings alongside the graphs such that each obtained graph is discussed immediately just below the graph. We use combinations of the five controls, four controls, three controls and two controls at a time. The control measures used include information/ enlightenment on the dangers associated with the use of *Cannabissativa*, represented by τ, abstain from the use of *Cannabissativa* if already started (back out) represented by ξ_1, take the victim to Rehabilitation center as a result of severe case represented by ξ_2, isolate the victim and take to a consultant in the case of mental imbalance caused by consumption of the substance represented by ξ_3 and intensive campaign against the consumption of cannabis sativa as a result of addiction represented by ξ_4.

This is done under the following scenarios:

1. Strategy A: $\tau \neq 0, \xi_1 \neq 0, \xi_2 = \xi_3 = \xi_4 = 0$.
2. Strategy B: $\tau \neq 0, \xi_1 \neq 0, \xi_2 \neq 0, \xi_3 = \xi_4 = 0$.
3. Strategy C: $\tau \neq 0, \xi_1 \neq 0, \xi_2 \neq 0, \xi_3 \neq 0, \xi_4 = 0$.
4. Strategy D: $\tau \neq 0, \xi_1 \neq 0, \xi_2 \neq 0, \xi_3 \neq 0, \xi_4 \neq 0$.
5. Strategy E: $\tau = 0, \xi_1 \neq 0, \xi_2 \neq 0, \xi_3 \neq 0, \xi_4 \neq 0$.
6. Strategy F: $\tau = 0, \xi_1 = 0, \xi_2 \neq 0, \xi_3 \neq 0, \xi_4 \neq 0$.
7. Strategy G: $\tau = 0, \xi_1 = 0, \xi_2 = 0, \xi_3 \neq 0, \xi_4 \neq 0$.
8. Strategy I: $\tau \neq 0, \xi_4 \neq 0, \xi_1 = \xi_2 = \xi_3 = 0$.
9. Strategy J: $\tau \neq 0, \xi_3 \neq 0, \xi_1 = \xi_2 = \xi_4 = 0$.
10. Strategy K: $\tau \neq 0, \xi_2 \neq 0, \xi_1 = \xi_3 = \xi_4 = 0$.

The simulation/ analysis is done within a period of 3 months study plan which ought to reflect in the graphical work and discussions.

5.1 Parameter values used in the simulation of *Cannabissativa* consumption.

S/NO	Parameter	Value	Source
1	^	4% of the population.	Primary and Secondary data.
2	μ	$\frac{1}{53.6}$	[14]
3	B	0.20	Primary and Secondary data.
4	T	$\in [0,1]$	[14]
5	$\alpha_1, \alpha_2, \dots, \alpha_{15}$	$\in [0,1]$	Primary and Secondary data.
6	$\xi_1, \xi_2, \dots, \xi_4$	0.5, i.e $\in [0,1]$	Primary and Secondary data.
7	δ_1	0.06	Primary and Secondary data.
8	δ_2	0.04	Primary and Secondary data.
9	δ_3	0.08	Primary and Secondary data.
10	δ_4	0.08	Primary and Secondary data.
11	δ_5	0.02	Primary and Secondary data.
12	M_1	-0.12	Calculated.
13	M_2	-1.22	Calculated.
14	M_3	-0.62	Calculated.
15	M_4	-0.62	Calculated.
16	M_5	-2.16	Calculated.
17	M_6	-0.08	Calculated.
18	M_7	-1.22	Calculated.
19	M_8	-0.65	Calculated.
20	M_9	-0.64	Calculated.
21	M_{10}	-0.10	Calculated.
22	M_{11}	-0.62	Calculated.
23	$\lambda_1, \lambda_2, \dots, \lambda_9$	0.02	Primary and Secondary data.
24	$K_1, K_2, \dots K_9$	0.32	Calculated.

