Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2019, 6(12):62-72**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

A Mathematical Model to Study the Impact of Public Health Awareness Campaign, Vaccination, Condom, Restriction of Free Movement and Treatment of Transmission of HIV/AIDS in Nigeria

***Atindiga, S. Terhemen[1], Mbah, G.C. Ezike[2], Adewoye, R. Adebisi[3], Kwaghbula, N. Gema[4], Kper, B. Torkuma[5]**

[1]Department of Basic Sciences, Akperan Orshi College of Agriculture, Yandev-Benue State, Nigeria
Email: sirstayhemen@gmail.com
[2]Department of Mathematics, University of Nigeria, Nsukka
[3]Department of Mathematics & Statistics, Rufus Giwa Polytechnic, Owo, Ondo State
[4]University of Agriculture, Makurdi Demonstration Secondary School, P.M.B. 2373, Makurdi Benue State
Email: gemanathaniel@gmail.com
[5]ICT Directorate, Akperan Orshi College of Agriculture, Yandev-Benue State, Nigeria
Email: agriculture4truelife@gmail.com

Abstract HIV/AIDS prevalence continues to be on increase in populations around the globe especially in sub-Saharan Africa with limited resources and inadequate public health awareness campaign services. A nonlinear mathematical model that incorporates the use of condom, vaccination, treatment, restriction of free movement in the presence of public health awareness campaign on the population. The awareness education causes a change in behaviour of the aware HIV susceptible individuals resulting to a total of seven compartments. Quantitative analyses of the model including those of the basic properties are presented. The effective reproduction number of the model is determined and stability equilibria analyzed. The disease free equilibrium pint of the model is shown to be locally asymptotically stable when its corresponding effective reproduction number is less than unity. Using the Lyapunov function of the Goh-Volterra type, we also proved that the endemic equilibrium point is globally asymptotically stable when its corresponding reproduction number is greater than unity. We finally validated our quantitative analyses with numerical simulation of the model implemented in maple17.

Keywords mathematical model, HIV/AIDS, effective reproduction number, equilibria

1. Introduction

Human immunodeficiency virus, HIV is the virus that leads to acquired immunodeficiency syndrome or AIDS if not treated. Unlike some other viruses, the human body cannot get rid of HIV completely, even with treatment [1, 2]. These authorities therefore opined that once an individual gets HIV, he/she has it for life.

A number of symptoms associated with the flu may be the first to arise as early signs of HIV, which include: chills, diarrhoea that lasts for more than a week, extreme and unexplained tiredness, fatigue, fever/ recurring fever or profuse night sweats, mouth ulcers, muscle aches, rapid weight loss, rash, prolonged swelling of the lymph glands in the armpits, groin, or neck, sore throat, pneumonia, swollen lymph nodes, sores of the mouth, sores of the anus, sores of the genitals [3]. AIDS is a pandemic, a disease which is present over a large area and is actively spreading [4]. The disease has had a great impact on the society both as illness and as a source of social and physical discrimination in the society and even in work place. The disease has significant economic impacts. There are so many misconceptions about HIV/AIDS such as the belief that it can be transmitted by non-sexual contact, which is a false belief [5].

A lot of mathematical models on the dynamics of HIV/AIDS, where several authors used different control measures such as condom, vaccination, anti-retroviral drugs, behavioural change, public awareness campaign, abstinence from pre-marital sex, faithfulness among the married partners, among others in checking the menace of this pandemic as can be found in the reported literature [6-12].

The main purpose of this work is to study the impact of public awareness campaign, vaccination, condom, restriction of free movement of young people and treatment on transmission of HIV/AIDS by formulating and analyzing a new mathematical model that extends and complements the ones in the previous paragraph. The remaining part of this paper is organized as follows; section 2 presents the model formulation, section 3 presents the model analysis using concept of stability theory of nonlinear differential system while in section 4, numerical simulation and discussion of results are stated. Section 5 concludes the research work.

2. Model Formulation and Analysis

We construct a nonlinear mathematical HIV/AIDS model with total human population $N(t)$ at time t is divided into seven compartments namely; susceptible class$S(t)$, vaccinated class$S_v(t)$, vaccinated class that uses condom $Svc(t)$, vaccinated, restricted who also use condom class $S_{vcr}(t)$, exposed class $S_{ve}(t)$, infectious population $I(t)$, infectious individuals on treatment $I_t(t)$. the total population is

$$N(t) = S(t) + S_v(t) + S_{vc}(t) + S_{vcr}(t) + S_{ve}(t) + I(t) + I_t(t) \quad (1)$$

The fraction of susceptible class moves to the vaccinated class, $S_v(t)$ by α_1, as a result of public campaign enlightmeent. Individuals in the vaccinated class, $S_v(t)$ move to the vaccinated and condom usage class $S_{vc}(t)$ at a rate $(1-\varphi)$, individuals from the $S_{vc}(t)$ leave this class for $S_{vcr}(t)$ at a rate q, while α_1 proportion of individuals move from the $S_{vc}(t)$ class to the susceptible class, a certain quantity $\lambda(1-e_1)$ from $S_{vc}(t)$ moves to $S_{ve}(t)$ class. A proportion of individuals from $S_{vcr}(t)$ is recruited into the $S_{ve}(t)$ class at the rate $\lambda(1-e)$. Certain individuals are recruited into the infected treated class $I(t)$ by ρ_2 from the $S_{ve}(t)$ class. A proportion $(1-\gamma)$ leaves the class $I(t)$ for $I_t(t)$. Those in the infectious treated class $I_t(t)$ can remain healthy and hard working living a normal life, if he/she is faithful to the therapeutic dose, but will leave the class through the diseased induced death rate, d_2 with the effect of withdrawal from the drug.

