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Research Article

Estimating Upsurge of Hiv Cases in Malaysia by Using Heun's Predictor-Corrector Method

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ABSTRACT

The prevalence of HIV/AIDS remains a significant global health concern, including in Malaysia. In this study, a mathematical model was developed to simulate the dynamics of HIV transmission and progression within the Malaysian population. The model incorporates various factors such as population size, infection rate, progression to AIDS, recruitment, natural death, and death due to the disease. Heun's predictor-corrector method was applied to numerically solve the model equations and predict the population of susceptible individuals, infected individuals, and AIDS cases over time. Real-world data on HIV/AIDS cases in Malaysia were used to validate the model and provide accurate predictions. The results indicated a gradual decline in the number of susceptible individuals and an increase in the number of infected individuals and AIDS cases over the simulation period. These findings can contribute to a better understanding of the dynamics of HIV/AIDS transmission in Malaysia and aid in the development of effective prevention and control strategies. Further research and refinement of the model are essential for continuous monitoring and projection of the HIV/AIDS epidemic in Malaysia, facilitating timely interventions and resource allocation for healthcare planning and policy-making.

Keywords: HIV, Transmission, Epidemic, Heun's method, Dynamics, Trends

1. INTRODUCTION

HIV (human immunodeficiency virus) is a pervasive viral infection that not only attacks but also weakens the body's immune system, leaving it vulnerable to a multitude of infections. This relentless virus gradually deteriorates the function of immune cells, leading to immunodeficiency in infected individuals. Its impact has spread far and wide, becoming an endemic disease not only in Malaysia but also in various countries across the globe originating in Africa and subsequently spreading to other parts of the world, HIV has been a prevalent health concern since at least the mid to late 1970s (Timothy et al., 2008). In Malaysia, the incidence rate has seen a noteworthy decline over the years, with recorded cases dropping from 28.5 per 100,000 people in 2002 to 9.3 per 100,000 population in 2020 (Ministry of Health Malaysia, 2021). However, despite progress in combating the virus, it continues to exert a significant toll on individuals and communities.

One alarming aspect of this epidemic is its disproportionate impact on young people (UNAIDS, 2020). Globally, approximately 40% of new HIV infections occur in individuals aged 15 to 24 years, and Malaysia is no exception to this trend (Ministry of Health Malaysia, 2021). Among the Malaysian population, HIV infections are predominantly found in young individuals, highlighting the urgency of addressing this issue. The consequences of this epidemic reach far beyond health, as it affects individuals in their prime productive years, resulting in a drain on human resources and impeding social and economic development. To comprehend the gravity of the situation, it is crucial to examine the statistics. In 2005, the number of HIV infections among young people under the age of 30 reached 26,810 cases. Just two years later, in 2007, this number rose to 29,269 cases, illustrating the persistent nature of the epidemic. As of the latest data in 2020, the cumulative number of reported HIV infections in Malaysia stood at 125,878, with 3,146 new infections reported during that year alone (Ministry of Health Malaysia, 2021).

HIV transmission in Malaysia remains predominantly linked to the sharing of needles among drug users and the exchange of various body fluids from infected individuals, including blood, breast milk, semen, and vaginal secretions (Mukandavire et al., 2016). Additionally, transmission from an HIV-positive mother to her child during pregnancy and delivery is also a concern. These modes of transmission highlight the significance of targeted interventions for high-risk populations, such as harm reduction programs, needle exchange initiatives, and comprehensive antenatal care for pregnant women living with HIV (Coovadia, 2004). It is important to note, however, that HIV cannot be transmitted through ordinary day-to-day contact such as kissing, hugging, shaking hands, or sharing personal belongings, food, or water. By disseminating accurate information and dispelling misconceptions, we can combat stigma, promote safer practices, and work towards effectively curbing HIV transmission in Malaysia. Figure 1 provides a visual representation of the various modes of HIV transmission.