5.2 Graphs resulting from the simulation

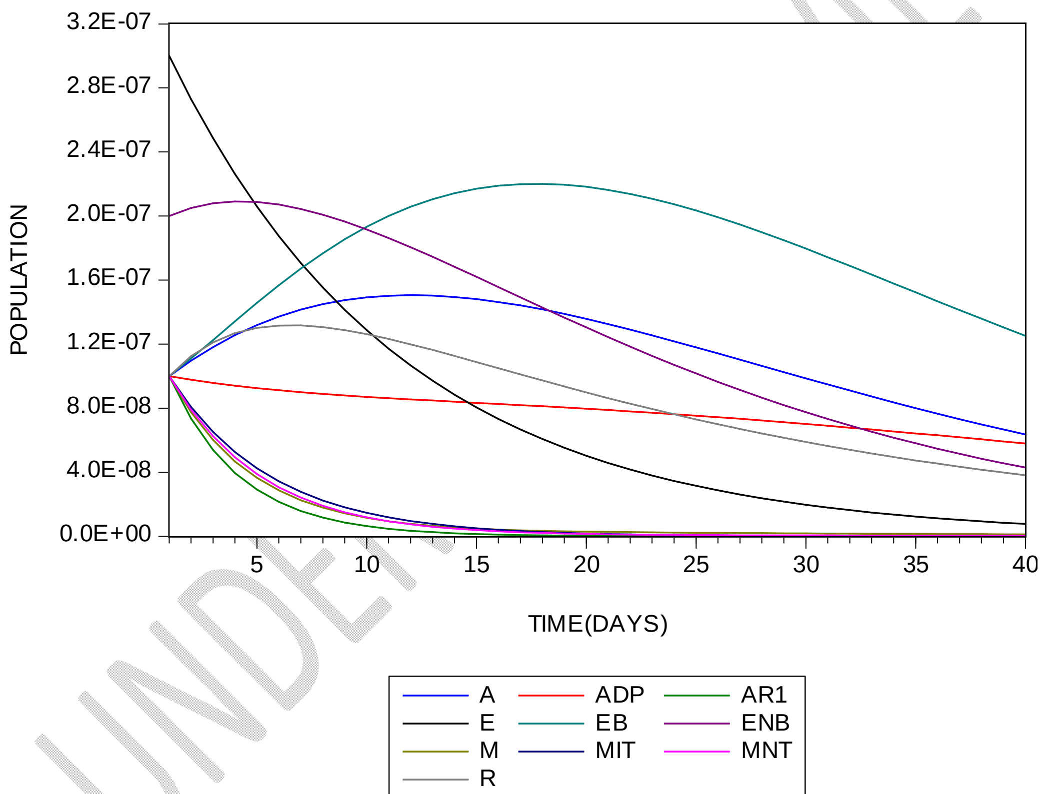

Fig. 2. Graphical plot of simulated data on intake of *Cannabis* from different compartment

Key: *A= Addicted; E= Exposed; M= Full blown madness; R= Removed/Recovered; ADP= Addicted permanently; EB= Exposed and backed out; MIT= Mad but isolated for treatment; AR1= Addicted and taken to rehabilitation centre; ENB= Exposed but not backed out; MNT= Mad but not isolated for treatment*

From Fig. 2, it can be seen that the Addicted class (A) remained constant throughout the whole period while the Exposed but backed out class(E_B) attained the highest level but gradually came down as a result of the control measure.

The other various compartments behaved the way they deem fit with the exception of the mad but not isolated class (M_{NT}) as well as the Addicted but sent to Rehabilitation class (A_R). The Exposed class (E) decreased uniformly because of the enlightenment control about the damage and health hazards associated with the consumption *Cannabissativa*.