Basic assumptions of the model

Table 1: Parameter description, values and source of values

Parameter description	Parameter	Value	Source
Recruitment level into the susceptible class	b	100,000	[13]
Rate at which susceptible population is vaccinated	α_1	0.01	[14]
vaccine efficacy	φ	0.25	Assumed
The campaign which leads to behavioural change in individuals	c	$0 \leq c \leq 1$	[14]
Rate at which individuals who are in the condom-vaccinated class move back to the susceptible class as they lose immunity due to vaccination	a_1	0.01	[15]
Rate at which individuals who are in the vaccinated-condom class move to the class of the vaccinated, restricted that use condom	q	$0 \leq q \leq 1$	[16]
Effectiveness of vaccination, usage of condom and restriction of free movement	e	$0 \leq e \leq 1$	[15]
Rate of exposure to the infectious individuals	ρ_2	0.025	[14]
Efficacy of vaccine/condom	e_1	$0 \leq e_1 \leq 1$	[15]
Rate at which the infected are given treatment	$1-\gamma$	0.1	[15]
Death rate due to infection for those in the AIDS class	d_2	0.18	[17]
Natural death (per capita death rate)	μ	0.02	[18]

The following assumptions were made while formulating the model

1. Individuals are only recruited into the susceptible class
2. Once one has stopped receiving treatment he/she will surely die of the disease.
3. Vaccination is given to the uninfected population only
4. The studied population varies with time and is homogeneous.
5. Birth rate and death rate are not the same.

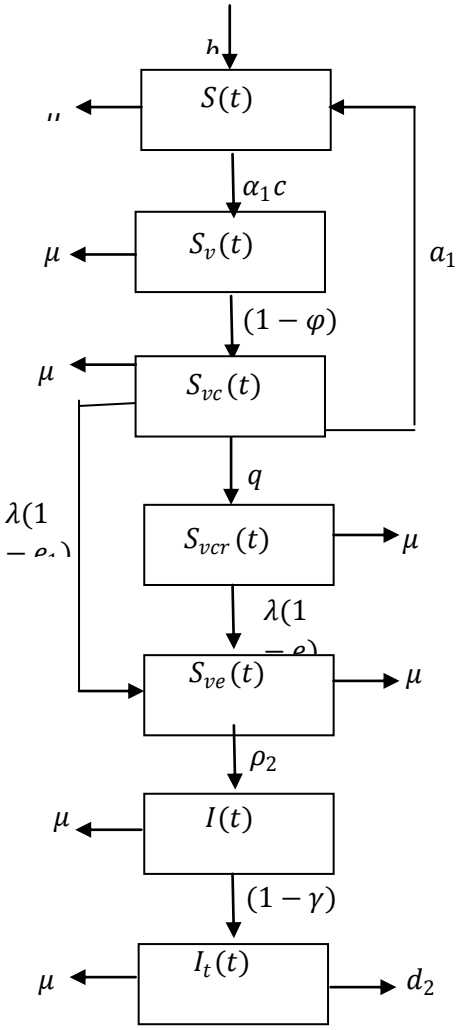

Figure 1: Contact of HIV/AIDS by those who are; vaccinated, use condom, receive treatment and also restricted from free movement in the presence of effective public health awareness campaign

The corresponding model equations are as follows

$$\begin{aligned}
\frac{dS}{dt} &= b + a_1 S_{vc} - \alpha_1 cS - \mu S \\
\frac{dS_v}{dt} &= \alpha_1 cS - (1-\varphi)S_v - \mu S_v \\
\frac{dS_{vc}}{dt} &= (1-\varphi)S_v - (1-e_1)\lambda S_{vc} - a_1 S_{vc} - qS_{vc} - \mu S_{vc} \\
\frac{dS_{vcr}}{dt} &= qS_{vc} - (1-e)\lambda S_{vcr} - \mu S_{vcr} \\
\frac{dS_{ve}}{dt} &= (1-e_1)\lambda S_{vc} + (1-e)\lambda S_{vcr} - \rho_2 S_{ve} - \mu S_{ve} \\
\frac{dI}{dt} &= \rho_2 S_{ve} - (1-\gamma)I - \mu I \\
\frac{dI_t}{dt} &= (1-\gamma)I - d_2 I_t - \mu I_t
\end{aligned} \qquad (2)$$

$\lambda = \frac{n_1 \varepsilon_1 ES}{N} + \frac{n_2 \varepsilon_2 IS}{N} + \frac{n_3 \varepsilon_3 I_t S}{N}$, effective contact rate of the susceptible individuals.

2.1 Invariant Region.

Theorem (1): The solutions of the model (2) are feasible for all $t > 0$ if they enter the invariant region, Ω.

Proof:

We shall let $\Omega = (S, S_v, S_{vc}, S_{vcr}, S_{ve}, I, I_t) \in {R_+}^7$ be any solution of the system, (2) with non-negative initial conditions. From (2) we have that;

$N + \mu N \leq b$

Hence solving the inequality above, we obtain;

$$N \leq \frac{b}{\mu} + (N_0 - \frac{b}{\mu})e^{-\mu t} \quad (3)$$

Applying the inequality theorem by [19] on differential equations to (3) yields the following results

$0 \leq N \leq \frac{b}{\mu}$ as $t \to \infty$

We shall let $= \frac{b}{\mu}$, where kp is the carrying capacity as the total population approaches kp, therefore, the feasible solution of the model enters the region,

$$\Omega = (S, S_v, S_{vc}, S_{vcr}, S_{ve}, I, I_t)\epsilon {R^7}_+ \left\{ S > 0, S_v > 0, S_{vc} > 0, S_{vcr} > 0, S_{ve} > 0, I > 0, I_t > 0, N \leq \frac{b}{\mu} \right\} \quad (4)$$

At this region, the model is well posed and biologically feasible in the region, Ω. If $N \leq \frac{b}{\mu}$, then every solution with the initial condition in the region, Ω_2 will remain in it at any time, $t > 0$.

When $> \frac{b}{\mu}$, then the population will reduce to kp.

2.2 Positivity of Solution

Theorem (2): The positivity shall be determined from the proof.