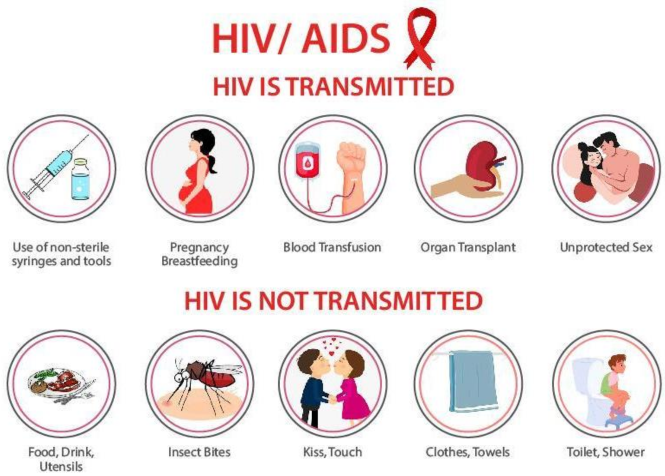

Figure 1. Mode of Transmission

The diagram depicts the primary routes through which HIV can be transmitted. It highlights key modes of transmission, including the sharing of needles among drug users, sexual contact with an infected individual, mother-to-child transmission during pregnancy, childbirth, or breastfeeding, and the exchange of contaminated blood or blood products. By visually presenting the different modes of transmission, the diagram aims to enhance understanding and awareness of how HIV can be spread. This information is crucial in combating the stigma surrounding HIV and promoting accurate knowledge about prevention measures. It serves as a valuable tool for educational campaigns, healthcare professionals, and policymakers to illustrate the importance of targeted interventions and prevention strategies specific to each mode of transmission. These modes of transmission highlight the significance of addressing the specific risk factors associated with HIV spread in Malaysia. Implementing targeted interventions and promoting awareness about safe practices can play a crucial role in curbing the transmission of the virus. By dispelling misconceptions and fostering a better understanding of how HIV is and is not transmitted, we can work towards reducing stigma and discrimination against those affected by the virus.

Mathematical models are fundamental in the study of infectious diseases as it has appeared to be a vital tool for understanding the dynamics of the spread of many diseases, especially infectious diseases such as HIV cases (Maimunah & Dipo, 2018). The primary goal of this study is to construct a comprehensive mathematical model that accurately captures the dynamic nature of HIV infection in Malaysia. This model will utilize systems of differential equations to depict the intricate interactions among susceptible, infected, and individuals in AIDS populations. By incorporating various essential parameters, including population size, infection rate, recruitment rate, natural death rate, disease-related mortality, and probability of transmission, we aim to gain valuable insights into the spread and progression of HIV within the Malaysian context. Through this modelling approach, we can effectively assess and evaluate the efficacy of targeted prevention and intervention strategies tailored to address the specific challenges posed by HIV in Malaysia. Understanding the dynamics of HIV transmission in Malaysia is crucial for designing effective prevention and control strategies. By accurately predicting the future trends of HIV/AIDS cases, healthcare policymakers and stakeholders can make informed decisions regarding resource allocation, targeted interventions, and public health campaigns. This research will contribute to ongoing efforts to combat the HIV/AIDS epidemic in Malaysia, ultimately striving toward the goal of achieving an AIDS-free generation.

The accurate modelling and prediction of complex dynamic systems have long been fundamental challenges in various scientific fields. In recent years, Heun's Predictor Corrector Method has emerged as a powerful mathematical tool for approximating solutions to differential equations and simulating the behaviour of dynamic systems (Emmanuel et al, 2023). This method, known for its accuracy and stability, offers a promising avenue for investigating and understanding intricate processes within a wide range of disciplines. Heun's Predictor Corrector Method is a numerical technique used to solve ordinary differential equations (ODEs) and differential equation systems. It combines two steps: prediction and correction. In the prediction step, the method estimates the solution using an initial approximation, and in the correction step, it refines this estimate by considering the slope at multiple points within a small time interval. This iterative approach often yields highly accurate results, making it particularly valuable for modelling and simulating systems characterized by nonlinearities, feedback loops, and complex interactions.

Recent research across diverse scientific fields has effectively utilized Heun's Predictor Corrector Method, yielding noteworthy achievements. These studies have showcased the method's proficiency in elucidating complex phenomena, including ecological population dynamics, epidemiological models, and chemical reaction kinetics (Barsotti et al., 2008 & López-González, et al., 2023). Importantly, they have underscored the method's accuracy in tracking temporal dynamics and its adaptability in scenarios marked by variable parameters and initial conditions.

