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Computational Model for the Control of HIV/AIDS Disease In Heterosexual Population

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--***ABSTRACT***--
A computational model for the control HIV/AIDS disease in a heterosexual population has been proposed. Results from the numerical experiments show that the control of HIV/AIDS in heterosexual populations is dependent on the following factors: Rate of taking the preventive measures, proportion of the infected taking the preventive measures, average number of contacts, the time of initiation of the preventive measures and the consistency use of the preventive measures by both susceptible and infected. The physical interpretations of the results indicate further that HIV/AIDS can be controlled in finite time under the conditions mention above. Eradication of the disease has been found to be dependent on the rate of use of these preventive measures as indicated by the pictorial representation in Figs2-5. Behavioural change remains the best practices in effective control of HIV/AIDS.

KEYWORDS: *Computation, HIV/AIDS, Heterosexual, Model, Preventive Measures*

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I. INTRODUCTION

Human Immunodeficiency Virus (HIV) is a retrovirus that causes Acquired Immune Deficiency Syndrome (AIDS) by infecting cells of the immune system [4].When a body is affected with HIV, the viruses simply enter into the body cell and multiply, primarily in the white blood cell and later kill these cells weakening the Immune system, thereby leaving the person vulnerable to various infections and illnesses [10].
AIDS is a severe immunological disorder caused by the retrovirus HIV, resulting in a defect in cell-mediated immune response that is manifested by increased susceptibility to opportunistic infections and to certain rare cancers, especially *Kaposi's sarcoma*[3]&[6].
HIV is transmitted basically in four ways**:**

[1] Sexual intercourse
[2] Blood transfusion (and other body fluids)
[3] Mother to child
[4] Sharing contaminated skin piercing instruments.

Everyone that has AIDS has HIV, but not everyone that has HIV has AIDS; *CD4 cell counts* (part of the immune system) are used to make this distinction [3]. Anti-HIV programme has two major parts: Medication and behavioral change (prevention). For now medication has not yet obtain cure for HIV/AIDS and because of its nature of incurability, behavioral change (prevention) become very necessary in the fight against the epidemic; this includes: Abstinence, Be faithful, Condom usage; Health education; Prevention of mother to child transmission (PMTCT); Blood screening; Treatment of sexually transmitted infection and Voluntary Counselling and Confidential Testing (VCCT) [2], reveals prevalence of HIV/AIDS by age (adult 15-49 years carries the higher virus) and by gender (Women account for 59% of the PLWHA).Abstinence, Be Faithful, correct and consistent Condom use-approach to HIV/AIDS prevention: The ABC approach employs population-specific interventions that emphasize abstinence for youth and other unmarried persons, including delay of sexual act; mutual faithfulness and partner reduction for sexually active adults; correct and consistent use of condoms by those whose behavior places them at risk for transmitting or becoming infected with HIV [1].
Treatment as prevention is a term increasingly used to describe HIV prevention methods that use antiretroviral treatment to decrease the chance of HIV transmission. Antiretroviral treatment is already being used to reduce the risk of HIV from being passed on to another person - for example from an HIV positive pregnant woman to her unborn baby. It is also used to prevent HIV infection from being established in someone who has recently been exposed to the virus - for example a healthcare worker who has received a needle sticks injury. Although HIV treatment can significantly reduce infectiousness if taken exactly as prescribed, it cannot eliminate the risk of transmission completely, as HIV is never completely eradicated from the blood [9].