Let $\Omega = \left\{ S(0), S_v(0), S_{vc}(0), S_{vcr}(0), S_{ve}(0), I(0), I_t(0) \geq 0 \right\} \epsilon {R^7}_+$, then the solution set $\left\{ S(t), S_v(t), S_{vc}(t), S_{vcr}(t), S_{ve}(t), I(t), I_t(t) \right\}$ of the systems of equation (2) is positive for all $t > 0$

Proof:

From the first of (2) we have that;

$$\frac{dS}{dt} = b + a_1 S_{vc} - \alpha_1 cS - \mu S$$

That is

$$b + a_1 S_{vc} - \alpha_1 cS - \mu S \geq -(\alpha_1 c + \mu)S$$

We therefore can say that;

$$\frac{dS}{S} \geq -(\alpha_1 c + \mu)dt$$

Integrating;

$$\ln S \geq -(\alpha_1 c + \mu)t + C$$

Where C is the constant of integration,

$$S(t) = e^{-(\alpha_1 c + \mu)t} e^c$$

Therefore, applying initial conditions we have;

$$S(t) \geq S(0)e^{-(\alpha_1 c + \mu)t} \geq 0 \quad (5)$$

Since $(\alpha_1 c + \mu) \geq 0$

The solution is therefore positive at any time $t \geq 0$

Similarly it can be shown that;

$S_v(t) \geq S_v(0)e^{-((1-\varphi)+\mu)t} \geq 0$, $S_{vc}(t) \geq S_{vc}(0)e^{-((1-e_1)\lambda + a_1 + q + \mu)t} \geq 0$

$S_{vcr}(t) \geq S_{vcr}(0)e^{-((1-e)\lambda+\mu)t} \geq 0$, $S_{ve}(t) \geq S_{ve}(0)e^{-(\rho_2+\mu)t} \geq 0$

$I(t) \geq I(0)\, e^{-((1-\gamma)+\mu)t} \geq 0$, $I_t(t) \geq I_t(0)e^{-(d_2+\mu)t} \geq 0$ for all $t \geq 0$. Proof completes.

We have also determined that the model (2) is positive and invariant in the region, $\Omega \epsilon {R^7}_+$. The above theorem is important because it guarantees that the model is well posed and biologically feasible in the region Ω since

population cannot be negative. Thus for any starting non-negative initial conditions, the trajectory lies in Ω. Therefore, the system is both mathematically and epidemiologically well-posed, [20]. Thus it is significant to consider the dynamics of the flow by the model (2) in Ω.

3. Existence of Equilibria and stability analysis

The disease free equilibrium (DFE) and the endemic equilibrium (EE) points are the two non-negative equilibria of the system (2) is found.

3.1 DFE and Effective reproduction number

The model (2) has DFE obtained to be;

$$E = (S, S_v, S_{vc}, S_{vcr}, S_{ve}, I, I_t) = (\frac{b}{\mu}, 0,0,0,0,0,0) \quad (6)$$

The linear stability of E can be analyzed by the threshold R_e called the reproduction number which is defined as the average number of secondary infections generated by a single infected individual in a totally susceptible population. This is determined using the next generation method on system (2) as used in [21] in the form of matrices F (non-negative) and V (non-singular). Where F denote infection terms and V the transition term at E.

Thus

$$F = \begin{pmatrix} \frac{\{(1-e_1)+(1-e)\}n_1\varepsilon_1 E}{N} & \frac{\{(1-e_1)+(1-e)\}n_2\varepsilon_2 I}{N} & \frac{\{(1-e_1)+(1-e)\}n_3\varepsilon_3 I_t}{N} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$V = \begin{pmatrix} (\rho_2+\mu) & 0 & 0 \\ -\rho_2 & (1-\gamma)+\mu & 0 \\ 0 & -(1-\gamma) & d_2+\mu \end{pmatrix}$$

$$R_e = \rho(FV^{-1}) = \frac{\{(1-e_1)+(1-e)\}\{n_1\varepsilon_1+\rho_2(n_2\varepsilon_2+n_3\varepsilon_3)\}}{(\rho_2+\mu)[1+(-1+\gamma-\mu)\{1+(d_2+\mu)\}]}$$

The threshold quantity R_e is now the effective reproduction number of the system (2) for the control of HIV/AIDS using the control strategies as vaccination, public campaign awareness campaign and the restriction in free movement and treatment. The R_e is therefore, the average number of new infections generated by a single infected individual into a susceptible population in the presence of vaccination, public campaign awareness campaign, the restriction of free movement and treatment.

The **endemic equilibrium** point of the system (2) denoted by E^* is expressed in terms of R_e as

$$s^* = \frac{A A_1 b}{A A_0 A_1 - B B_0 a_1}, \; s^*_v = \frac{A_1 B b}{A A_0 A_1 - B B_0 a_1}, \; s^*_{vc} = \frac{B b B_0}{A A_0 A_1 - B B_0 a_1}$$

$$s^*_{vcr} = \frac{B b q B_0}{A_2 \left(A A_0 A_1 - B B_0 a_1\right)}, \; s^*_{ve} = \frac{\left(q A_3 + A_2 B_1\right) B b B_0}{A_2 \left(A A_0 A_1 - B B_0 a_1\right) A_4}$$

$$i^* = \frac{B b B_0 \rho_2 \left(q A_3 + A_2 B_1\right)}{A_2 A_4 B_2 \left(A A_0 A_1 - B B_0 a_1\right)}, \; i_t{}^* = \frac{B b A_5 B_0 \rho_2 \left(q A_3 + A_2 B_1\right)}{A_2 A_4 A_6 B_2 \left(A A_0 A_1 - B B_0 a_1\right)}$$

Where;

$A_0 = \alpha_1 c + \mu$, $A = (1-\varphi) + \mu$, $A_1 = \{(1-e_1)\lambda + a_1 + q + \mu\}$,$A_2 = \{(1-e)\lambda + \mu\}$,

$A_3 = \{(1-e)\lambda$, $A_4 = \rho_2 + \mu$, $A_5 = 1-\gamma$, $A_6 = d_2 + \mu$, $B_0 = 1-\varphi$, $B_1 = \{(1-e_1)\lambda$,

$B_2 = (1-\gamma) + \mu$, $\lambda = \frac{n_1\varepsilon_1 ES}{N} + \frac{n_2\varepsilon_2 IS}{N} + \frac{n_3\varepsilon_3 I_t S}{N}$

So the endemic state exists since $R_e > 1$. This means that the disease is present throughout in the population

3.2 Global Stability of The Endemic Equilibrium, E^*

Theorem (3): if $R_e > 1$ then the endemic equilibrium of the model (2) is globally asymptotically stable and unstable otherwise.