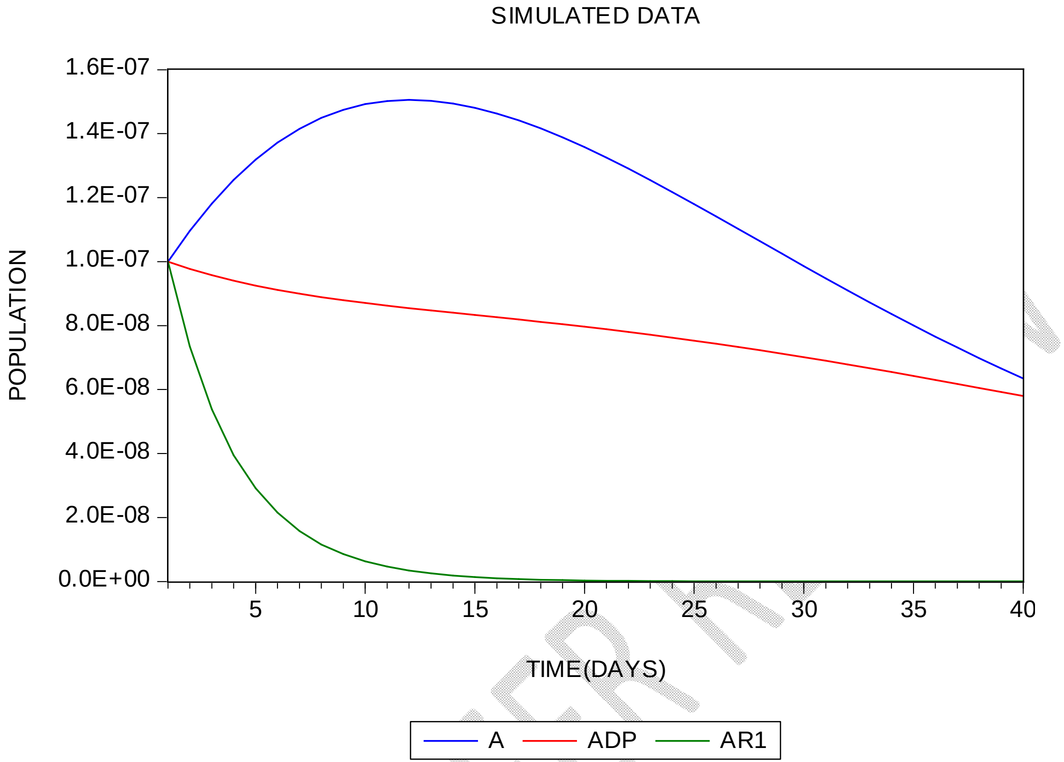

Fig. 3.Graphical plot of simulated data on the addicted, addicted permanently and addicted and taken to rehabilitation centre.

Key: *A= Addicted; ADP= Addicted permanently; AR1= Addicted and taken to rehabilitation centre*

The Fig. 3, shows that the Addicted class gradually reduced resulting from the control that advised victims to be sent to Rehabilitation centre whereas the permanently Addicted class remained constant.The Rehabilitation centre class brought down the number of victims tremendously.