In May 2011, a study involving 1,763 HIV-serodiscordant couples was stopped before its original closing date of 2015. Interim analysis of the results showed those who started antiretroviral therapy immediately significantly lowered the risk of HIV transmission to their sexual partners, compared to those starting treatment later, when their CD4 count had fallen below 250 cells/$mm^{3.}$ The results showed a 96 percent reduction in risk of transmission, which was enough to release the results early and close the trial [12].[8]studied the Model effects of condom use in controlling HIV/AIDS among heterosexual community. In their work, consistent used of condom by both parties were not mentioned. This makes our study look alike to their work as regards to heterosexual settings (especially in Africa), where vulnerability in females are greater than males in terms of sexual activities.[7]studied the transmission dynamics of HIV/AIDS with use of condom where he concluded that eradication of the disease depends on the rate of use of condom but did not mention if the condom usage could be applicable to both sexes.According to [5], HIV testing and knowledge of HIV serostatus have important individual and public health benefits, including reduction of morbidity, mortality and HIV transmission. VCT provides the opportunity for people to know their HIV status with quality counseling support to help them cope with a positive or a negative test result.[12] studied the mathematical model for the transmission dynamics of HIV/AIDS in a two-sex population considering counseling and antiretroviral therapy. From their study, they saw that the control of HIV/AIDS in heterosexual populations is dependent on the net transmission rates of the infection.[10]derived the predictive control model of HIV/AIDS spread. In their study, conclusion shows that it is better to prevent HIV spread immediately it is noticed but have not mentioned how to preventive it especially in heterosexual population.

[11]studied the analysis of the transmission dynamics of HIV/TB as co-infection, their analysis shows that the use of TasP can lead to effective control of HIV/AIDS but have not mention the condition of the susceptible that are not infected with the disease. Approaches in responding to HIV/AIDS by the computational model were reviewed. Models are urgently needed for health related problems especially sexually transmitted diseases such as HIV/AIDS in heterosexual group. An understanding to this model would be of important help as it will serve as an indicator in determining special behaviours of the system and predict future under different conditions.

II. METHODOLOGY

The model is developed based on the following assumptions:

[1] Age structure is ignored
[2] Natural birth and death rates are the same for both sexes;
[3] Infected persons in addition to dying naturally; irrespective of whether they use the preventive measure die due to the infection;
[4] The population is heterosexual (that is males and females);
[5] Transmission is considered by heterosexual contact only, i.e other means of transmission are excluded;
[6] The preventive measures used are: Abstinence, Be faithful to partner, Condom usage, HIV Testing, Sex Education and TasP.
[7] Both infected males and females use the preventive measure; and
[8] Both susceptible males and females use the preventive measure. The variation between individual parameters such as their contact rates depends on location on the connectivity of flow diagram.