Proof:

We construct the Lyapunov function, to establish the global stability of the endemic equilibrium, $\boldsymbol{E}^*$ of the system as follows;

$$V(s^*, s_v^*, s_{vc}^*, s_{vcr}^*, s_{ve}^*, i^*, i_t^*) = (s - s^* - s^* \log\frac{s^*}{s}) + (s_v - s_v^* - s_v^* \log\frac{s_v^*}{s_v}) + (s_{vc} - s_{vc}^* - s_{vc}^* \log\frac{s_{vc}^*}{s_{vc}}) + (s_{vcr} - s_{vcr}^* - s_{vcr}^* \log\frac{s_{vcr}^*}{s_{vcr}}) +$$

$$(s_{ve} - s_{ve}^* - s_{ve}^* \log\frac{s_{ve}^*}{s_{ve}}) + (i - i^* - i^* \log\frac{i^*}{i}) + (i_t - i_t^* - i_t^* \log\frac{i_t^*}{i_t}) \quad (7)$$

Evaluating the derivatives of V directly along the solution path of (7), we have,

$$\frac{dV}{dt} = \left(\frac{s+s^*}{s}\right)\frac{ds}{dt} + \left(\frac{s_v+s_v^*}{s_v}\right)\frac{ds_v}{dt} + \left(\frac{s_{vc}+s_{vc}^*}{s_{vc}}\right)\frac{ds_{vc}}{dt} + \left(\frac{s_{vcr}+s_{vcr}^*}{s_{vcr}}\right)\frac{ds_{vcr}}{dt}$$
$$+ \left(\frac{s_{ve}+s_{ve}^*}{s_{ve}}\right)\frac{ds_{ve}}{dt} + \left(\frac{i+i^*}{i}\right)\frac{di}{dt} + \left(\frac{i_t+i_t^*}{i_t}\right)\frac{di_t}{dt} \quad (8)$$

But from(2.1), we have that,

Therefore substituting, we get;

$$\frac{dV}{dt} = \left(\frac{s+s^*}{s}\right)\{b + a_1 s_{vc} - (\alpha_1 c + \mu)s\} + \left(\frac{s_v+s_v^*}{s_v}\right)\{\alpha_1 cs - ((1-\varphi)+\mu)s_v\}$$
$$+ \left(\frac{s_{vc}+s_{vc}^*}{s_{vc}}\right)\{(1-\varphi)s_v - ((1-e_1)\lambda + a_1 + q + \mu)s_{vc}\}$$
$$+ \left(\frac{s_{vcr}+s_{vcr}^*}{s_{vcr}}\right)\{qs_{vc} - ((1-e)\lambda + \mu)s_{vcr}\} +$$
$$+ \left(\frac{s_{ve}+s_{ve}^*}{s_{ve}}\right)\{(1-e_1)\lambda s_{vc} + (1-e)\lambda s_{vcr} - (\rho_2 + \mu)s_{ve}\}$$
$$+ \left(\frac{i+i^*}{i}\right)\{\rho_2 s_{ve} - ((1-\gamma)+\mu)i\} + \left(\frac{i_t+i_t^*}{i_t}\right)\{(1-\gamma)i - (d_2+\mu)i_t\} \quad (9)$$

We therefore solved to obtain;

$$\frac{dV}{dt} = b + a_1(s_{vc} + s_{vc}^*) + \frac{s^*}{s}\{b + a_1(s_{vc} + s_{vc}^*)\} - \frac{(s+s^*)^2}{s}(\alpha_1 c + \mu)$$
$$+\alpha_1 c(s + s^*) + \frac{s_v^*}{s_v}\alpha_1 c(s + s^*) - \frac{(s_v+s_v^*)^2}{s_v}((1-\varphi)+\mu)$$
$$+(1-\varphi)(s_v + s_v^*) + \frac{s_{vc}^*}{s_{vc}}(1-\varphi)(s_v + s_v^*) - \frac{(s_{vc}+s_{vc}^*)^2}{s_{vc}}((1-e_1) + a_1 + q + \mu)$$
$$+q(s_{vc} + s_{vc}^*) + \frac{s_{vcr}^*}{s_{vcr}}q(s_{vc} + s_{vc}^*) - \frac{(s_{vcr}+s_{vcr}^*)^2}{s_{vcr}}((1-e)\lambda + \mu)$$
$$+\{(1-e_1)\lambda(s_{vc} + s_{vc}^*) + (1-e)\lambda(s_{vcr} + s_{vcr}^*)\}$$
$$+\frac{s_{ve}^*}{s_{ve}}\{(1-e_1)\lambda(s_{vc} + s_{vc}^*) + (1-e)\lambda(s_{vcr} + s_{vcr}^*)\} - \frac{(s_{ve}+s_{ve}^*)^2}{s_{ve}}(\rho_2 + \mu)$$
$$+\rho_2(s_{ve} + s_{ve}^*) + \frac{i^*}{i}\rho_2(s_{ve} + s_{ve}^*) - \frac{(i+i^*)^2}{i}\left((1-\gamma)+\mu\right)$$
$$+(1-\gamma)(i + i^*) + \frac{i_t^*}{i_t}(1-\gamma)(i + i^*) - \frac{(i_t+i_t^*)^2}{i_t}(d_2 + \mu) \quad (10)$$

Hence, collecting the positive and negative terms from (*10*), we have the following expression;

$$\frac{dV}{dt} = X - Y \quad (11)$$

Where,

$$X = b + a_1(s_{vc} + s_{vc}^*) + \frac{s^*}{s}\{b + a_1(s_{vc} + s_{vc}^*)\} + \alpha_1 c(s + s^*)$$
$$+\frac{s_v^*}{s_v}\alpha_1 c(s + s^*) + (1-\varphi)(s_v + s_v^*) + \frac{s_{vc}^*}{s_{vc}}(1-\varphi)(s_v + s_v^*)$$
$$+q(s_{vc} + s_{vc}^*) + \frac{s_{vcr}^*}{s_{vcr}}q(s_{vc} + s_{vc}^*)$$
$$+\{(1-e_1)\lambda(s_{vc} + s_{vc}^*) + (1-e)\lambda(s_{vcr} + s_{vcr}^*)\}$$
$$+\frac{s_{ve}^*}{s_{ve}}\{(1-e_1)\lambda(s_{vc} + s_{vc}^*) + (1-e)\lambda(s_{vcr} + s_{vcr}^*)\}$$

$$+\frac{s_{ve}^*}{s_{ve}}\{(1-e_1)\lambda(s_{vc}+s_{vc}^*)+(1-e)\lambda(s_{vcr}+s_{vcr}^*)\}$$

$$+\rho_2(s_{ve}+s_{ve}^*)+\frac{i^*}{i}\rho_2(s_{ve}+s_{ve}^*)+(1-\gamma)(i+i^*)+\frac{i_t^*}{i_t}(1-\gamma)(i+i^*) \quad (12)$$

$$Y=-\left[\frac{(s+s^*)^2}{s}(\alpha_1 c+\mu)+\frac{(s_v+s_v^*)^2}{s_v}\big((1-\varphi)+\mu\big)+\frac{(s_{vc}+s_{vc}^*)^2}{s_{vc}}\big((1-e_1)\lambda+\ a_1+q+\mu\big)+\frac{(s_{vcr}+s_{vcr}^*)^2}{s_{vcr}}\big((1-\right.$$

$$e\lambda+\mu+sve+sve*2sve\rho 2+\mu+i+i*2i1-\gamma+\mu+it+it*2itd2+\mu \quad (13)$$