By integrating real-world data and utilizing Heun's predictor-corrector method for numerical simulation, we leverage the advantages of Heun's Predictor Corrector Method to

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investigate a mathematical model that captures the complex interactions among susceptible, infected, and individuals with AIDS populations in Malaysia. Building upon the achievements of previous research, we aim to further explore the potential of this method in enhancing our understanding of estimating HIV/AIDS cases. Through the application of Heun's method, we seek to provide valuable insights to predict and assess the future trends and magnitudes of HIV/AIDS infections in Malaysia, taking into account various factors such as transmission rates, recruitment rates, and natural death rates and contribute to the growing body of knowledge in the field.

This study's uniqueness arises from its utilization in the integration of Heun's Predictor Corrector Method into the mathematical model for HIV/AIDS cases in Malaysia. While previous research has explored similar models, the application of this specific numerical method enhances the accuracy and reliability of predictions regarding HIV/AIDS dynamics in the Malaysian context. This novel approach allows for a more detailed analysis of population dynamics, helping to inform tailored prevention and intervention strategies for addressing the spread and impact of HIV/AIDS in Malaysia.

In this study, we present our methodology, data sources, and research objectives, followed by a detailed analysis of our findings and their implications. Through this study, we hope to not only shed light on the estimation of the number of HIV/AIDS cases but also highlight the continued relevance and applicability of Heun's Predictor Corrector Method in addressing complex dynamic systems in contemporary research.

2. MATERIALS AND METHODS

The derivation of the HIV/AIDS model involves formulating a system of differential equations based on the underlying dynamics of the disease. The model considers different population compartments, such as susceptible individuals, infected individuals, and individuals with AIDS, and tracks the transitions between these compartments over time (Figure 2).

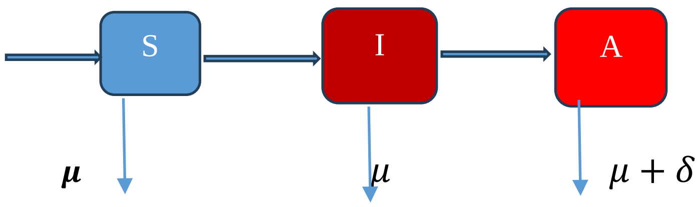

Figure 2. Flow of individual Compartments

2.1. Derivation of the method

Susceptible Population (S): The rate of change in the susceptible population is determined by recruitment, deaths due to natural causes, and new infections, the recruitment rate as λ represents the rate at which individuals enter the susceptible population, the natural death rate is denoted as μ_s, representing the mortality rate of susceptible individuals. The equation for the susceptible population is:

$$\frac{dS}{dt} = \lambda - \mu_s s - \beta SI \quad \textbf{(1)}$$

Infected Population (I): The rate of change in the infected population depends on new infections, progression to AIDS, and deaths due to natural causes, the rate at which susceptible individuals transition to the infected state is βSI, and the progression rate from the infected state to AIDS can be denoted by a constant rate γ and the death rate of infected individuals due to natural causes is denoted as μ_i. Therefore, the equation for the infected population is:

$$\frac{dI}{dt} = \beta SI - \gamma I - \mu_i I \quad \textbf{(2)}$$

AIDS Population (A): The rate of change in the AIDS population is determined by the progression from the infected state to AIDS and death due to AIDS-related complications. The rate at which infected individuals progress to AIDS is γI. The natural death rate of individuals in the AIDS population is denoted as μ_n. Therefore, the equation for the AIDS population is:

$$\frac{dA}{dt} = \gamma I - \mu_a A - \mu_n A \quad \textbf{(3)}$$

Recruitment: The recruitment of new susceptible individuals is denoted by the variable λ. The recruitment term represents the addition of new individuals into the susceptible population and can be considered as a constant rate over time. These equations now account for recruitment (λ), natural death rates of susceptible individuals (μ_s) and infected individuals (μ_i), as well as the death rate due to AIDS-related complications (μ_a). The parameters $\beta, \gamma, \mu_s, \mu_i, \mu_a$, and λ can be adjusted based on specific scenarios or data.

