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ANALYSIS AND MODELLING THE IMPACT OF PUBLIC HEALTH EDUCATION CAMPAIGN ON THE TRANSMISSION DYNAMICS OF HIV/AIDS

[1] **Moffat C. Nyaboe** - Department of Pure and Applied Mathematics, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.
Email: chamuchimoffat@yahoo.com
[2] **Johana K. Sigey** - Department of Pure and Applied Mathematics, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.
Email: jksigey@jkuat.ac.ke
[3] **Kangethe Giterere** - Department of Pure and Applied Mathematics, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.
Email: kgiterere@jkuat.ac.ke

ABSTRACT

The most important factor in the management and control of an infectious disease is the understanding of the dynamics of the disease in any given population. We have proposed and analyzed a nonlinear mathematical model for the spread of HIV/AIDS in a population with variable size structure. The model was developed by adopting the compartmental modeling approach where the population was partitioned into; Susceptible, Infected and Aids sub-populations. A threshold parameter is found that completely determines the stability dynamics and outcome of the disease. It is found that if the threshold parameter is less than one the disease free equilibrium is stable and the disease dies out. However, if the threshold parameter is more than one, there exists a unique endemic equilibrium that is locally asymptotically stable. Numerical simulation of the model is also performed by using fourth order Runge - Kutta method. Numerically, it has been found that the system exhibits steady state bifurcation for some parameter values. It is concluded from our analysis that public health education is more efficient if the susceptible individuals are educated in time and followed up by treatment in the exposed sub-population.

KEYWORDS: Jacobian matrix, population, Education, Basic reproduction ratio-R_o, Compartmental model, Susceptible, exposed, infective, educated, basic reproduction ratio, persistence, steady state equilibrium, bifurcation, Disease-free Equilibrium, Mathematical modeling.

1. Introduction

HIV/AIDS is a serious and highly infectious disease which may lead to hospitalization or death. Epidemiology is the study of the distribution and determinants of diseases, for both infectious and non-infectious diseases. Originally, the term was used to refer only to the study of epidemic infection diseases, but it is now applied more broadly to other diseases as well. Mathematical models have become important tools in analyzing the spread and control of infectious diseases. The model formulation clarifies assumptions, variables and parameters. Moreover models provide conceptual results such as thresholds, basic reproduction numbers, contact numbers and replacement numbers. Understanding the transmission characteristics of infectious diseases in communities, regions and countries can lead to better approaches to decreasing the transmission of these diseases. As explained in, mathematical models are used in comparing, planning, implementing, evaluating and optimizing various detection, prevention, therapy and control programs. We introduce the following definitions and theorems necessary to model the population dynamics of HIV/AIDS.

Since its emergence in the 1980s, the human immunodeficiency virus (HIV), and the associated syndrome of opportunistic infections which lead to the late stage HIV disease, known as the acquired immunodeficiency syndrome (AIDS), continue to be one of the most serious global public health menaces. Global and regional estimates of HIV have been provided by the Joint United Nations Programme on HIV/AIDS (UNAIDS) and the World Health Organization (WHO) since the late 1980s and country specific estimates since 1996 (UNAIDS, 2009; Garcia-Calleja *et al.*, 2006). Unlike the early years of AIDS epidemic where the majority of infected individuals were homosexuals, hemophiliacs, and intravenous drug users, today there is no geographical area, class and cultural group of the world untouched by this pandemic Koob and Harvan, (2003).

Based on the current trends, over 7300 persons become infected with HIV, 5400 die from AIDS-related causes including more than 760 children, every day UNAIDS, (2009). In other words, almost five people become infected with HIV and four people (i.e., three adults and one child) die from AIDS per minute UNAIDS, (2009) .With an estimated adult HIV prevalence of 26% in 2007, Swaziland has the most severe level of infection in the world UNAIDS, (2008).

The recent statistics have shown that an estimate of 22.4 million [20.8 million - 24.1 million] people (women account for approximately 60%) living with HIV in sub-Saharan Africa at the end of 2008 (UNAIDS, 2009; Garcia-Calleja et al., 2006). Moreover, 72% of world's AIDS-related deaths, 68% of new HIV infections among adults and 91% of new HIV infections among children occurred in sub-Saharan Africa (UNAIDS, 2009).

In addition, the epidemic has left behind more than 14 million AIDS orphans in the region in 2008. Once HIV has entered the body, its major target is a class of lymphocytes, or white blood cells, known as CD_4^+ T cells. Thus, the immune system initiates anti-HIV antibody and cytotoxic T cell production. However, it can take two to ten weeks for an individual exposed to HIV to produce measurable quantities of antibody. Because of the central role of CD_4^+ T cells in immune regulation, their depletion has widespread deleterious effects on the functioning of the immune system as a whole and leads to the immunodeficiency that characterizes AIDS.

Therefore, HIV levels in the bloodstream are typically highest when a person is first infected and again in the late stages of the illness. The progression of HIV infection to AIDS probably depends on how well the body can replace cells destroyed by virus (Perelson and Nelson, 1999). Modes of HIV transmission Epidemiological evidence shows that HIV is transmitted only through the intimate exchange of body fluids, such as blood, semen, vaginal secretion, and mother's milk (Dane and Miller, 1990). Thus, HIV could be passed from an infected mother to her child (i.e., vertical infection) during pregnancy, birth or through infected breast milk.

High-risk behaviors include unprotected sexual intercourse and intravenous drug use through sharing needles or syringes. The viral load against HIV is depicted. The early peak in viral load corresponds to primary infection. Primary infection is followed by a long asymptomatic period during which the viral load changes little. Ultimately, the viral load increases and the symptoms of full-blown AIDS appear. On average, the time from infection to AIDS is 10 years, but still some patient’s progress to AIDS much more rapidly, while others progress more slowly.