If $(12) < (13)$

Then , $\frac{dV}{dt}$ will be negative definite

Meaning that, $\frac{dV}{dt} < 0$

That is,

$\frac{dV}{dt} = 0$ if and only if $s = s^*, s_v = s_v^*, s_{vc} = s_{vc}^*, , s_{vcr} = s_{vcr}^*, s_{ve} = s_{ve}^*, i = i^*, i_t = {i_t}^*$

Thus the largest compact invariant set,

$[\{s^*, s_v^*, s_{vc}^*, , s_{vcr}^*, s_{ve}^*, i^*, {i_t}^*\} \in \Omega, \frac{dV}{dt} = 0]$ is the singleton set E^* and where E^* is the endemic equilibrium point.

Then by Lassalle invariant principle, if $< Y$, then E^* will be globally asymptotically stable in Ω [22].

4. Numerical Simulation of analytical results and Discussions

Some numerical solutions of the model is for different initial population sizes is presented using various values of the parameters stated in table 1 and to validate that those solutions are in agreement with the qualitative behaviours of the model. To study the behaviour of the model Eq. (2) numerically, Homotopy perturbation method (HPM) is used as in [22]. Parameters used in the simulation are summarised in table1. This is to illustrate some of the theoretical results arrived at in the paper. The HIV/AIDS transmission model system Eq.(2) was studied to investigate the impact of public health awareness campaign, vaccination, condom, treatment and restriction of free movement especially among our young people using parameter values in table1 and the following initial conditions;

$S(0) = 100{,}000$, $S_v(0) = 30{,}00, S_{vc}(0) = 20{,}00, S_{vcr}(0) = 5{,}00, S_{ve}(0) = 2{,}500, I(0) = 800,\ I_t(0) = 400$

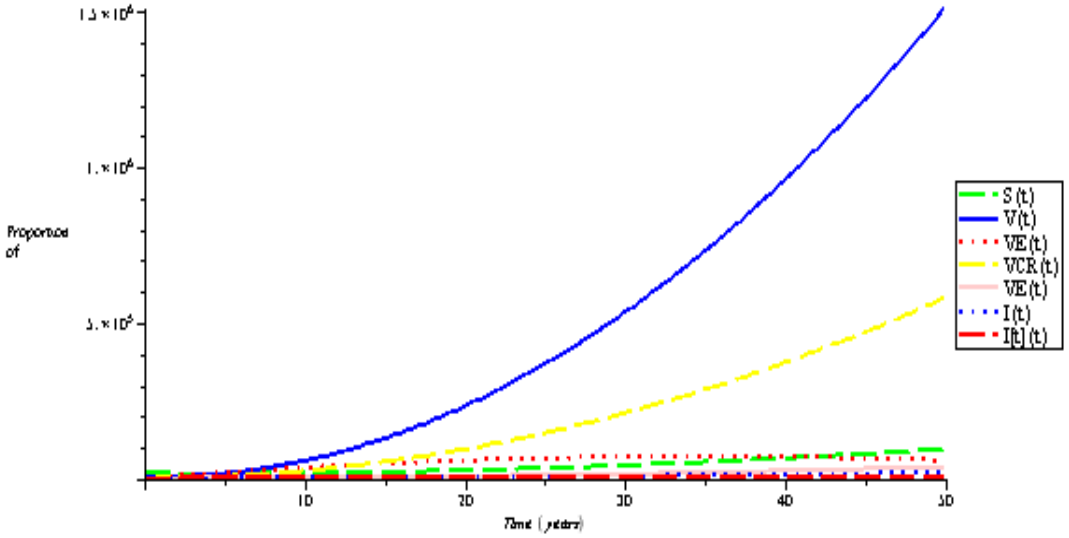

Figure 4.1: Graph of the General Population with Time

This graph shows a very significant increase in the number of those presenting themselves to be vaccinated. The second highest grown population being the vaccinated, condom usage and those restricted in their free movement. The growths of these two populations show that the public health campaign is very effective. This is true because the exposed population, the infected population and the susceptible population all finding it difficult to rise. This is even the reason why the population on treatment is also low since there is low exposure to the virus leading to low infection.

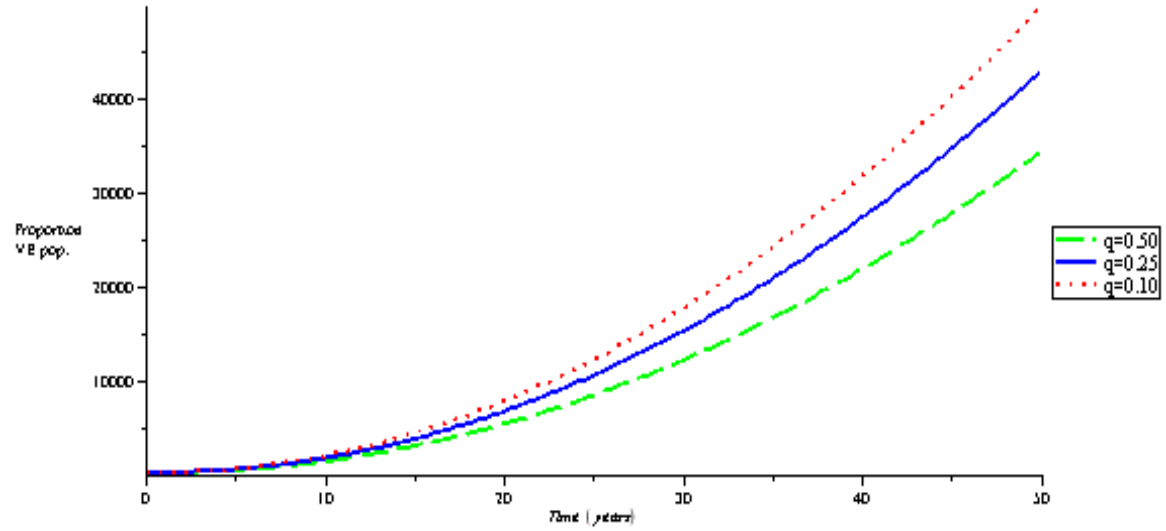

Figure 4.2: Effect of Restriction of Free Movement in the Population on Exposed Class with Time