2.2. Heun's Transformation for SI Modelling

Heun's Predictor Corrector Method / Improved Euler method is one of the classical methods for solving ordinary differential equations (ODE) models. Here is the formula of Heun's Predictor Corrector method for solving ODE with the general equation such that:

$$\left.\begin{aligned} \frac{dy}{dt} &= f\ (t, y) \\ Y_{i+1}^{p} &= y_i + \mathrm{hf}\ (t_i, y_i) \\ Y_{i+1}^{c} &= y_i + \frac{h}{2}[\mathrm{f}\ (t_i, y_i) + \mathrm{f}\ (t_{i+1}, y_{i+1})] \end{aligned}\right\} \quad \textbf{(4)}$$

with the initial condition, $y(t_0) = y_0$
The SI model is characterized as follows:

$$f_1\ (t, S, I) = \frac{dS}{dt} = \lambda - \mu_s s - \beta SI \quad \textbf{(5)}$$
$$f_2\ (t, S, I,) = \frac{dI}{dt} = \beta SI - \gamma I - \mu_i I \quad \textbf{(6)}$$
$$f_3\ (t, A, I) = \frac{dA}{dt} = \gamma I - \mu_a A - \mu_n A \quad \textbf{(7)}$$

based on the general formula, the formula for S(t) and I(t) can be represented as;

$$\left.\begin{aligned} S_{i+1}^{p} &= S_i + hf_i \\ S_{i+1}^{c} &= S_i + \frac{h}{2}\left(f_i + f_{i+1}^{p}\right) \\ I_{i+1}^{p} &= I_i + hf_i \\ I_{i+1}^{c} &= I_i + \frac{h}{2}\left(f_i + f_{i+1}^{p}\right) \end{aligned}\right\} \quad \textbf{(8)}$$

2.3. The flow chart and the algorithm of the method

The algorithm below illustrates the sequential steps in integrating Heun's method into the model, we estimate the population size at each step, refining the estimates by considering the slope at multiple points. This application of Heun's method improves the accuracy of the model's predictions and enables us to visualize the trends and patterns in the population dynamics of HIV/AIDS over time.

1. Define the necessary variables and parameters:
    i. Set the initial year (t) and step size (h).
    ii. Initialize arrays to store the results: S (susceptible population), I (infected population), and A (AIDS cases).
    iii. Set the initial values for S, I, and A based on the available data.
    iv. Define the progression rate (P) for each year.
2. Use Heun's method to estimate the population for each time step:
    i. Iterate over each time step from the initial year to the desired future year.
    ii. Calculate the rate of change for each population group:
        - For a susceptible population S: Use the rate of change formula considering transmission rate, infected population, and total population.
        - For infected population I: Use the rate of change formula considering recruitment, natural death rate, and progression rates.
        - For AIDS cases A: Use the rate of change formula considering progression rates and infected population.
    iii. Calculate the approximate values for the next time step using Heun's method:
        - Update the values of S, I, and A based on the calculated rates of change and the step size (h).
3. Display the estimated results:
    i. Print the estimated values of S, I, and A for each time step.
    ii. Plot the estimated population curves for S, I, and A over time.
4. Analyse and interpret the results:
    i. Evaluate the trends and patterns observed in the estimated population curves.
    ii. Conclude the progression and impact of HIV/AIDS based on the model's estimates.
    iii. Assess the effectiveness of interventions or strategies in reducing the population of infected individuals.

Adhering to the algorithm, the simulations were executed using MATLAB code written in the MATLAB programming language, all on a Windows operating system. The code was designed to be transparent and easily comprehensible.

2.4. Application of Heun's method using provided data

This study was performed to predict the outbreak of HIV cases using Heun's Predictor Corrector Method. Here we have data in Figure 3 that is being collected from Health, Pharma and Medtech State of Health reports regarding the predicted number of people with HIV in Malaysia starting from the year 1986 to the year 2021. By using the given data, we want to assign the parameter with the provided value. Note that we focus on the years 2020 and 2021. In addition, we assume that birth rate and death rates occur. For the total number of populations, we estimate N = 100000 since the collected data is based on the 100000 population. The number of infected people, I = 3146 and the mortality rate, M for the year 2020 and year 2021 are 6.22 and 4.82, respectively, but we take the average for both years which is M = 5.52.

We have: N = 100000, I = 3146; S = N – I = 100000 – 3146 = 96854, B = 0.2.

Then we tabulate all data above and apply Heun's Predictor Corrector Method to approximate the value of S and I. We will do this explicitly for the transformation from $t_0 = 0$ and $t_1 = 1$ to an initial condition value.