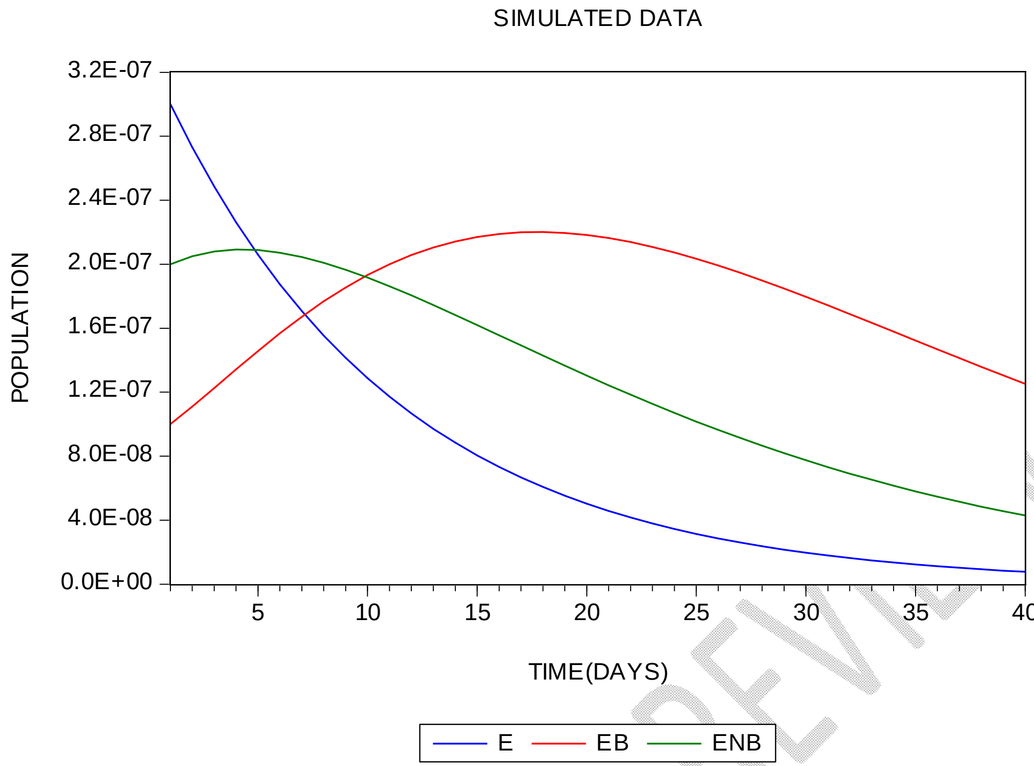

Fig. 4. Graphical plot of simulated data on the exposed, exposed and backed out and exposed but not backed out.

Key; *E= Exposed; EB= Exposed and backed out; ENB= Exposed but not backed out*

In Fig. 4, the Exposed class gradually reduced in number as a result of Enlightenment control. The Exposed but backed out class equally reduced in number gradually while exposed but not backed out class reduced drastically in number as a result of the control parameters.

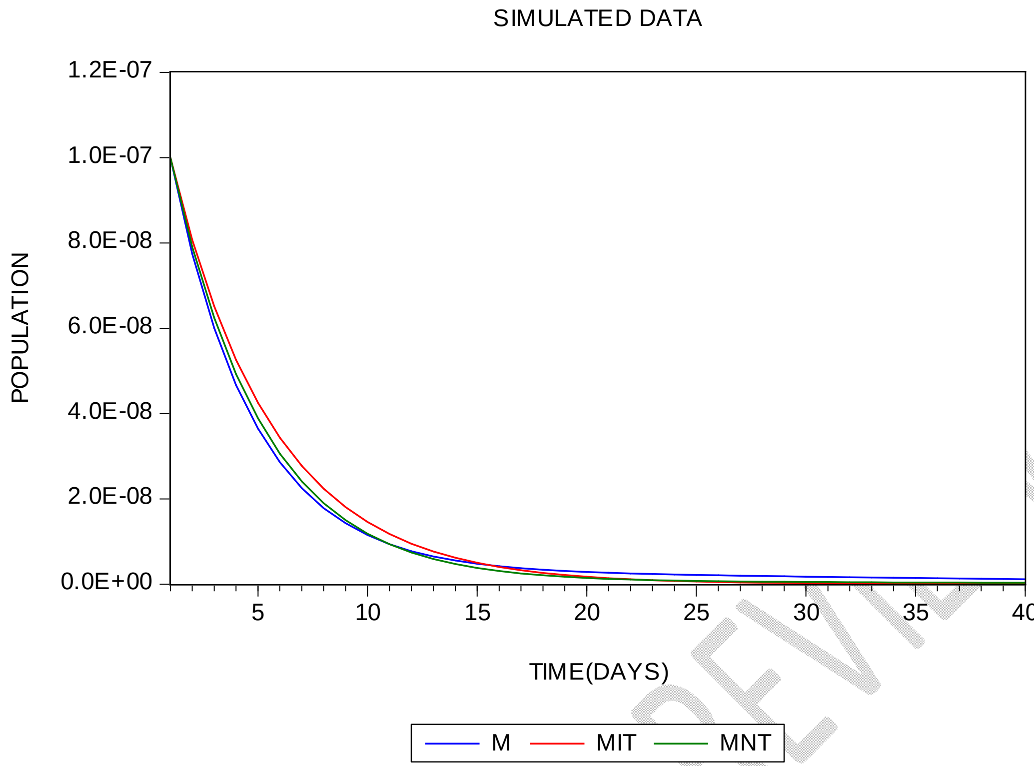

Fig. 5. Graphical plot of simulated data on the mad, mad but isolated for treatment and mad but not isolated for treatment

Key; *M= Mad; MIT= Mad but isolated for treatment; MNT= Mad but not isolated for treatment*

The control measures to isolate the mad ones as a result of *Cannabissativa* consumption and send for treatment received the same fate as those not isolated for treatment (Fig. 5). This shows that when one becomes mad as a result of *Cannabissativa*, it becomes difficult or almost impossible to be restored back to normalcy hence the high risk and danger in consuming this substance.

