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The Spread and Control of HIV/AIDS Infection Using the *SIR* Model

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Abstract: This research discussed the *SIR* model and how it models the spread of HIV/AIDS in Malaysia. The data used were collected from HIV/AIDS Asia Pacific Research Statistical Data. Several parameters and initial conditions need to be assumed as research limitations such as value of parameter γ and the disease transmission rate, β. The aim of this research is to calculate the basic reproductive number, R_0. The basic reproductive number R_0, is a measure of the communicable rate of the virus, reflecting the average number of new infections caused by an infected individual in a completely unharmed population from any disease. Then, we applied a numerical solution method, which is Euler's method to predict the susceptible and infected cases. We plot the predicted susceptible and infected cases using Microsoft Excel. Based on the results and the discussion obtained, the transmission is likely to decrease and indicates that disease spread is under relatively reasonable control.

Keywords: HIV/AIDS, *SIR* Model, Spread and Control

1 Introduction

The virus known as HIV (human immunodeficiency virus) targets the immune system of the body. AIDS can develop from HIV if it is not treated (acquired immunodeficiency syndrome [19]. According to Koh [2], the first reported cases in Malaysia were in 1986 and drastically increased by the end of 2010 from the first three reported cases to 91,362 HIV infections, 16,352 AIDS cases and 12,943 AIDS-related deaths. HIV/AIDS infections are most common among injection drug users (IDUs), sex workers (TS), men who have sex with men (MSM) and transgender people (TG). According to a previous study conducted by Mondal and Shitan [3], the cumulative number of HIV infections and AIDS cases have been 94,841 and 17, 686, respectively, since Malaysia first reported HIV cases 25 years ago while 14,986 people have died because of this disease and from those cases, and the main risk factor was figured out to be injection drug users (57%), followed by sexual transmission (32%) with overall HIV prevalence rate in the country was found to be approximately (0.40%).

Until now, there is no specific effective treatment found to completely cure HIV. People who contract HIV are said to be infected for life. On the other hand, it can be monitored with proper medical treatment. There is a treatment called Antiretroviral therapy (ART) that can slow down the growth of HIV in a patient's body [20]. HIV patients who receive that treatment successfully will live long, healthy and can also protect their partners. Generally, this epidemic affected the whole country. It can weaken the nation's health system with various threats.

Several models were developed to explain the temporal progression of the disease where the most famous is possibly the Susceptible-Infected Recovered, SIR model [7]. A three compartmental SIR model with a control function was proposed by Zakary et al. [17] to show and prove the impacts of awareness initiatives in lowering the number of HIV/AIDS infections. A general model, which is SIR model, was proposed by Shanta and Biswas [18], to study the possible control and preventive approach, especially the influence of media regarding awareness programs throughout the period of any pandemic or epidemic.

The common SIR model considers three distinct compartments of active population that change over time, which are susceptible population S(t), infected population I(t) and recovered population R(t)[18]. Sheima and Frank [21] used the SIR model for which the population is partitioned into compartments of Susceptible Individuals, Infective Individuals and Recovered Individuals, with size S(t), I(t), and R(t), respectively, to analyze HIV/AIDS in Khartoum.

In order to raise community awareness of the spread of HIV/AIDS and decrease the number of cases from rising in the future, this research will compute the number of basic reproductive. After that, we used Microsoft Excel to analyze and interpret the results of the data prediction.

In section 2, the flowchart of the research methodology is shown, along with discussions of the assumptions and formulation of the SIR model, data collection, and parameter setting. The basic reproductive number, R_0 and the use of Euler's method to predict cases of susceptible, infected, and recovered were also covered in this section. Numerical results are shown graphically in section 3. Finally, the overall summary with findings is discussed in section 4.

2 Methodology

In this section, several steps were taken to achieve the goal of this research. The flowchart of the research methodology is shown in Figure 1.

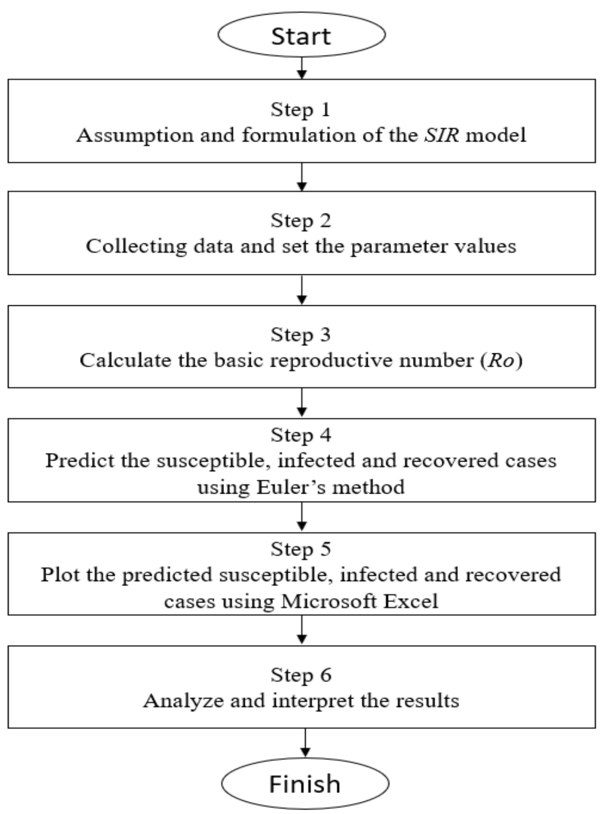

Figure 1: Flowchart of the research methodology

A SIR model assumption and formulation

This section will discuss the SIR model and how it models the spread of HIV/AIDS in Malaysia. This model is suitable to apply with the following assumptions:

i Fixed population is the adult population because HIV/AIDS is mainly transmitted through sexual contact. We are solely interested in the adult population [10].
ii The only way for the person to leave the susceptible group is to get infected. The only way to escape the infected group is to recover from the disease.
iii The rate of disease spread is related to sexual interaction between susceptible and infective individuals.
iv The individual who becomes infected and finally dies is believed to be zero and is excluded from this research.