Figure 3.2 explains the fact that the rate of restriction of free movement in the population will definitely affect the exposure rate of the population to HIV/AIDS. With all other parameters being the same with different values $(q = 0.10, q = 0.25, q = 0.50)$ in the restriction of free movement, there is clear difference in the number of those to be exposed. The higher the sensitization of the public on the need to possibly restrict movements of our children, the better the control/fight against the dreaded HIV/AIDS.

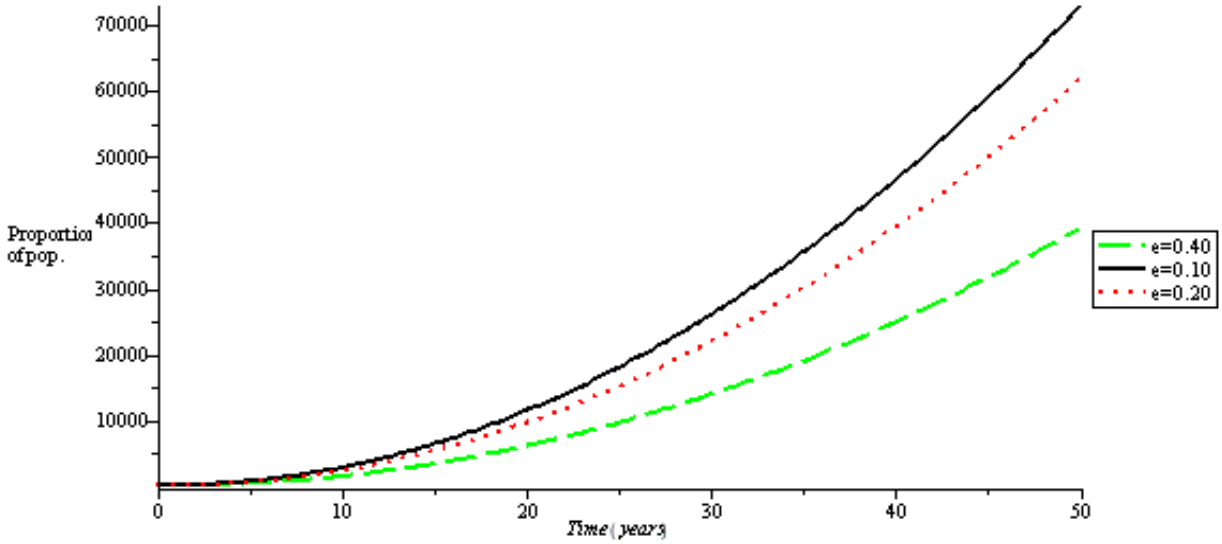

Figure 4.3: Effect of Efficiency of Vaccine, Condom and Restriction of Free Movement on the Exposed Population with Time

The figure 3.3 shows variation of the exposed population at different values of efficiency of the vaccines, condom and restriction of free movement $e = 0.40, e = 0.20 \; and \; e = 0.10$. It is seen that as efficiency rates decreases, the rate at which the population will becomes exposed to the virus increases with time. This means that if vaccines, condom and restriction of free movement are very efficient with high potency, the less the exposure rate of the population.

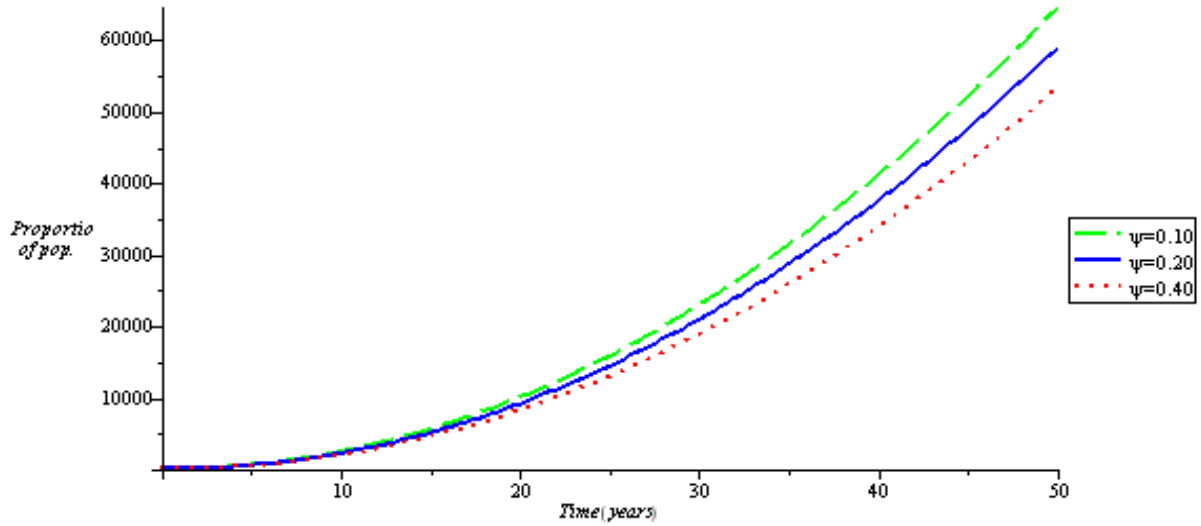

Figure 4.4: Graph of Different Values of Restriction of Free Movement on the Exposed Population with Time

This graph indicates that the more the discipline of restriction of free movement is accepted in the population, the less the population will be exposed to the virus. This is practically demonstrated in the graph where the rate of restriction of free movement is varied with corresponding variation in the exposure rates to HIV/AIDS. The restriction of free movement values used in the graph is $\psi = 0.40,\ \psi = 0.20\ and\ \psi = 0.10$ while every other parameter value remains the same.