2. Related works/Literature survey

HIV is classified as an infectious disease which rapidly spreads amongst communities and changes its distributions in space, time and social space (Wallace, 1991; Daniel S.L., 2003). Many factors, including increased mobility, are associated with an increased risk of HIV infection (Welz *et al*., 2007; Altmann. M, 1995; Brauer F, 2001). The transmission of HIV is also strongly associated with the spatial distribution of high risk groups. The distribution of AIDS cases not only varies by cities and states, but also by geographical regions Lange *et al*., (1988).

The models that are labeled by SI, SIS, SEIS, and SEIR are mostly used where the sub-populations are Susceptible, Exposed, Infected and Recovered or Removed.

Nyabadza *et al* (2010), Castillo-Chavez *et al* (1989), looked at a model of HIV/AIDS that examine the diminution in infection by promoting a change in sexual behavior through public health information campaigns and individuals with AIDS to abstain from sexual activities. Both the endemic and disease free equilibrium have been investigated. Numerical simulations are presented using the fourth order of Runge-Kutta. The results from their research have shown that media campaigns had led to a reduction in the prevalence of the disease but may not be the only ultimate strategy in the fight against HIV/AIDS. It has also shown that an increase in the distribution of public health information campaigns has led to a decrease in occurrence of a disease. In the case of the individual with AIDS abstaining from sexual activities, it has also reduced the effect of the disease.

The impact of educational campaigns as a control measure for the spread of HIV/AIDS has been investigated by Mukandavire *et al* (2009), Elbasha and Gumel A.B. (2006). The authors present a sexual transmission model with explicit incubation period. Their results suggested that educating sexually immature and sexually mature individuals concurrently is more effective in slowing down HIV/AIDS than concentrating on cohort public health educational campaign of sexually immature or sexually mature individuals only. It is shown that in their study, in situations where education is effective and with reasonable average number of HIV infected partners, public health campaigns can slow down the epidemic.

An epidemic HIV/AIDS model with treatment has been investigated in the research paper by Cai *et al* (2009). The model allows some infected individuals to move from symptomatic phase to the asymptomatic phase by all kinds of treatments. The authors introduced the time delay to the model in order to investigate the effect of the time delay on the stability of the endemically infected equilibrium. This discrete time delay has also been used to the model to describe the time from the start of the treatment in the symptomatic stage until the treatment effects become clear. It was found that treatment can be used to make the disease free equilibrium (E_0) stable when it would be unstable in the absence of treatment. On the other hand using the time delay can induce oscillation in the system. Biologically, this means that there is a critical value for the treatment-induced delay which determines the stability of the infected equilibriumE^*. That is, the infected equilibriumE^* is asymptotically stable when antiretroviral drugs on average show positive effects in patients within less than time delay.

A continuous model for HIV/AIDS disease progression has been formulated and physiological interpretations were provided by Ida *et al* (2007), Elbasha and Gumel A.B. (2006). The abstract theory was then applied to show existence of unique solutions to the continuous model describing the behavior of the HIV virus in the human body and its reaction to treatment by antiretroviral therapy. The product formula has suggested appropriate discrete models describing the dynamics of host pathogen interactions with HIV1 and is applied to perform numerical simulations based on the model of the HIV infection process and disease progression. Finally, the results of the numerical simulations are visualized and it was observed that they agreed with medical and physiological aspects.

A simple deterministic HIV/AIDS model incorporating condom use, sexual partner acquisition, behavior change and treatment as HIV/AIDS control strategies has been formulated by Nyabadza *et al* (2011) using a system of ordinary differential equations with the object of applying it to the current South African situation. The authors fit the model to a data from UNAIDS/WHO on HIV/AIDS (2008), LaSalle (1976), in South Africa and the epidemiological facts sheets shows the current prevalence scenario. The results compare very well with other research outcomes on the HIV/AIDS epidemic in South Africa. Projections were made to track the changes in the number of individuals who were able to be under treatment, an important group as far as public health planning is concerned.

Nyabadza and Mukandavire (2011), Garcia-Calleja (2006), formulated a deterministic HIV/AIDS model that incorporates condom use, screening through HIV counseling and testing (HCT). A regular testing and treatment as control strategies has been proposed with the objective of quantifying the effectiveness of HCT in preventing new infections and predicting the long-term dynamics of the epidemic. The authors fit the model to a current prevalence data in South Africa from UNAIDS/WHO reports and epidemiological fact sheet. They looked at a recently launched HTC campaign to model its possible impact on the dynamics of the disease. The model shows that HTC alone has a very little impact in reducing the prevalence of HIV unless the ability of the campaign exceeds an evaluated threshold in the absence of bifurcation. The result has shown that force of infection can only be reduced through behavior change, condom use and reduction in the number of sexual partners and these form the pillars of prevention of new infection. The results have shown that the presence of bifurcation has an important implication in the control of HIV/AIDS. The model has shown that it cannot be eliminated by simply reducing the value of reproduction number R_0 to below unity.

Bhunu *et al* (2009) have considered a more robust systematic and complete qualitative analysis of a two strain HIV/AIDS model with treatment of AIDS patients. The treatment with amelioration results in an increase in number of HIV patient and a decrease in Aids patients. Bhunu *et al* (2009) have advised that treatment with amelioration should always be accompanied by public health education. The authors investigated that if the drugs used for therapy are 100 percent effective and a positive change in the sexual behavior of treated individuals is achieved, treatment with amelioration will not increase the development of HIV/AIDS in societies but will help communities by lengthening the lives of the infected, thus, reducing morbidity/mortality and socio-economic costs. Further the analysis of the reproduction numbers show that the use of antiretroviral therapy to improve the quality of life of AIDS patients with antiretroviral sensitive, HIV results in an increase of antiretroviral resistant HIV cases supporting the argument that antiretroviral resistance develops as a result of selective pressure on non-resistant strains due to antiretroviral use.