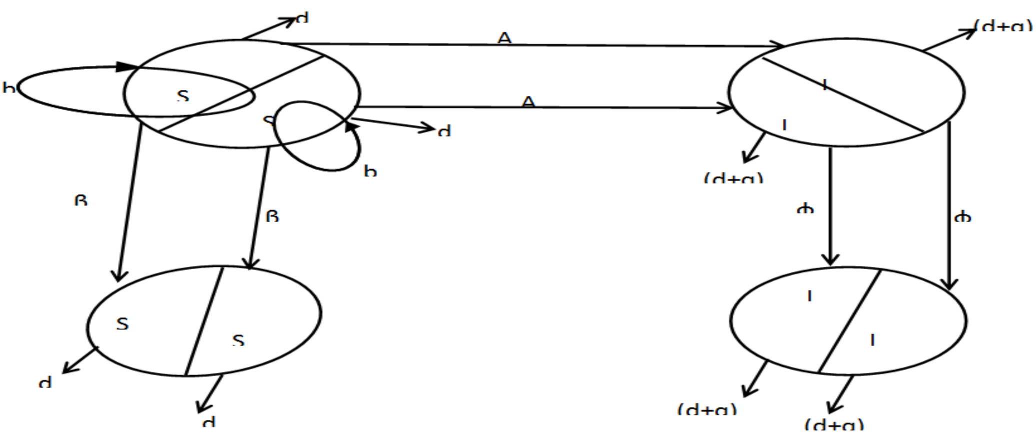

Fig. 1: Flow diagram for the model

Table 1: Model parameters

Variable/parameter		***Description***
S_m	=	Susceptible males not taking preventive measures
S_{mm*}	=	Susceptible males taking preventive measures
S_f	=	Susceptible females not taking preventive measures
S_{fm*}	=	Susceptible females taking preventive measures
I_m	=	Infected males not taking preventive measures
I_{mm*}	=	Infected males taking preventive measures
I_f	=	Infected females not taking preventive measures
I_{fm*}	=	Infected females taking preventive measures
N_m	=	Total population of males
N_f	=	Total population of females
b	=	Natural birth rate or recruitment rate
d	=	Natural death rate or removal rate
q	=	Death rate due to the disease
β_m	=	Rate at which susceptible males take preventive measures
β_f	=	Rate at which susceptible females take preventive measures
ϕ_m	=	Rate at which Infected males take preventive measures
ϕ_f	=	Rate at which infected females take preventive measures
A_m	=	Rate at which susceptible males are infected or recruited into the Infected pool
A_f	=	Rate at which susceptible females are infected or recruited into the infected pool
C_m	=	Average number of contacts by males with females
C_f	=	Average number of contacts by females with males
P_m	=	Probability of transmission by infected males
P_f	=	Probability of transmission by infected females
m*	=	Preventive measures (ABC, HIV Testing, Sex Education, &TasP)

II.I Model Equations

From the above flow diagram, we have 8 compartments. The population of each compartment changes over time. Therefore, the following model equations are derived from the flow diagram:

$$S'_m = bN_m - (\beta_m + d)S_m \quad (1)$$

$$S'_f = bN_f - (\beta_f + d)S_f \quad (2)$$

$$S'_{mm*} = \beta_m S_m - dS_{mm*} \quad (3)$$

$$S'_{fm*} = \beta_f S_f - dS_{fm*} \quad (4)$$

$$I'_m = A_m S_m - (\phi_m + d + q)I_m \quad (5)$$

$$I'_f = A_f S_f - (\phi_f + d + q)I_f \quad (6)$$

$$I'_{mm*} = \phi_m I_m - (d + q)I_{mm*} \quad (7)$$

$$I'_{fm*} = \phi_f I_f - (d + q)I_{fm*} \quad (8)$$

The total population of males and females $N_m$and N_f *at* t_0, are as follows:

$$N_m = S_m + I_m + S_{mm*} + I_{mm*} \quad (9)$$

$$N_f = S_f + I_f + S_{fm} + I_{fm} \quad (10)$$

The incidence rates are given as:

$$A_m = \frac{C_m P_f I_f}{N_f} \quad (11)$$

$$A_f = \frac{C_f P_m I_m}{N_m} \quad (12)$$

II.II. Model Equation in Proportion

We transformed the model equations into proportions such that we can reduce the number of equations for easy description of the incidence of the disease. To achieve this, we divide equation (9) and (10) by N_m and N_f respectively and obtained the following equations;

$$x_m = \frac{S_m}{N_m} \quad (13.1)$$

$$y_m = \frac{I_m}{N_m} \quad (13.2)$$

$$x_f = \frac{S_f}{N_f} \quad (13.3)$$
$$y_f = \frac{I_f}{N_f} \quad (13.4)$$
$$z_m = \frac{S_{mm*}}{N_m} \quad (13.5)$$
$$z_f = \frac{S_{fm*}}{N_f} \quad (13.6)$$
$$e_m = \frac{I_{mm*}}{N_m} \quad (13.7)$$
$$e_f = \frac{I_{fm*}}{N_f} \quad (13.8)$$

such that

$$x_m + y_m + z_m + e_m = 1 \quad (13.9)$$
$$x_f + y_f + z_f + e_f = 1 \quad (13.10)$$