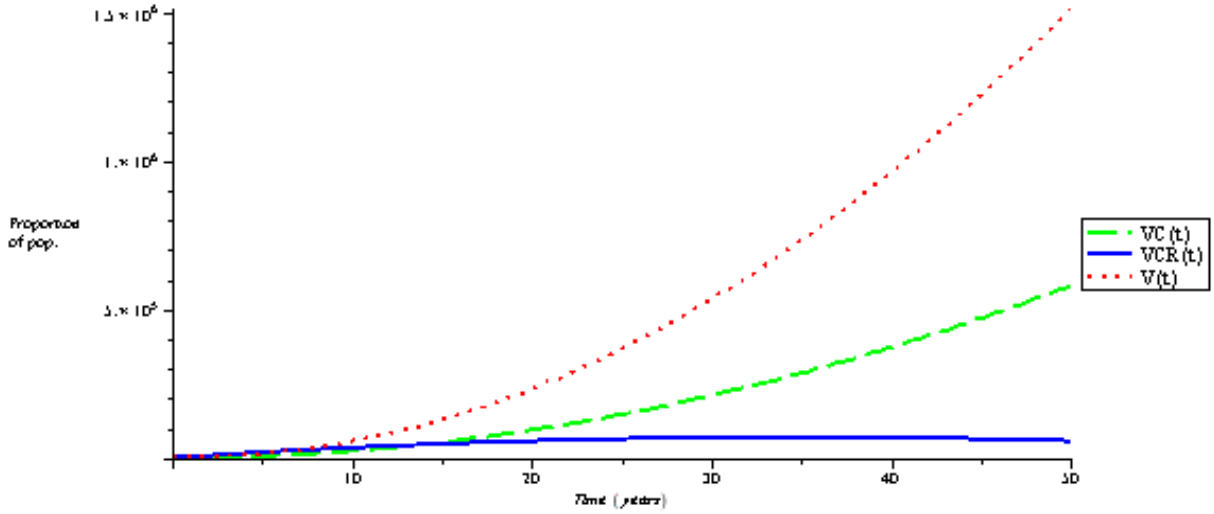

Figure 4.5: graph of comparison of the VC(t), VCR(t) and V(t) populations with time

Figure 4.5 shows that more the public will accept to be vaccinated than being vaccinated and also using condom due to the stigma attached to condom and its usage. The VCR (t) class grows least here since a good number of those who are vaccinated will claim that they do not need to be restricted in their movement any longer.

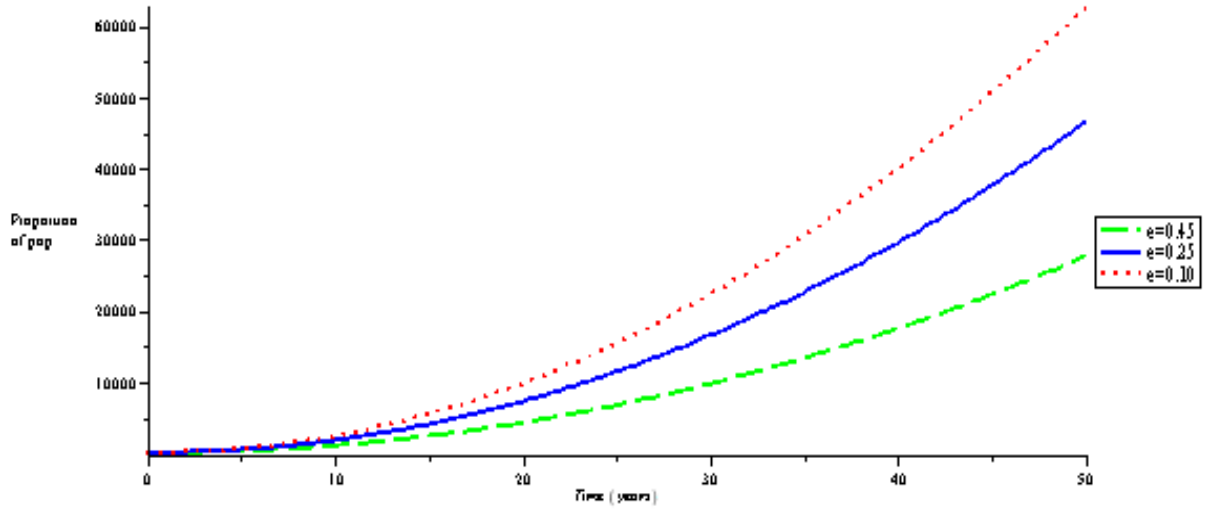

Figure 4.6: Variation of Efficiency of Condom, Vaccines and Restriction of Free Movement on Infected Population with Time

The figure 4.7 shows that, with high efficiency level of vaccines, condom and restriction of free movement with high potency, the better the fight against HIV/AIDS. The efficiency values used in the graph are $e = 0.45$, $e = 0.25$ and $e = 0.10$. Low efficiency leads to high infection and vice versa.