A non-linear mathematical model has been proposed and analyzed to study the spread of HIV/AIDS with direct inflow of infective in a population with inconsistent volume structure. Naresh *et al* (2008) has looked at a model without inflow of HIV infective including interaction with pre-AIDS individuals and Model without inflow of HIV infective and no interaction with pre-AIDS individuals. It was found that if the direct inflow of the infective has been allowed in the community the disease always persist. The endemicity is extensively reduced if direct inflow of infective is restricted and pre-Aids individuals do not take place in sexual activities. Karen and Susan C.W. (1999), Naresh *et al* (2008) suggested sexual partners should be restricted and unsafe sexual iteration should be avoided with an infective in order to reduce the spread of the disease. Thus the spread of infection can be slowed down if direct inflow of infectives is restricted into the population. It was also noted that the increase in the number of sexual partners further reduces the total population by way of spreading the disease. Thus in order to reduce the spread of the disease, the number of sexual partners should be restricted and unsafe sexual interaction should be avoided with an infective.

Zurakowskia A.R. Teel (2006),Lange, F.R., *et al* (1988), has proposed the interaction of the immune system and human immunodeficiency virus where we will introduce the possibility of using highly active anti-retroviral therapy (HAART) to stimulate the vaccine. They further present a model predictive control (MPC) based method for determining optimal treatment. Finally they analyze the simulations by using algorithms where they apply robustness measurement noise, robustness modeling error, robustness combined errors, and varying the cost function. An SIR model with six compartments where there is an interaction between HIV and TB epidemics has been investigated. They further look at sensitivity of the steady states with respect to changes in parameter values. The authors examine that most of the control measures studied have an obvious positive impact in controlling the HIV or TB epidemics, this is the case for condom use, increased TB detection and preventive treatment. The situation for ART is more complicated. However, although the future for the prevalence of HIV is uncertain, it seems that a generalized access to ART would lead to a significant decrease of the TB notification rate. They further concluded that it is difficult to guess if the observations drawn from the model with parameters adapted to the particular South African township are still valid for less crowded areas with high HIV prevalence, finally reliable data on both HIV and TB are still rare.

Mukandavire and Garira (2007) formulated and analyzed a sex-structured model for heterosexual transmission of HIV/AIDS. The model has been further divided into two classes, consisting of individuals involved in high-risk sexual activities and individuals involved in low-risk sexual activities. The model is described as the movement of individuals from high to low sexual activity group as a result of public health education campaigns. The threshold parameter which is the basic reproduction number has been obtained and their stability (local and global) of the disease-free equilibrium. The model has been extended to incorporate sex workers, and their role in the spread of HIV/AIDS in settings with heterosexual transmission was explored. In order to assess the possible community benefits of public health educational campaigns in controlling HIV/AIDS comprehensive analytic and numerical techniques were employed.

Mukandavire and Garira (2011) concluded that the presence of sex workers enlarges the epidemic threshold R_0, thus fuels the epidemic among the heterosexuals, and that public health educational campaigns among the high risk heterosexual population reducesR_0, thus can help slow or eradicate the epidemic. The models mentioned so far are deterministic and they do not consider the stochastic disturbance of environment which exists in fact. When the environmental noise is not taken into account, an ordinary differential equation is used for AIDS transmission for instance. The introduction of stochastic modeling has provided new insights into the population dynamics of the disease .In particular, stochastic modeling of HIV/AIDS can be found by Ding *et al* (2011) and Jiang *et al* (2010)

In the papers of Lahrouz *et al* (2009) and Garba and Gumel A.B. (2010), they have formulated an SIRS epidemic model with saturated incidence rate and disease-inflicted mortality. In the same paper, the authors have further looked at the stochastic version. The global existence and positivity of the solution of the stochastic system has been established.

Under suitable conditions on the intensity of the white noise perturbation, the global stability in probability and P^{th} moment of the system has been proved. In this regard, this dissertation refers mainly to the papers.

Standard mathematical models of the spread of infectious diseases are well known and have been widely applied for many diseases including HIV in different regions in the world Anderson and May, (1991). There is still no cure or vaccine for HIV, and anti-retroviral drugs (ARVs) are still not widely accessible, particularly in the resource-poor nations (which suffer the vast majority of the HIV burden globally). Yet, HIV remains preventable through the avoidance of high-risk behaviors, such as unprotected sexual intercourse and sharing of drug injection needles.

Moreover, education, as a sole anti-HIV intervention strategy, may not be sufficient to motivate behaviour change Berker and Joseph, (1988). Studies show that public health education increases self-efficacy, which is a determinant for controlling risky behaviour Lindan *et al* (1991). Furthermore, the benefits of new methods of HIV prevention could be jeopardized if they are not accompanied by positive efforts to change risky behaviour. This is in line with the well-known fact that sexual education and awareness of the risk and life-threatening consequences of AIDS can lower the incidence rate in HIV infection Valesco-Hernandez and Hsieh, (1994) and Wang (2006).

Public health education campaigns have been successfully implemented in numerous countries and communities, such as: Uganda, Thailand, Zambia and the US gay community Daniel and Rand, (2003); De Walque, (2007).Between 1991-1998, HIV prevalence dramatically declined in Uganda from 21% to 9.8% (with a corresponding reduction in non-regular sexual partners by 65% coupled with greater levels of awareness about HIV/AIDS; Daniel and Rand (2003).