At every step, the explicit reduced model equations in proportion are;

$$y'_m = c_m p_f y_f (1 - y_m)(1 - e_m - z_m - y_m) - y_m [\phi_m + b + q - (y_m + e_m) q] \quad (14.1)$$
$$y'_f = c_f p_m y_m (1 - y_f)(1 - e_f - z_f - y_f) - y_f \{\phi_f + b + q - (y_f + e_f) q\}, y'_f(0) = y_f^0 \quad (14.2)$$
$$z'_m = (\beta_m - c_m p_f y_f z_m)(1 - e_m - y_m - z_m) - z_m \{b - (y_m + e_m) q\},\ z'_m(0) = z_m^0 \quad (14.3)$$
$$z'_f = (\beta_f - c_f p_m y_m z_f)(1 - e_f - y_f - z_f) - z_f \{b - (y_f + e_f) q\}, z'_f(0) = z_f^0 \quad (14.4)$$
$$e'_m = \phi_m y_m - e_m \{q + b + c_m p_f y_f (1 - e_m - y_m - z_m) - (y_m + e_m) q\},\ e'_m(0) = e_m^0 \quad (14.5)$$
$$e'_f = \phi_f y_f - e_f \{q + b + c_f p_m y_m (1 - e_f - y_f - z_f) - (y_f + e_f) q\}, e'_f(0) = e_f^0 \quad (14.6)$$

II.III Numerical scheme

Starting with the initial value problem for y'_m in (14.1), the numerical method was developed based on approximating the time derivative by its first-order forward difference approximant given by;

$$\frac{dy_m(t)}{dt} = \frac{1}{l} y_m(t + l) - y_m(t) \quad (15) \text{ as } l \to 0$$

Where l >0, is an increment in t (step length).

Discretizing the interval t≥t0 =0 at the point t_n= nl (n=0, 1, 2, 3…) the solution at the grid point corresponding to t_n(14.1-14.6). The implicit-first-order method for solving in (14.1)-(14.6) is given by;

$$\Rightarrow y_m^{n+1} = \frac{l c_m p_f y_f^n (1 - e_m^n - z_m^n - y_m^n) + y_m^n}{1 + l c_m p_f y_f^n (1 - e_m^n - z_m^n - y_m^n) + l\{\Phi_m + b + q - (y_m^n + e_m^n) q\}} \quad (16.1)$$

$$\Rightarrow y_f^{n+1} = \frac{l c_f p_m y_m^{n+1} (1 - e_f^n - z_f^n - y_f^n) + y_f^n}{1 + l c_f p_m y_m^{n+1} (1 - e_f^n - z_f^n - y_f^n) + l\{\Phi_f + b + q - (y_f^n + e_f^n) q\}} \quad (16.2)$$

$$\Rightarrow z_m^{n+1} = \frac{l \beta_m (1 - e_m^n - y_m^{n+1} - z_m^n) + z_m^n}{1 + l c_m p_f y_f^{n+1} (1 - e_m^n - z_m^n - y_m^{n+1}) + l\{b - (y_m^{n+1} + e_m^n) q\}} \quad (16.3)$$

$$\Rightarrow z_f^{n+1} = \frac{l \beta_f (1 - e_f^n - y_f^{n+1} - z_f^n) + z_f^n}{1 + l c_f p_m y_m^{n+1} (1 - e_f^n - z_f^n - y_f^{n+1}) + l\{b - (y_f^{n+1} + e_f^n) q\}} \quad (16.4)$$

$$\Rightarrow e_m^{n+1} = \frac{l \Phi_m y_m^{n+1} + e_m^n}{1 + l\{q + b + c_m p_f y_f^{n+1} (1 - e_m^n - z_m^{n+1} - y_m^{n+1}) - (y_m^{n+1} + e_m^n) q\}} \quad (16.5)$$

$$\Rightarrow e_f^{n+1} = \frac{l \Phi_f y_f^{n+1} + e_f^n}{1 + l\{q + b + c_f p_m y_m^{n+1} (1 - e_f^n - z_f^{n+1} - y_f^{n+1}) - (y_f^{n+1} + e_f^n) q\}} \quad (16.6)$$

III NUMERICAL EXPERIMENTS

We run the simulation for the period of *t* = 20 years while studyingfour distinct situations as follows:

[1] Dynamics of the disease under low rate of taking of the preventive measures by susceptible and high rate of taken the preventive measures by infected.