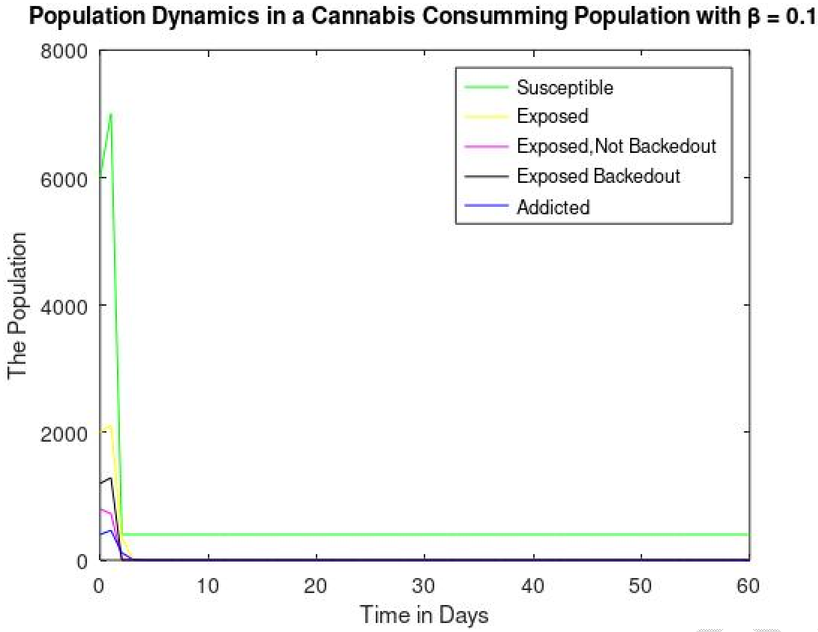

Fig. 6: Behaviour of the population in the presence of *Cannabis* for $\beta = 0.1$.

When $\beta = 0.1$, the susceptible class quickly shot up to7000 and within about two days came down to about 400 persons who got interacted with the use of *Cannabissativa*(Fig. 6).

The Exposed, Exposed and backed out, Exposed and not back out as well as the addicted have no effects at this level of interaction.

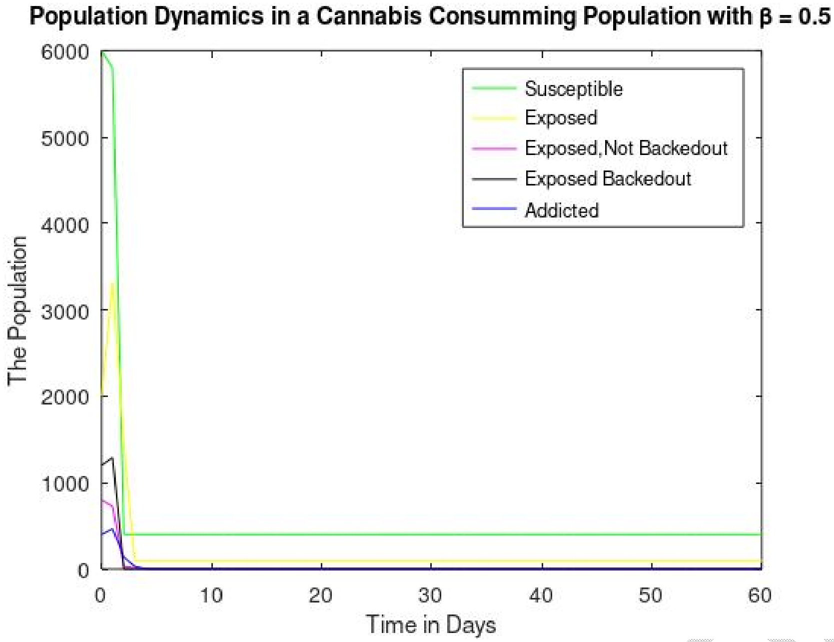

Fig. 7. Behaviour of the population in the presence of Cannabis for $\beta = 0.5$.

When $\beta = 0.5$, the susceptible class of about 400 individuals, about 100 persons become Exposed while the Exposed not backed out, addicted and Exposed and backed out had no effects and remain constant from about the second day to the end of research period (Fig. 7).