3. STATEMENT OF THE PROBLEM

HIV/AIDS pandemic in a population continues to be a major public health menace more specifically in developing countries like Kenya. There is still no cure or vaccine for HIV, and anti-retroviral drugs (ARVs) are still not widely accessible, particularly in the resource-poor nations (which suffer the vast majority of the HIV burden globally). The emergence of drug-resistant HIV strain in the last two decades has been a major problem in tackling this scourge. A mathematical model for investigating the impact of that role of public health education campaign on the transmission dynamics of HIV/AIDS is developed. The purpose of this study is to extend some of the aforementioned studies, by designing and analyzing a new comprehensive model, for HIV transmission in a population, that incorporates the role of public health education campaign and using the model to evaluate the impact of some targeted public health education strategies.

4. MOTIVATION OF THIS RESEARCH

The motivations of this research are to:

a) Assess various biological factors such as incubation that are affecting the spread of HIV/AIDS.

b) Model the transmission dynamics of HIV/AIDS for Computational mathematical researchers.

c) Optimize a model for reducing HIV/AIDS cases in Kenya since it is a developing country without increasing public spending.

d) Study the magnitude of public protection since it greatly influences the total number of cases avoided and the value of public treatment cost savings.

5. RESEARCH OBJECTIVES

5.1.GENERAL OBJECTIVES

It is possible to mathematically model the progress of an infectious disease in order to discover the likely outcome of an epidemic or to help manage it by different control programs.

5.1.1. SPECIFIC OBJECTIVES

The objectives of this research are to:

a) Propose a mathematical model for the HIV/AIDS on transmission dynamics.

b) Assess the impact of HIV/AIDS in Kenya.

c) Validate the effect of HIV/AIDS model with data from Kenya.

6. CONTRIBUTIONS OF THIS ARTICLE ARE:

a) Change the perception that mathematical models for the HIV/AIDS which were considered merely speculative and imprecise, but in this study, with the inclusion of explicit elements of biology and behavior in the models, it is possible that they lead to a deeper understanding of the future spread of disease.

b) Bring to the attention of other researchers that even though the actual data needed for the models might not be accurate or even available, this modeling is still vital in investigating how changes in the various assumptions and parameter values affect the course of the epidemic. Mathematical modeling helps in the set of conditions by which the extinction of susceptible population is reached.

c) Show that the improvements in data capture produce major challenges in developing frameworks capable of utilizing this data to predict the complex patterns of evolution of infectious diseases in increasingly dense and interconnected human populations. This mathematical model and its computer simulation is useful in analyzing the spread and control of HIV/AIDS as a killer disease.

7. Assumptions of the model

(i) At the beginning of the epidemic, at $t = 0$, that S (0) a large population, that I(0) is very small and that A(0) = 0.

(ii) The AIDS patients who received public health education die due to AIDS at a slower rate than the AIDS patients who did not.

(iii) Public health education will be offered to all infected individuals except for the education of high-risk people with AIDS and hence will not only be restricted to susceptible individuals.

(iv) Intensive public health education of newly-recruited sexually-active individuals will be carried out.

8. METHODOLOGY

Mathematical models have been used for centuries to develop a better understanding of systems in order to control or optimize results. A wide range of applications include everything from radar development to production rates within factories to the spread of disease.

Epidemic models are mathematical models concerned with the spread of infectious diseases.

Models are created to study treatment and infection rates in order to optimize our ability to predict quarantine and control disease.

We assume that all parameters in the model are nonnegative and that $b > 0; d_i > 0;\ i = 1;\ 2;\ 3;\ 4:$

8.1. GOVERNING EQUATIONS

In this section the governing equations of the model will be discussed in detail. The model takes the form of the following deterministic system of nonlinear differential equations: Gao *et al* (2013) model

$$\frac{dS_u}{dt} = \varphi(1 - P) - \xi S_u - [\lambda_u + (1 - k)\lambda_e] S_u - \mu S_u$$

$$\frac{dS_e}{dt} = \varphi P + \xi S_u - (1 - \epsilon)[\lambda_u + (1 - k)\lambda_e] S_e - \mu S_e$$

$$\frac{dI_u}{dt} = [\lambda_u + (1 - k)\lambda_e] S_u - \sigma_u I_u - \mu I_u - \psi_1 I_u$$

$$\frac{dA_u}{dt} = \sigma_u I_u - \psi_1 A_u - \mu A_u - \delta_u A_u$$

$$\frac{dI_e}{dt} = (1 - \epsilon)[\lambda_u + (1 - k)\lambda_e] S_e + \psi_1 I_u - \sigma_e I_e - \mu I_u$$

$$\frac{dA_e}{dt} = \sigma_e I_e + \psi_2 A_u - \mu A_e - \delta_e A_e$$

Where,

$$\lambda_u = \frac{\beta(\lambda u + \eta u A u)}{N} \text{ and } \lambda_e = \frac{\beta(\lambda e + \eta e A e)}{N}$$

The rates ¸ λ_u and λ_e above are the forces of infection associated with HIV transmission by uneducated (at the rate λ_u) and educated (at the rate λ_e) infected individuals, respectively. The parameter β is the effective contact rate (that is, contact that may result in HIV infection), while the parameters $\lambda_u > \lambda_e > 1$ account for the relative infectiousness of individuals with AIDS symptoms in comparison to the corresponding infected individuals with no AIDS symptoms.

It will be investigated about the manner in which the educated infected individuals (in I_u or A_u class) modify their behaviour positively in order to reduce their risk of HIV transmission by a factor k, with $0 < k < 1$.