[2] Dynamics of the disease under high rates of taking the preventive measures by proportion of susceptible male and infected males

[3] Dynamics of the disease with reduced number of average contacts and very high rate of taking preventive measures

[4] Dynamics of the disease with high initial rate of taking preventive measures by infected males

The pictorial representation of all the four cases for,$y_m(t_n)$,$y_f(t_n)$,$z_m(t_n)$, $z_f(t_n)$,$e_m(t_n)$ & $e_f(t_n)$ are shown.

III.1 Experiment one

We study the Dynamics of the disease under low rate of taking of the preventive measures by susceptible and high rate of taken the preventive measures by infected. The following values for the parameters were used:b=0.50, q=0.10, l=0.10, c_m=5.00, c_f=5.00, β_m=0.20, β_f=0.20,ϕ_m=0.50, ϕ_f=0.50, p_m=0.15, p_f=0.15, and let $y_m(0)$=0.25, $z_m(0)$=0.20, $e_m(0)$=0.25, $y_f(0)$=0.25, $z_f(0)$=0.20, $e_f(0)$=0.25.

Fig. 2 displayed the Dynamics of the disease under low rate of taking the preventive measures by the proportions of the susceptible (β_m=0.20, β_f=0.20) and high rate of taken the preventive measures by the proportion of the infected (ϕ_m=0.50, ϕ_f=0.50). The results shows decrease in the proportion of the infected and the infected taking the preventive measures with time even when the proportion of the susceptible taking the preventive measures remain increased as indicated by their graph.

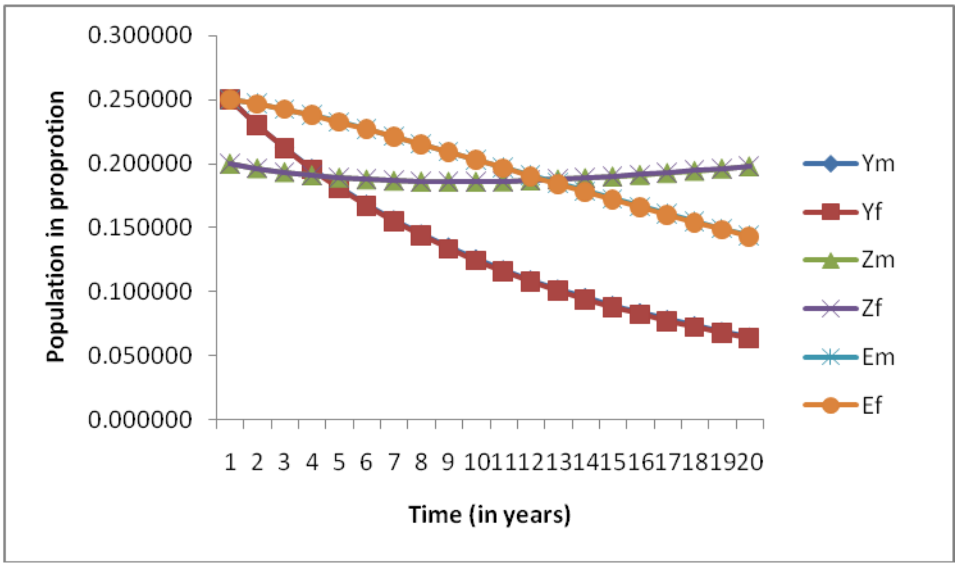

Fig.2: Dynamics of the disease under low rate of taking of the preventive measures by susceptible and high rate of taken the preventive measures by infected

III.II Experiment two

We study the Dynamics of the disease under high rates of taking the preventive measures by proportion of susceptible and infected with low proportion of the infected. We again used the following values for the parameters:b=0.50, q=0.20, l=0.10, c_m=5.00, c_f=5.00, β_m=0.50, β_f=0.50, ϕ_m=0.50, ϕ_f=0.50, p_m=0.15, p_f=0.15, and again let $y_m(0)$=0.20, $z_m(0)$=0.25, $e_m(0)$=0.25, $y_f(0)$=0.20, $z_f(0)$=0.25, $e_f(0)$=0.25.