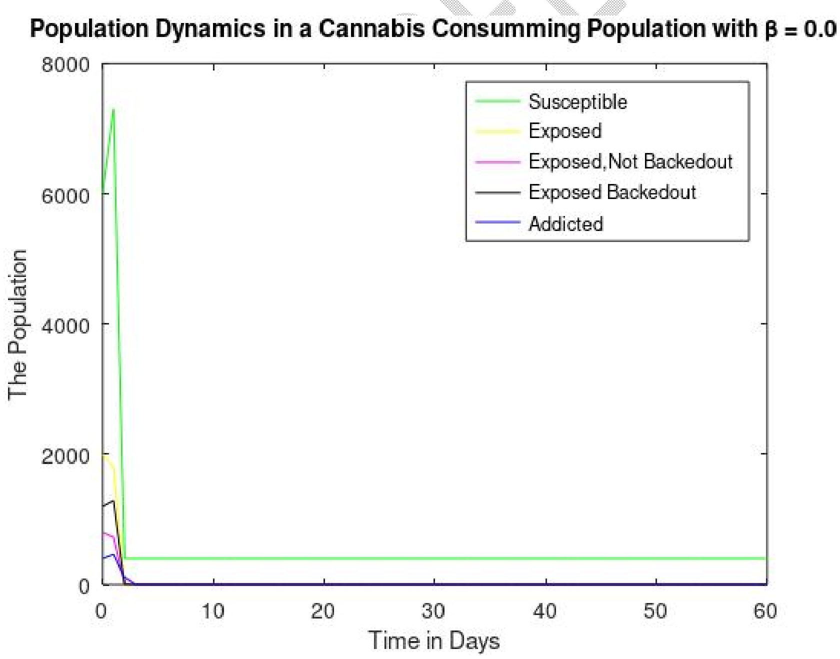

Figure 8: Behaviour of the population in the presence of Cannabis for $\beta = 0.0$.
When there is no interactional force in the society under discussion, the users of about 400 out of about 2,500 persons remained constant while other compartments are of no effect (Fig. 8).

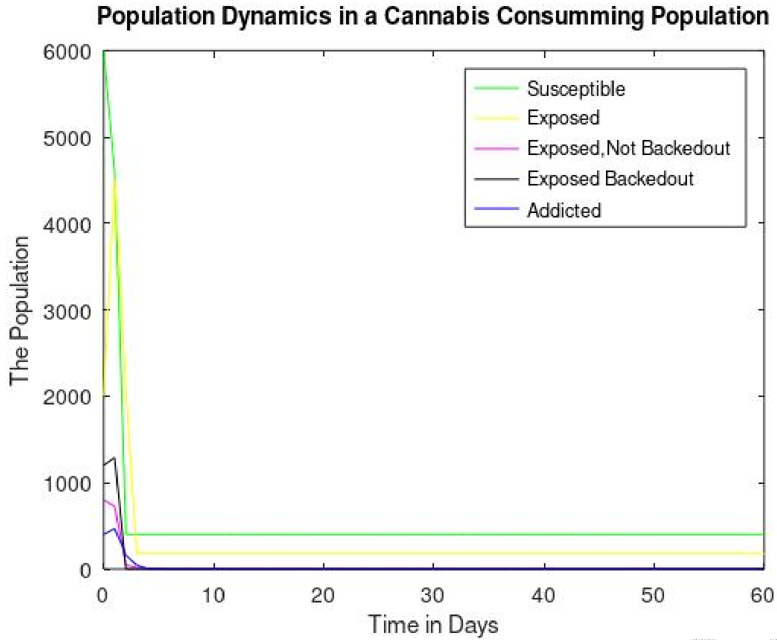

Fig. 9. The population dynamics of the cannabis society in the absence of isolated treatment and intensive campaign against *Cannabis* consumption.

Figures 8 and 9 maintained the same level of Exposure under the rehabilitation and isolation of victims as well as intensive campaign against *Cannabis* consumption.