This model is to help in the understanding of the disease by; allowing for HIV transmission by the individuals with AIDS symptoms, offering public health education to all infected individuals which will only be restricted to susceptible individuals and stratifying the infected population in terms of whether or not they received public health education

In addition to the aforementioned extensions, this study will contribute to the literature by giving detailed qualitative analysis of the model.

8.2.Positivity and Boundedness of Solutions

Positivity of Solutions Model above describes a human population, and, therefore it is very important to prove that all quantities (susceptible, infected and those with AIDS symptoms population) will be positive for all times. Positivity implies that the system persists i.e. the population survives. From the model system, we note that

All education-related parameters and variables are set to zero in order to understand the dynamical behaviour of education-free sub-model without education. By setting $A_e = \sigma_e = I_e = k = P = \xi = \psi_1 = \psi_2 = \epsilon = 0$, education-free model is obtained as follows:

$$\frac{dS_u}{dt} = \varphi - (\lambda_u + \mu) S_u$$

$$\frac{dI_u}{dt} = \lambda_u S_u - (\sigma_u + \mu) I_u$$

$$\frac{dA_u}{dt} = \sigma_u I_u - (\mu + \delta_u) A_u$$

8.3. **Existence of steady states of the system**

The equilibrium points of the system can be obtained by equating the rate of changes to zero.

$$\frac{dS}{dt} + \frac{dI}{dt} + \frac{dA}{dt} = 0$$

8.4. Numerical experiment

We showed analytically that the developed model equation is locally asymptotically stable at the disease free equilibrium point. In this sub-section, we carry out the effect of public health education campaign on the compartmentalized population

INITIAL DATA

Table 1: Initial Values for the Numerical Experiments

Variables	**Description**	**Value**	**SOURCE**
N	Adult population	19	Kenya bureau of statistics census 2009
S_u	Uneducated susceptible individuals	14	Kenya bureau of statistics census 2009
S_e	Educated susceptible individuals	0.1421	Kenya bureau of statistics census 2009
I_u	Uneducated infected with no AIDS symptoms	2	Kenya bureau of statistics census 2009
I_e	Educated infected with no AIDS symptoms	0.087	Kenya bureau of statistics census 2009
A_u	Uneducated infected with AIDS symptoms	0.2	Kenya bureau of statistics census 2009
A_e	Educated infected with AIDS symptoms	0.0009	Kenya bureau of statistics census 2009

Parameters	**Description**	**Nominal value**	**SOURCE**
λ_u	Force of infection of uneducated individuals	0.2541	Gumel et al.
λ_e	Force of infection of educated individuals	0.0164	Gumel et al.

Π	Recruitment rate of susceptible	3.2000	Kenya bureau of statistics census 2009
μ	Natural mortality rate	0.0154	Kenya bureau of statistics census 2009
δ_u	Disease-induced mortality rates for uneducated individuals	0.4700	Gumel et al.
δ_e	Disease-induced mortality rates for educated individuals	0.0400	Gumel et al.
ρ	Fraction of educated newly-recruited individuals	0.5000	Elbasha and Gumel
ξ	Rate of educating susceptible	0.5000	Elbasha and Gumel
ψ_1	Education rates of individuals in I_u class	0.5000	MATLAB's Statistical Toolbox
ψ_2	Education rates of individuals in A_u class	0.5000	MATLAB's Statistical Toolbox
β	Effective contact rate	0.4000	Elbasha and Gumel
η_u	Modification parameters for uneducated individuals	1.5000	MATLAB's Statistical Toolbox
η_e	Modification parameters for educated individuals	1.2000	MATLAB's Statistical Toolbox
ε	Efficacy of educated in	0.5000	MATLAB's

	preventing infection		Statistical Toolbox
1-κ	Reduction in transmissibility of educated individuals	0.3000	MATLAB's Statistical Toolbox
σ_u	Progression rates to AIDS for uneducated class	2.6000	Karen and Susan
σ_e	Progression rates to AIDS for educated class	0.0700	Karen and Susan

The initial conditions used are as follows: Su(0) = 14 million, Se(0) = 0.4121 million, Iu(0) = 2 million, Au(0) = 0.2 million, Ie(0) = 0.087 million, and Ae(0) = 0.0009 million.

9. RESULTS AND DISCUSSION

9.1. Results

In this work, we have developed a mathematical model for the dynamics of HIV/AIDS under the combined effort of public health education and drug therapy at the exposed and infected class. We represent simulation results and discussion on results as follows;

9.1.1. Simulation of results

We give a graphical representation of our experimental results with varying rates of β is the effective contact rate, $\lambda$the forces of infection and μ is the Mortality rate.

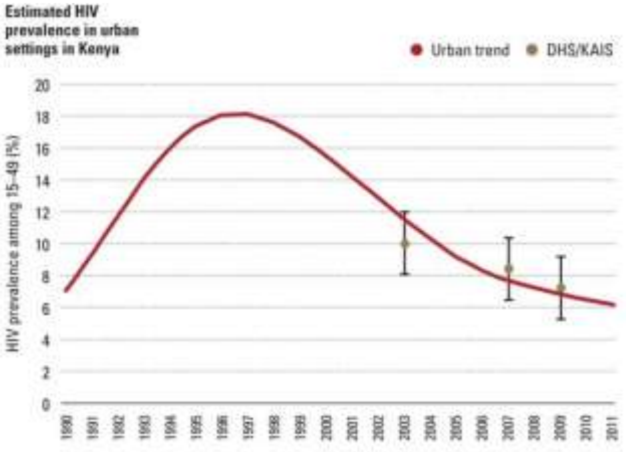

Figure 1: Shows the dynamics of HIV prevalence with $\beta = 0.45$ contact rate and $\lambda=0.25$ force of infection that shows the prevalence being higher among the general population in urban areas.