Fig.3 also shows the Dynamics of the disease under high rates of taking the preventive measures by susceptible and infected has positive response to the susceptible thereby reducing proportion of the infected as shown in the graph.

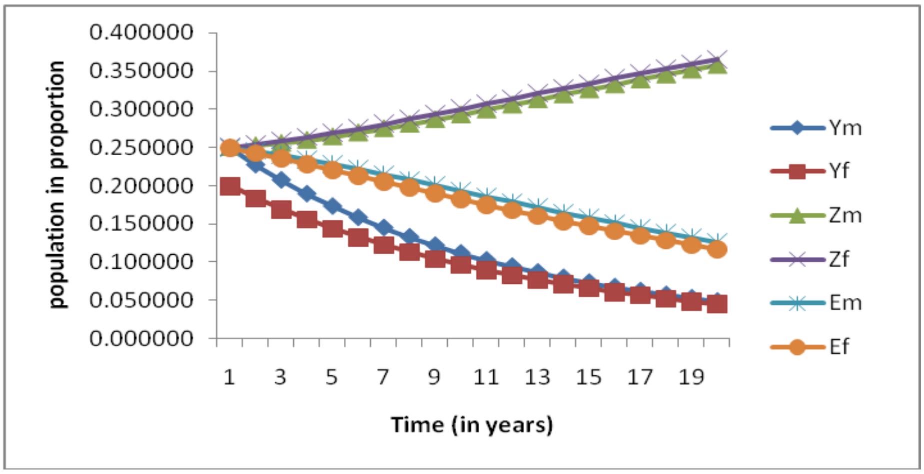

Fig.3: Dynamics of the disease under high rates of taking the preventive measures by proportion of susceptible male and infected males

III.III Experiment Three

In this experiment, we study the Dynamics of the disease with reduced number of average contacts and very high rate of taking preventive measures. We again used the following values for the parameters:b=0.50, q=0.20, l=0.10, c_m=3.00, c_f=3.00, β_m=0.90, β_f=0.90, ϕ_m=0.90, ϕ_f=0.90, p_m=0.15, p_f=0.15, and again let $y_m(0)$=0.20, $z_m(0)$=0.50, $e_m(0)$=0.50, $y_f(0)$=0.20, $z_f(0)$=0.50, $e_f(0)$=0.50.

Fig.4 shows the dynamics of the disease with reduced number of average contacts and very high rate of taking preventive measures as depicted from the graph. This clearly indicated that as the number of contacts reduced and the proportion of infected is low, the proportions of infected is reducing. The lower the number of average contact together with high rate of taking the preventive measures by both the susceptible and infected the lower the chance of transmission of the disease. Proportions of the susceptible that are taking the preventive measures from the graph are increasing with time. From this, study, average number of contacts has an important role to play in the behavioural change in controlling HIV/AIDS.

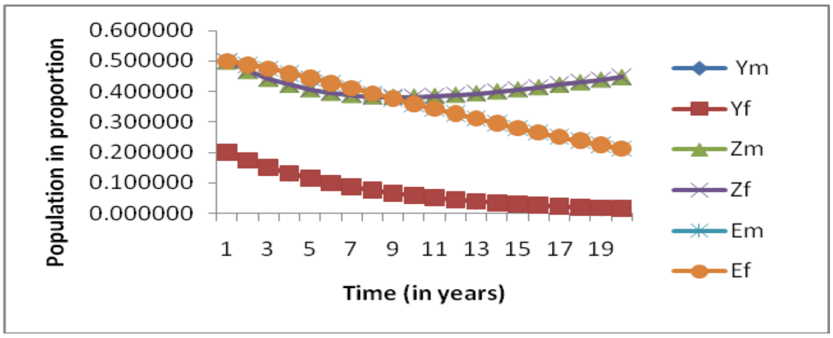

Fig.4: Dynamics of the disease with reduced number of average contacts and very high rate of taking preventive measures

III.IV. Experiment four

In this experiment, Dynamics of the disease with high initial rate of taking preventive measures by infected males. We again used the following values for the parameters:b=0.50, q=0.10, l=0.10, c_m=3.00, c_f=3.00, β_m=0.20, β_f=0.20, ϕ_m=0.50, ϕ_f=0.20, p_m=0.15, p_f=0.15, and again let $y_m(0)$=0.50, $z_m(0)$=0.20, $e_m(0)$=0.50, $y_f(0)$=0.20, $z_f(0)$=0.20, $e_f(0)$=0.20.