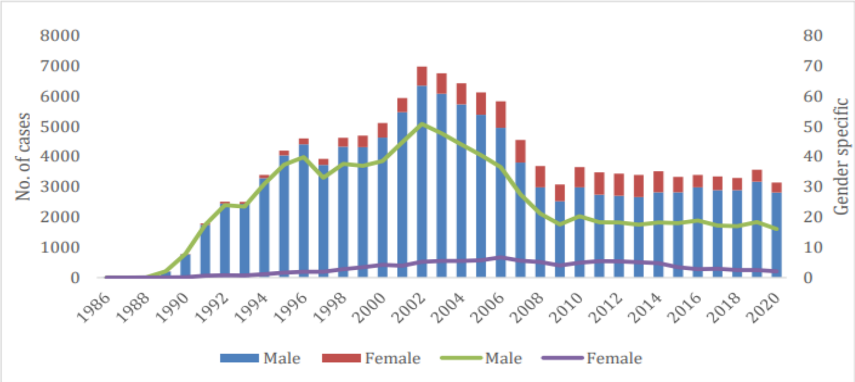

Figure 3. Number of HIV/AIDS Cases in Malaysia between 2015 and 2020

Table 1 presented below provides the estimated values extracted from Figure 3. The data represents key observations and measurements derived from the graphical representation, allowing for more precise analysis and interpretation of the underlying trends and patterns.

Table 1. Summary of the parameters and values

Parameter	Value	Names of Parameter
S_0	94094	Susceptible Population
I_0	5906	Infected Population
B	0.2	Contact rate
N	100000	Population Number
M	5.52	Mortality rate
λ	500	Recruitment rate
μ_n	0.1	Natural death rate
μ_a	0.05	The death rate due to disease
γI	0.03	The rate at which infected individuals progress to AIDS

3. RESULTS AND DISCUSSION

The analysis conducted aimed to examine the impact of parameter values on the population dynamics of the HIV/AIDS model over time. Figure 5 illustrates the plot of the HIV-infected population over time, considering varying values of the parameter β, which represents the rate of HIV transmission within the population. The results depicted on the graph demonstrate that as the value of β decreases from 0.2 to 0.002, there is a notable decline in the infected population over time. This indicates that implementing measures to effectively reduce the contact rate among infected individuals is crucial in decreasing the overall population of infected individuals. Figure 6 provides plots of the rates at which infected individuals progress to AIDS, representing the contact from the infected class to the AIDS class. The results reveal that an increase in the contact rate contributes to a higher population of individuals in the AIDS class. This highlights the importance of focusing on reducing the contact rate among infected individuals and ensuring timely treatment for those who are infected to prevent the growth rate of the AIDS population. Furthermore, Figures 7 and 8 provide a visual representation of the estimated population of infected individuals and susceptible individuals from 2020 to 2031. These figures offer valuable insights into the projected trends and magnitudes of the HIV/AIDS population over the specified period. The estimated population trends serve as a stark reminder of the ongoing challenges posed by HIV/AIDS and emphasize the need for sustained efforts to effectively reduce the burden of the disease.