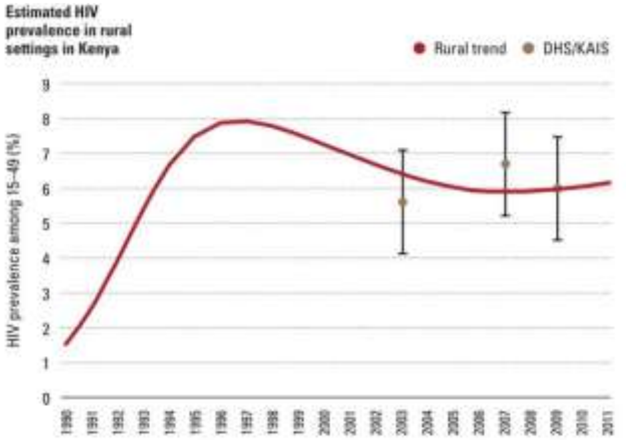

Figure 2: Shows the dynamics of HIV prevalence with $\beta= 0.75$ contact rate and $\lambda=0.5$ force of infection HIV prevalence showing that the infection is lower among the general population in rural areas. However, men in rural areas are more likely to be infected by HIV than men in urban areas (4.5% compared to 3.7%).

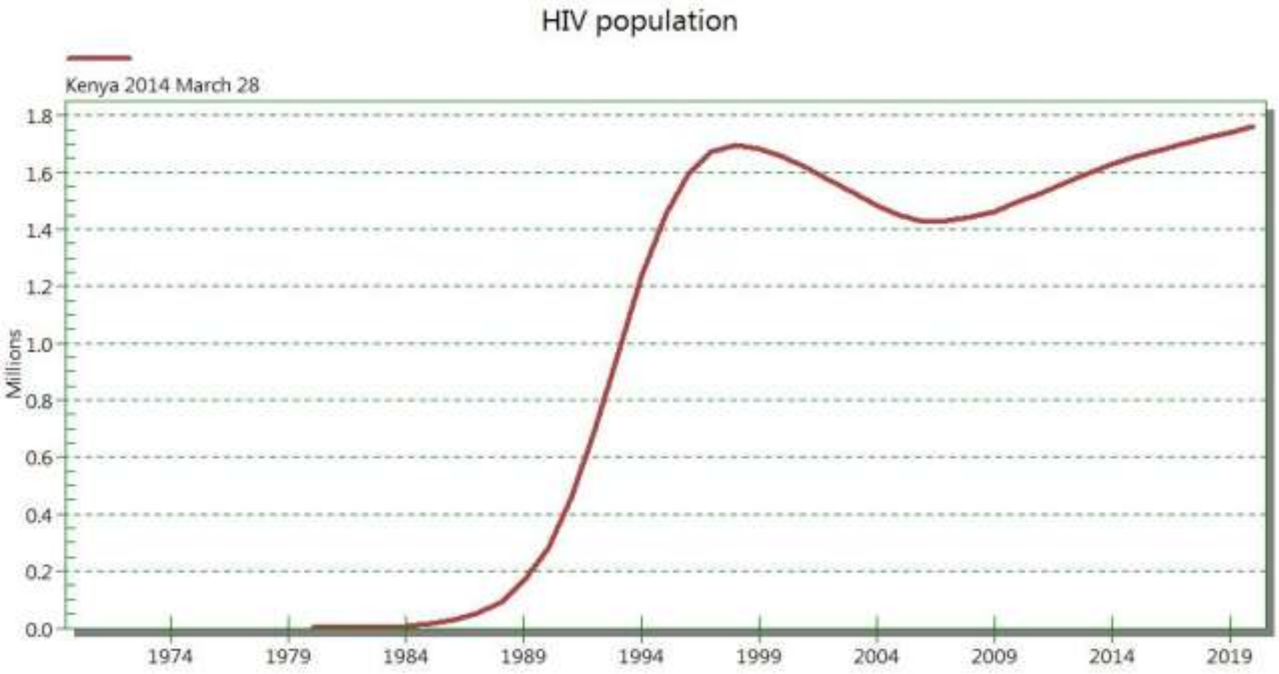

Figure 3: Shows the dynamics of HIV prevalence with β= 0.95 contact rate , λ=0.75 force of infection and µ = 0.45. This shows that the number of people living with HIV is estimated to have increased from about 1.4 million in 2009 to 1.6 million in 2013. Women constitute about 57% of the infected population, while men account for 43%. About 80% to 90% of the infected populations are adults. Though the HIV prevalence rate has been on the decline in the last few years, the number of people living with HIV and AIDS has been on the increase, and is currently estimated at 1.6 million. This number is projected to increase due to improved survival (reduced mortality due to HIV) attributed to ART program.