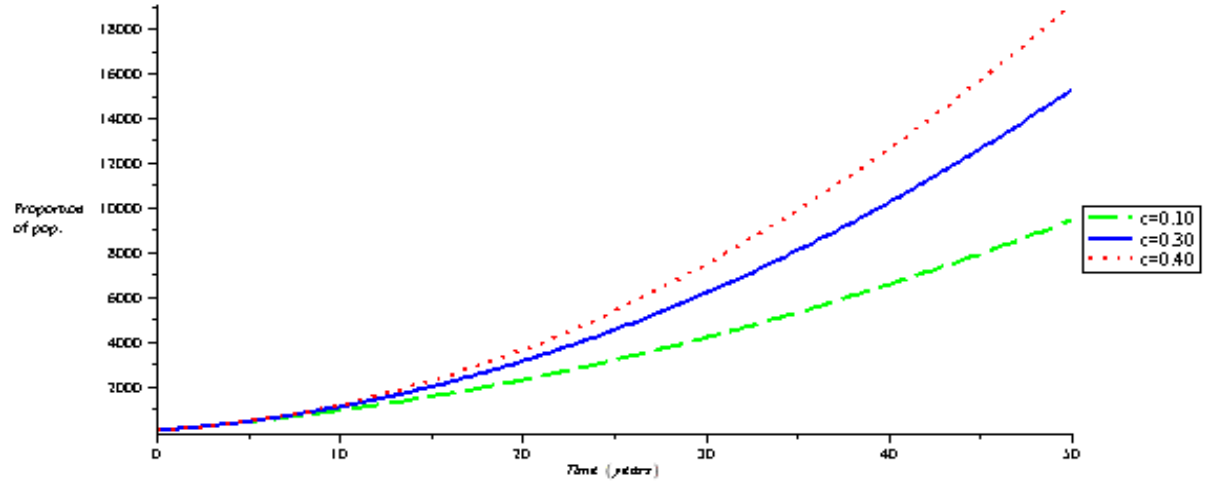

Figure 4.7: Variation of Campaign on Infected Population on Treatment with Time

With different campaign values for the need for therapy shows the difference in the number of truckers and sex workers that will accept the therapy. With the campaign values as $C = 0.40, C = 0.30$ and $C = 0.10$, the curves for treatment behave positive towards treatment. This means that with high level of sensitization, more infected people will go for therapy.

4. Conclusion

The results from the study indicate that, the most effective way to control the virus/disease, HIV/AIDS within the population is through the use very effective public health awareness campaign such as; organized training most especially at transit towns, radio, flyers, televisions, churches, mosques, schools, town criers and all official and unofficial gatherings on the need for the public to abide in the culture of always using condom whenever engaging in sexual act, go for screening to ascertain their true status and for daily pills where necessary, avail themselves for vaccination when ever its available. Guardians and or parents should resist their children from free movement most especially at odd hours/joints. The public should be educated on the consequences of contracting/transmitting the virus. Government, NGOs, groups, health workers and individuals should make screening centers, ART and even HIV/AIDS preventative vaccines available/accessible/affordable

for the general public. If there is positive attitudinal change in respect to these strategies, then HIV/AIDS will be a thing of the past in no distant time.

References

[1]. UNAIDS (2016). Global HIV & AIDS Statistics (http://www.unaids.org/en/resources/fact-sheet-2017)

[2]. WHO (2015) Global health sector response to HIV 2000-2015: focus on innovations in Africa pp 57-63.

[3]. Coffee, M., Lurie, M.N., Garnett G.P. (2007) Modelling the impact of migration on the HIV epidemic in South Africa. Pub Med., 21(3):343–350.

[4]. Kalling, L.O (2008) The first post modern pandemic; 25years of HIV/AIDS J. Internmed, 263(3):218-242.

[5]. Harder, V.A (2012); Aids at 30: A history Potomac Books Inc. P.324 ISBN1-59797-294-0.

[6]. Zuckerman (2001). Principles and Practice of Travel Medicine. John Wiley and Sons. Baffin Lane, Chic ester, West Sussex P019 1UD, U.K.

[7]. Kaur, N., Ghosh, M. and Bhatia, S.S.(2012) Modeling the spread of HIV in a stage structured population: effect of awareness, Intl. J. Biomathematics, 5(5):182-197.

[8]. Abdallah, S.W., Estomih, S.M., Oluwole, D.M. (2012). Mathematical Modelling of HIV/AIDS Dynamics with Treatment and Vertical Transmission. J. Appl. Math., 2(3); 77-89.

[9]. Tennenbaum, S., Kassem, T.G., Roudenko, S. and Castillo-Chavez (2006). The role of transactional sex in the spread of HIV in Nigeria. Contemporary Mathematics, 410:3367-389

[10]. Kimbir, A.R., Musa, S. and Bassey, A.B. (2006). On a two-sex mathematical model for the prevention of HIV/AIDS in a varying population, ABACUS, 33(2A): 1-13.

[11]. Kimbir, A.R. and Aboiyar, T. (2003) A mathematical model for the prevention of HIV/AIDS in a varying population. J. Nigerian Mathematical Society, 22, 43-55.

[12]. Lungu, E., Massaro, T.J., Ndelwa, E., Anea, N., Chibava, S. and Malunguza, N. J. (2013); Mathematical Modeling of the HIV/Kaposi's Sarcoma Co-infection Dynamics in Areas of High HIV Prevalence, Comput Math Methods Med.

[13]. Udoy, S.B., Bimal, K.D. and Prodip, K.G. (2015). Mathematical analysis of an HIV/AIDS epidemic model.

[14]. Okosun,K.O., Makinde, O.D., Takaidza, I. (2013); Impact of optimal control on the treatment of HIV/AIDS and screening of unaware infectives. Appl. Math., 37(6): 3802-3820.

[15]. Udoo, I.J.M. (201 8). Modelling impact of public awareness and behaviour changes with treatment on HIV/AIDS dynamics in resource-poor setting. J. Nigerian Society for Mathematical Biol. Vol. 1, pp. 19-46. American Journal of Mathematics and Statistics, 5(5):253-258.

[16]. Hove-Musekwa S.D and Nyabadza F. (2009). The dynamics of an HIV/AIDS with screened disease carriers. Computational and Mathematical Methods in Medicine, 10(4): 287-305.

[17]. Bhunu C.P., Mushayabasa, S., Kojouharov, H., Tchuenche, J.M. (2011) Mathematical analysis of an HIV/AIDS model: Impact of Education Programmes and Abstinence in Sub-Saharan Africa. J. Math. Model Agor, 10: 31-35.

[18]. Lakshmikanthan, V., Leela, S., and Martknyuk, A. (1989). Stability analysis of nonlinear systems, Marcel Dekker, New York. Pure and Applied mathematics: A series of monographs and textbooks, Vol. 125

[19]. Birkhorff, G., Rota, G.C. (1982). Ordinary Differential Equations. Needham Heights, Ginn

[20]. Driesche van den P. and Watmough, J. (2002) Reproduction numbers and sub- threshold endemic equilibria for compartmental models of disease transmission Math. Biosci., 180:29-48.

[21]. LaSalle, J., Lefschetz, S. (1961). Stability by Lyapunov's Direct Method with Applications. Academic Press New York.

[22]. He, J.H. (2000) A Coupling Method of Homotopy Technique and Perturbation Technique for Nonlinear Problems. International Journal of Non-Linear Mechanics, (35):37-43. http://dx.doi.org/10.1016/S0020-7462 (98)00085-7