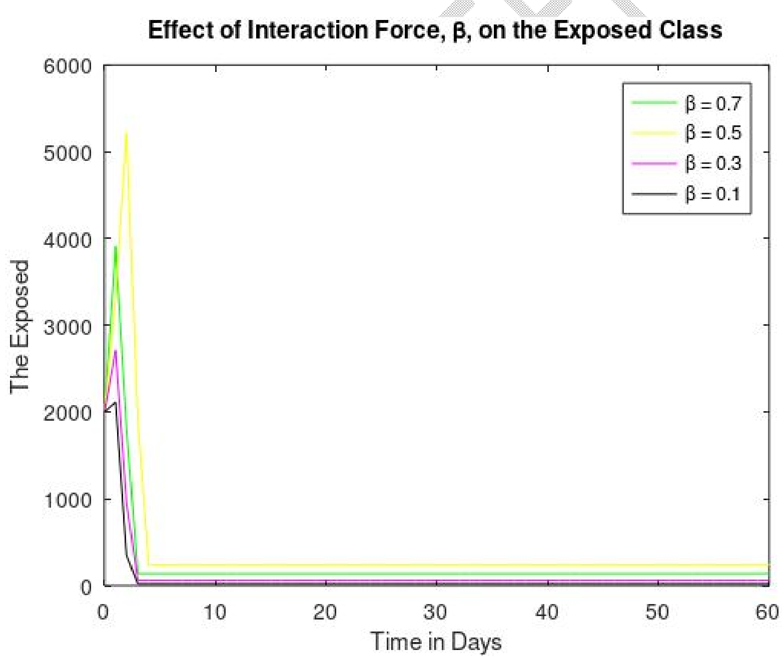

Fig. 10. The effect of interaction force on the exposed class.

Fig. 10, shows that at the varying values of interactional force (β), $\beta = 0.5$ becomes more manifest. Efforts greeter that $\beta = 0.5$ may be considered futile. This shows that no matter the level of desperation by users in any given society, not more than about 300 persons out of about 5,200 persons have the possibility of being exposed.

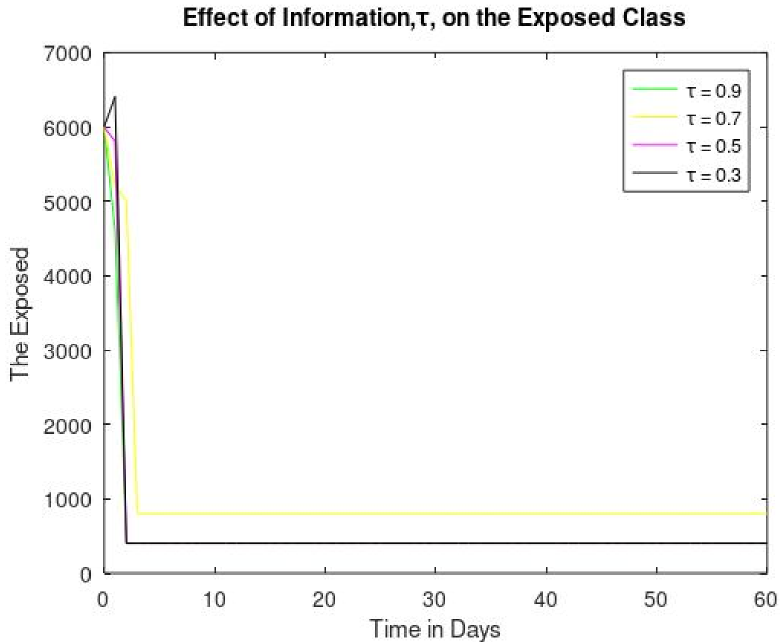

Fig. 11. The dynamics of the exposed class under varying strength of Information on the dangers of *Cannabissativa*.

In the presence of varying values of Enlightenment Control, it is clear to see that about 800 persons observed the control at $\tau = 0.7$ which supersedes that of $\tau = 0.9$ and the other values. This means that after $\tau = 0.7$, more efforts are not required as it will not contribute meaningfully (Fig. 11).

This means that about 70% effort is required to put into place to save some people from encountering or interacting with the users.