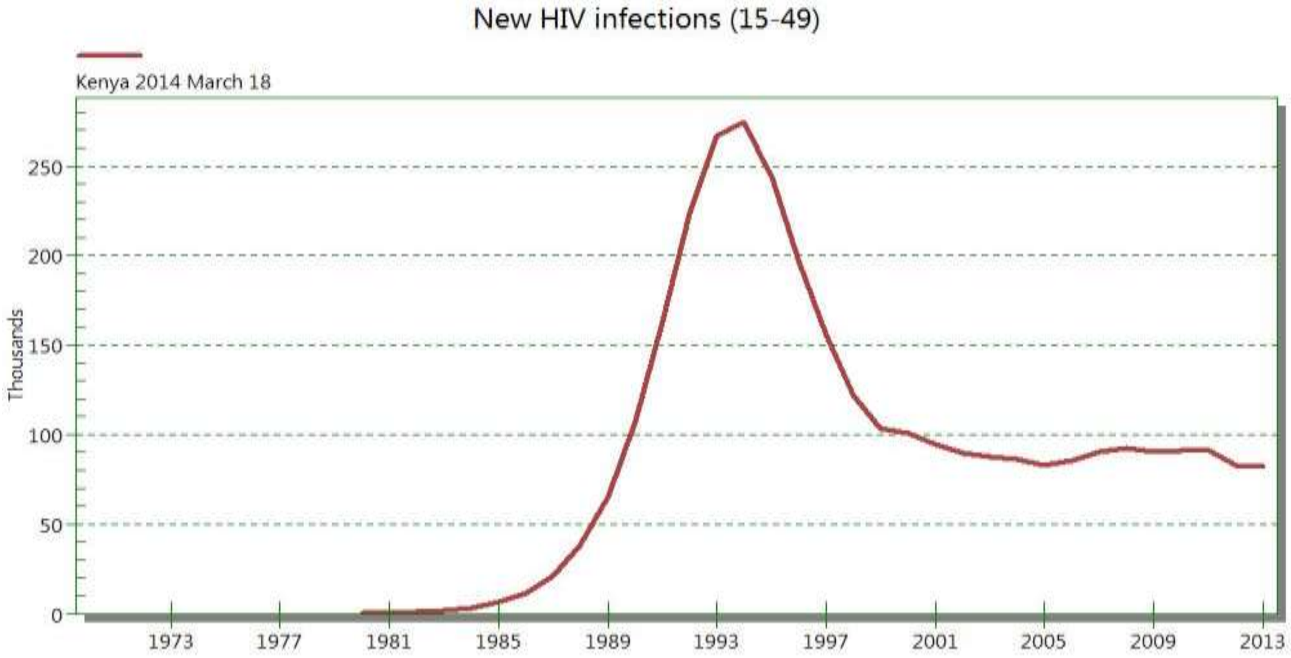

Figure 4: Shows the dynamics of HIV prevalence with $\beta = 0.45$ contact rate ,λ=0.25 force of infection and μ = 0.3 . This shows that the trend in new infections among adults aged 15-49 for the period up to 2013. New infections among adults contribute over 80% of the total new infections. The new infections among adults stabilized at an average of 93,000 annually over the last five years. Among children, new infections declined from about 20,000 to 11,000 annually over the same period. An estimate of new infections among men and women and children is shown in the table below

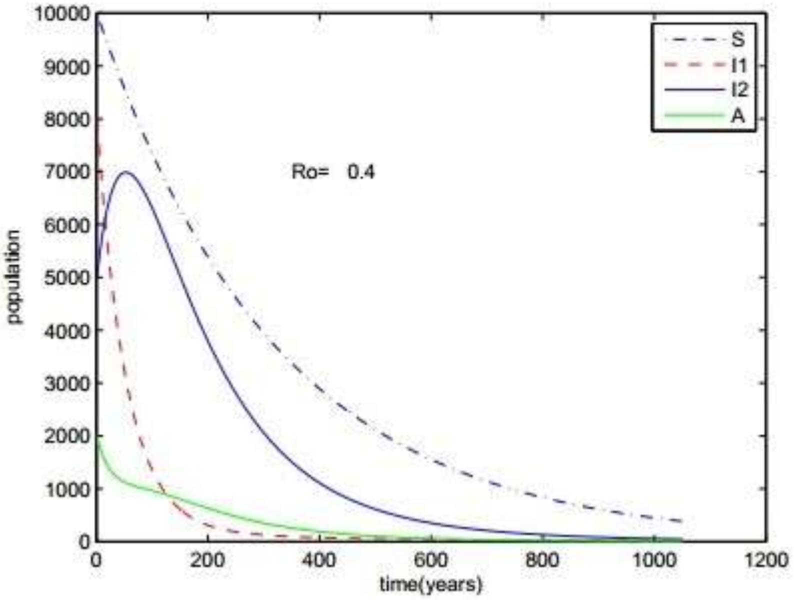

Figure 5: Graph showing the dynamics of HIV/AIDS with $R_0 = 0.4$,these results shows the effect of public health education e.g Safe sex, condom use , counseling and testing and abstinence as an intervention approach on HIV/AIDS disease.

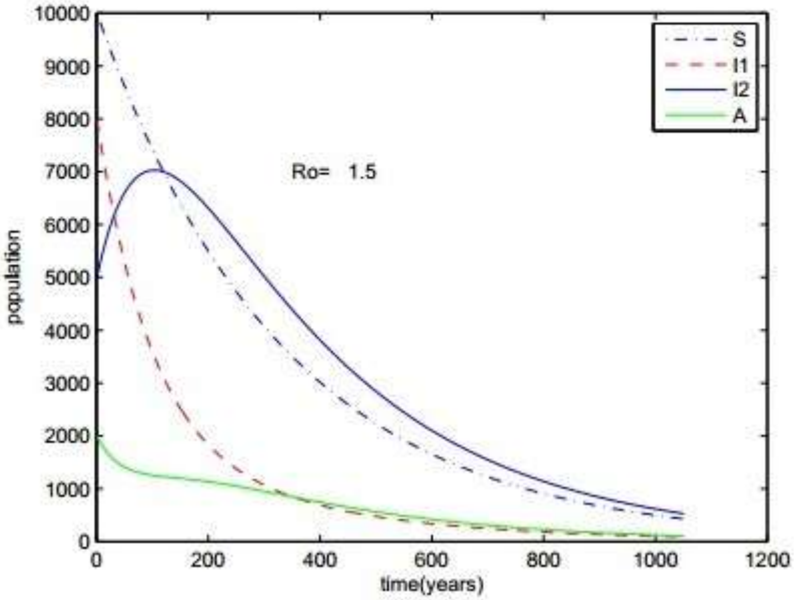

Figure 6: Graph showing the dynamics of HIV/AIDS with $R_0 = 1.5$, shows when HIV/AIDS exist in the population where public health education is limited to only one strategy e.g. abstinence alone or counseling and testing as the only strategy, hence these simulations suggest a single strategy is not enough in the fight against the epidemic.