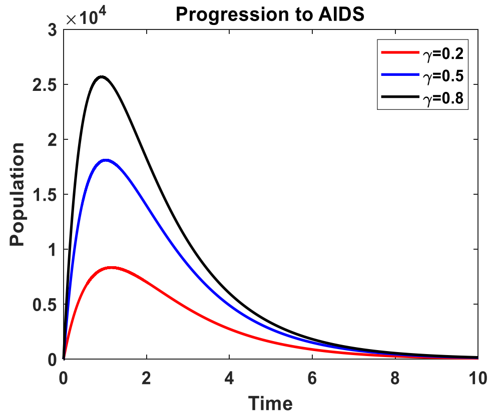

Figure 4. Effect of contact rate on the population

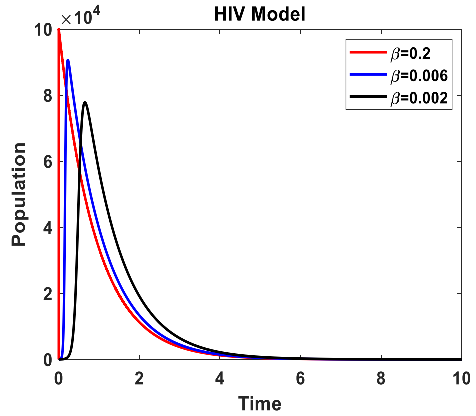

Figure 5. Effect of gamma rate on the population

The estimated population of infected individuals depicted in Figure 7 highlights the urgency of implementing comprehensive prevention strategies. The upward trajectory of the population underscores the importance of targeted interventions to curb new infections, such as promoting safe sexual practices, advocating for harm reduction programs, and providing accessible and accurate information about HIV/AIDS. It also emphasizes the critical need for early diagnosis and prompt initiation of appropriate treatment and care to improve outcomes for individuals living with HIV. In parallel, Figure 8 showcases the estimated population of susceptible individuals. This figure reminds us of the ongoing vulnerability within the population and the importance of proactive measures to prevent new infections. Comprehensive education campaigns, widespread testing, and access to preventive measures such as preexposure prophylaxis (PrEP) are essential in reducing the pool of susceptible individuals and curbing the transmission of HIV. Taken together, these figures highlight the significance of sustained efforts in addressing the HIV/AIDS epidemic. The estimated population trends underscore the urgent need for comprehensive prevention strategies, early diagnosis, and access to appropriate treatment and care. By implementing evidence-based interventions, fostering awareness, and promoting inclusivity, we can make significant strides toward reducing the burden of HIV/AIDS and improving the lives of those affected by the disease.

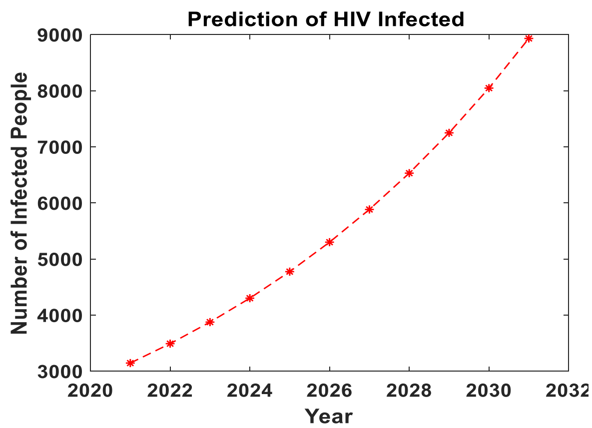

Figure 6. Estimated number of infected people

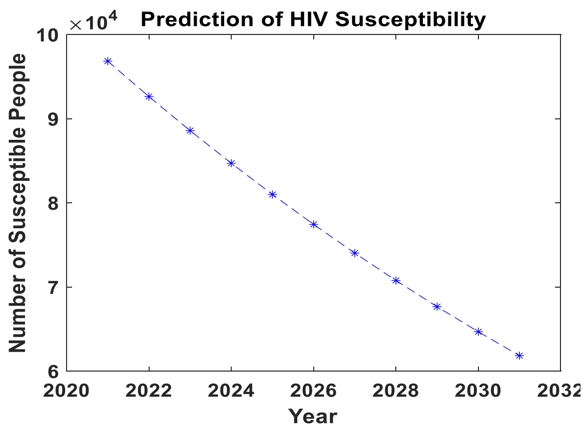

Figure 7. Estimated number of susceptible people

Together, these figures illustrate the significance of Heun's method in our efforts to combat HIV/AIDS. By combining evidence-based interventions with Heun's method, awareness campaigns, and inclusive practices, we can make substantial progress in reducing the HIV/AIDS burden and enhancing the lives of those affected by the disease.

4. CONCLUSION

Reducing the population of infected individuals is a critical objective in combating the spread and impact of HIV/AIDS. Through a comprehensive and multi-faceted approach, significant progress can be made in curbing the transmission of the virus and improving the health outcomes of affected individuals. In conclusion, to effectively combat the HIV/AIDS epidemic and reduce the population of infected individuals, several key considerations should be taken into account. These include implementing preventive measures to reduce the contact rate among infected individuals, ensuring timely treatment for infected individuals to prevent disease progression, addressing the specific challenges associated with the transition from the infected class to the AIDS class, and Implementing interventions to prevent mother-to-child transmission of HIV, including routine HIV testing during pregnancy, provision of antiretroviral drugs to HIV-positive pregnant women, and safe delivery practices. This can significantly reduce the number of new infections among children. By focusing on these strategies and utilizing the insights gained from the analysis, we can work towards achieving a significant reduction in the HIV/AIDS population and ultimately improve public health outcomes.

Declaration of Interest
The authors declare that there is no conflict of interest.

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