6. CONCLUSION:

It is discovered that there are users of *Cannabissativa* in our society for all time.*Cannabissativa* is used for some of our medical problems either as drug or as enhancer among others.The interactional force defined as

$$\beta = \frac{\lambda_1 E + \lambda_2 E_{NB} + \lambda_3 E_B + \lambda_4 A + \lambda_5 A_{DP} + \lambda_6 A_R + \lambda_7 M + \lambda_8 M_{IT} + \lambda_9 M_{NT}}{N}$$

β is the interactional force between the susceptible and the victims of *Cannabissativa* while $\lambda_1, \lambda_2, \ldots \ldots, \lambda_9$ are the contact rates in their respective compartments.

$N = S + E + E_{NB} + E_B + A + A_{DP} + A_R + M + M_{IT} + M_{NT} + R$, has limits of impartation on the society and cannot be greater than 0.7 for it to achieve maximum effects on the society.

The enlightenment control defined as τ need to receive a boost as to be able to sensitize the citizens well enough of the health hazards of *Cannabissativa* if abused.

Government need to set up an agency that will be able to conduct enough sensitization on the dangers of *Cannabissativa* either through community town criers or through Autonomous community Chiefs vis-à-vis other palatable means of communication.

This is because our research showed a handsome number of people especially among our youths that get interacted with users as a result of naivety or ignorance. Of all the control parameters in use in this research, Enlightenment control (τ) is most effective.

REFERENCES:

1. Florian ML, Kronkright DP, Norton RE. The Conservation of Artifacts Made from Plant Materials. Getty Publications. 1991. pp. 49–. ISBN 978-0-89236-160-1.
2. Bonini SA, Premoli M, Tambaro S, Kumar A, Maccarinelli G, Memo M, Mastinu A. *Cannabissativa*: a comprehensive ethnopharmacological review of a medicinal plant with a long history. Journal of Ethnopharmacology, 2018, 227: 300-315
3. Russo E. History of cannabis and its preparations in saga, science, and sobriquet, Chemistry and Biodiversity. 2007; 4:1614-1648.
4. Gigliano SG. *Cannabissativa* L. Botanical problems and molecular approaches in forensic investigations, Forensic Sci Rev, 2001; 13: 1-17.
5. Orrin D, Verducci C, Thiele EA, Laus LC, Patel AD Filloux F, Szaflarski JP, Wilfong A Clark GD Park YD Seltzer LE, Bebin EM, Plamini R, Wechsler RT, Friedman D. Open – label use of highly purified CBD (Epidiolex®) in patients with CDKL5 deficiency disorder and Aicardi, Dup15q & Doose syndrome. Epilepsy and Behavior, 2018; 86: 131-137
6. Hernandez F, Chandra S. The current state and potential direction of cannabis research, Journal of Experimental and Integrative Medicine. 2016; 6: 44-48.
7. Ashton CH. Pharmacology and effects of cannabis: A brief review. British Journal of Psychiatry.2001; 178: 101-106.
8. Crippa JAS, Zuardi AW,Hallak JEC. Therapeutical use of the cannabinoids in psychiatry, Rev. Bras. Psiquiatr, 2010; 32: 56-66.
9. Menetrey A, Augusburger M, Favarat B, Pin MA, Ruthuizen LE, Appenzeller M, Bucklin T, Mangin P, Gerald C. Mathematical models for the prediction of time of marijuana exposure. Journal of Analytical Toxicology, 2005, 29 (5): 327-338
10. Chapwanya M, Lubuma JMS, Luterman H, Matusse A, Nyabadza F, Terefe Y. Mathematical model for the Cannabis epidemic in a South African province with a non-linear incidence rate. Journal of Statistics and Management Systems, 2021, 24:8
11. Toben B, Kimergad A, Hinderson P. Implementation of mathematical models to predict new Cannabis use by urine drug testing: It is time to move forward. Journal of Analytical Toxicology, 2021; 45 (6): e15-e19.
12. Abramson CI, Markland Stepanov II. The importance of mathematical model to explore the effects of marijuana and other plant based products on learning and memory. Natural Science, 2019; 11: no5
13. Saini P, Panghal A, Mittal V Gupta R. Hempseed (*Cannabissativa* L) bulk mass modelling based on engineering properties. Journal of Food Process Engineering, 2021; 45(1): e13925
14. Tivde T, Iorkua M, Isienyi US. Mathematical modelling of lac operon for human health. International Research Journal of Engineering and Technology (IRJET), 2015, 2:9