9.1.2. DISCUSSION

We established the disease-free Equilibrium point (DFE) and analyzed the stability of our model at disease free equilibrium point. The analytical results showed that our model is locally asymptotically stable when the basic reproduction number,R_0 <1. The basic reproduction number, $R_{0,}$ can solve concrete problems since it completely determines the stability dynamics and outcome of the disease. It was found that if the threshold parameter is less than one the disease free equilibrium is stable and the disease dies out. However, if the threshold parameter is more than one, there exists a unique endemic equilibrium that is locally asymptotically stable. Theoretical determination of threshold conditions for R_0, is of important public heath interest. We reach total agreement with WHO and UNICEF recommendations on HIV/AIDS control, as herd resistance increases with number of opportunity. Some techniques are not suitable to know if the free-disease equilibrium point is globally stable; in such case, the disease can be eradicated irrespective of the initial sizes of the compartment, as encountered in the real situation. Any other limitation is the lack of success when prospecting global stability for SEIR epidemiological models with non-constant population. This is directed to the stakeholders, public health agencies health care providers and the various county governments to enable them determine how best to allocate scarce resources for HIV/AIDS prevention and management in the country. The model has shown success in attempting to predict the causes and reason for rapid spread of HIV/AIDS transmission within a certain population. The model strongly indicated that the spread of a disease largely depend on the contact rates with infected individuals within a population.

The model also pointed out that early detection and therapeutic treatment has a positive impact on the reduction of HIV/AIDS transmission; that is there is a need to detect new cases as early as possible so as to provide early management and treatment for the disease. More people should be educated in order create awareness to the disease so that the community will be aware of the deadly disease. Eradication of contagious diseases such as HIV/AIDS has remained one of the biggest challenge facing developing countries.

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AUTHOR BIOGRAPHY

1ST AUTHOR : CHAMUCHI NYABOE MOFFAT

He was born on 23rd March, 1982 in Cherenganyi, Kitale town, Western part of Kenya. He holds a Bachelor of Education Science (option in Mathematics and chemistry); specialized in Mathematics from Kenyatta University from Kenyatta University and a Master of science degree in Applied Mathematics from Jomo Kenyatta University of Agriculture and Technology, Kenya and he is currently pursuing a Doctor of philosophy degree in Applied Mathematics in Jomo Kenyatta University of Agriculture and Technology, Kenya. He has much interest in the study of the Mathematical Modelling of the effects of carriers on infectious diseases and their resistance to humans and their respective applications to Mathematics and engineering. Affiliation: Jomo Kenyatta University of Agriculture and Technology, (JKUAT), Kenya.
Tel: +254-721971936
E-mail: *chamuchimoffat@yahoo.com*
He has much interest in the study of modeling and Epidemiology and their respective applications to engineering

.2ND AUTHOR

PROF JOHANA KIBET SIGEY

Sigey holds a Bachelor of Science degree in mathematics and computer science first class honors from Jomo Kenyatta University of Agriculture and Technology, Kenya, Master of Science degree in Applied Mathematics from Kenyatta University and a Ph.D in applied mathematics from Jomo Kenyatta University of Agriculture and Technology, Kenya.
Affiliation: Jomo Kenyatta University of Agriculture and Technology, (JKUAT), Kenya.
Tel: +254-722795482
E-mail: jksigey@jkuat.ac.ke; jksigey2002@yahoo.com
He is currently the director, Jkuat, KisiiCBD. He has been the substantive chairman - department of pure and applied mathematics – Jkuat (January 2007 to July- 2012). He holds the rank of senior lecturer, in applied mathematics pure and applied Mathematics department – Jkuat since November 2009 to date. He has published 12 papers on heat transfer in respected journals.

Teaching experience: 2000 to date- postgraduate programmes: (jkuat)Master of Science in applied mathematics Units: complex analysis I and ii, numerical analysis, fluid mechanics, ordinary differential equations, partial differentials equations and Riemannian geometry. Supervision of postgraduate students: Doctor of philosophy: thesis (6 completed, 9 ongoing) and Master of Science in Applied Mathematics: (12 completed, 8 ongoing).

3RDAUTHOR: DR. KANGETHE GITERERE

Dr. Kangethe holds a Bachelor of Education Science degree in Education Mathematics from Kenyatta University, a Diploma in information Technology from Jomo Kenyatta University of Agriculture and Technology, a Master of Science degree in Applied Mathematics from Kenyatta University and a Ph.D in applied mathematics from Jomo Kenyatta University of Agriculture and Technology, Kenya.

Affiliation: Jomo Kenyatta University of Agriculture and Technology, (JKUAT), Kenya.

Tel: +254-723598408

E-mail: kgiterere@jkuat.acke

He holds the rank of a lecturer in applied mathematics in pure and applied Mathematics department – Jkuat. He has published 18 papers in respected journals.

Teaching experience: postgraduate programmes: (jkuat) Master of Science in applied mathematics and undergraduate programmes. Supervision of postgraduate students: Doctor of philosophy: thesis and Masters of science in Applied Mathematics.