From Fig.5, the dynamics of the disease with high initial rate of taking the preventive measures by infected males was studied. The graph indicate early taking of the preventive measures by infected males has significant role in preventing susceptible females from contacting the disease.

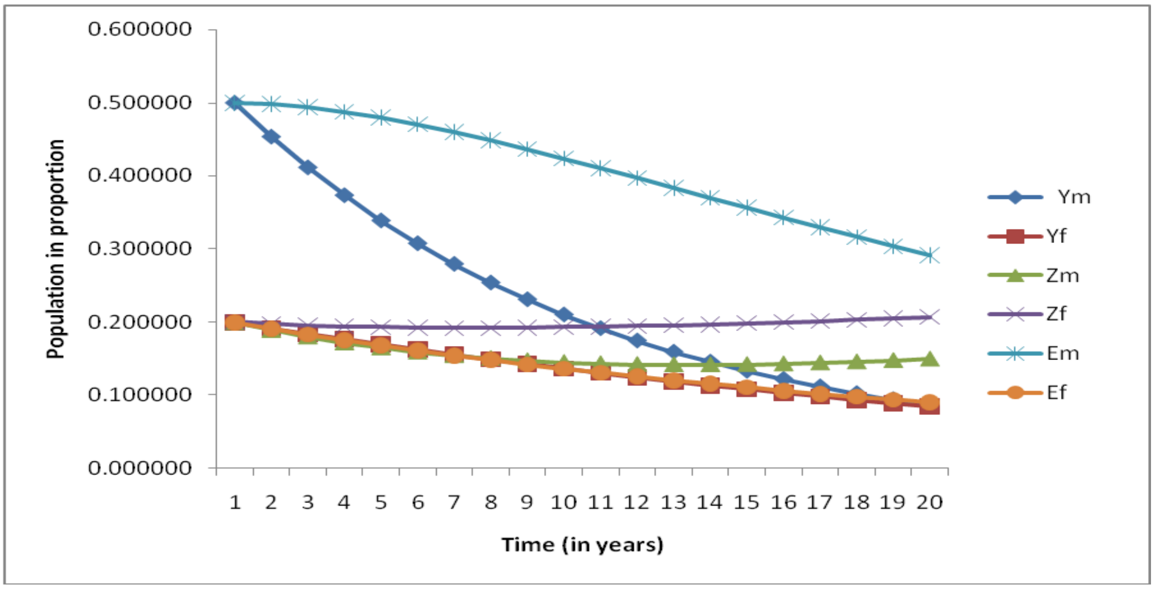

Fig.5: Dynamics of the disease with high initial rate of taking preventive measures by infected males

IV. CONCLUSION

Computational model was developed with the aim of investigating HIV/AIDS transmission in the presence of preventive measures. Numerical experiments from the study indicate HIV/AIDS can be controlled in heterosexual population by effective application of the preventive measure with time. The study further indicates high rate of taking the preventive measures by the infected with time reduced the risk of acquiring the disease by the susceptible. One other important other factor that proved to be significant in the dynamics of HIV/AIDS is the average number of contacts, the lower the average number of contacts, the fewer the number of susceptible recruited into the infected pool. Behavioural change remains the best practices in effective control of HIV/AIDS. This experiment places emphasis on abstinence unmarried persons, mutual faithfulness and partner reduction for sexually active adults; correct and consistent use of condoms especially by those whose behaviour places them at risk for becoming infected with HIV.

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