Through these assumptions, the mathematical model compartment is expressed in Figure 2.

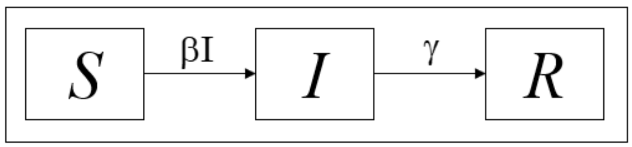

Figure 2: The SIR model compartment.

As the total population includes of those who are susceptible, infected, and recovered, the following equation can be applied:

$$S(t)+I(t)+R(t)=N(t)$$

where

N(t) = the total population at any time, *t*
S(t) = the susceptible population at any time, *t*
I(t) = the infectious population at any time, *t*
R(t) = the recovered population at any time, *t*.

Typically, the SIR model is used to depict the proportion of the susceptible population infected by exposure at the parameter β rate and the infected population's survival rate at the parameter γ. The model used in this analysis will lead to the following system of ordinary differential equations, which is taken from Ifguis et al. [15]:

$$\begin{aligned} \frac{dS}{dT} &= -\frac{\beta SI}{N} \\ \frac{dI}{dT} &= \frac{\beta SI}{N} - \gamma I \\ \frac{dR}{dT} &= \gamma I \end{aligned} \tag{1}$$

where

$\frac{dS}{dT}$ = the rate of susceptible population, *S* with respect to any time, *t*
$\frac{dI}{dT}$ = the rate of infected population, *I* with respect to any time, *t*

$\frac{dR}{dT}$ = the rate of recovered population, R with respect to any time, t
β = constant rate of disease transmission
γ = recovery rate.

B Data collection and parameter setting

The population cases are predicted using actual data. Table 1 shows the number of susceptible and infected individuals per 1000 in Malaysia from 2014 to 2020. These data were collected from [13].

Table 1: Data collection of susceptible and infected cases.

Year	Susceptible	Infected
2014	730	270
2015	740	260
2016	740	260
2017	750	250
2018	730	270
2019	710	290
2020	680	320

As one of our research limitations, several parameters, and initial conditions should be assumed. According to a recent datasheet from HIV/AIDS Asia Pacific Research [13], the percentage of people living with HIV who have suppressed viral loads is 43%. Therefore, it is assumed that the value of parameter $\gamma = 0.43$. Subsequently, the disease transmission rate, β were taken from Basak et al. [16]. The total population, N for this study was set at 1000. For initial conditions, we assume that $S(0) = S_0 \geq 0$, $I(0) = I_0 \geq 0$ *and* $R(0) = R_0 \geq 0$.

C Basic reproductive number

The basic reproductive number R_0, is a measure of the communicable rate of the virus, reflecting the average number of new infections caused by an infected individual in a completely unharmed population from any disease. It is a key concept in the epidemiology of infectious disease, which mean the risk of an infectious agent spread in the event of an outbreak. When $R_0 > 1$, the number of infected people is likely to increase, and when $R_0 < 1$, the transmission is likely to decrease and eventually stop. It is important to know the value of R_0 to assess the extent and scale of an epidemic, as well as to establish adequate measures and responses to protect the population from a disease and to contain the epidemic [12]. Moreover, R_0 depends on the socio-demographic variables and infectious agent biology. For example, the number of contacts may depend on population density, birth rate, cultural practices, or contact rate assumptions when parameterizing models. These factors are frequently comparable within an area but may differ between regions, supporting the idea that R_0 is context dependent. [11].

D Prediction of HIV/AIDS cases using Euler's method

In this section, we employed a numerical solution method, which is Euler's method. In this stage, we formulate and converted the SIR model equation (1) into Euler's formula. Therefore, the Euler formulas became:

$$S_n = S_{n-1} - \left(\frac{S_{n-1}}{N}\right)(\beta I_{n-1})(\Delta t)$$
$$I_n = I_{n-1} + \left(\frac{S_{n-1}}{N}\right)(\beta I_{n-1})(\Delta t) - (\gamma I_{n-1})(\Delta t) \quad (2)$$
$$R_n = R_{n-1} + (\gamma I_{n-1})(\Delta t)$$

where

$S_n, I_n, R_n =$ susceptible, infected, and recovered population for the current year

$S_{n-1}, I_{n-1}, R_{n-1} =$ susceptible, infected, and recovered population for the prior year

$\Delta t =$ step size in the time domain.

Using Euler's formula (2), we employed Microsoft Excel to calculate the predicted susceptible, infected, and recovered populations. Then, the predicted results were plotted and analyzed in the following section.

3 Result and Discussions

In this section, we analyzed and discussed the predicted results. Figure 3 depicts the expected cases from three compartments of the SIR Model, susceptible, infected and recovered per 1000 population until 2024. According to the prediction, the number of susceptible and infected people is expected to decrease from 2015 to 2024. Consequently, since the treatment for HIV, called antiretroviral therapy (ART), started showing its effectiveness with the value recovery rate, γ equal to 0.43, it is predicted that there will be recovered individuals in the population. As a result, the estimated recovered people are increasing from 2015 to 2024. This is a positive sign that the treatment for HIV, called ART, is compelling.

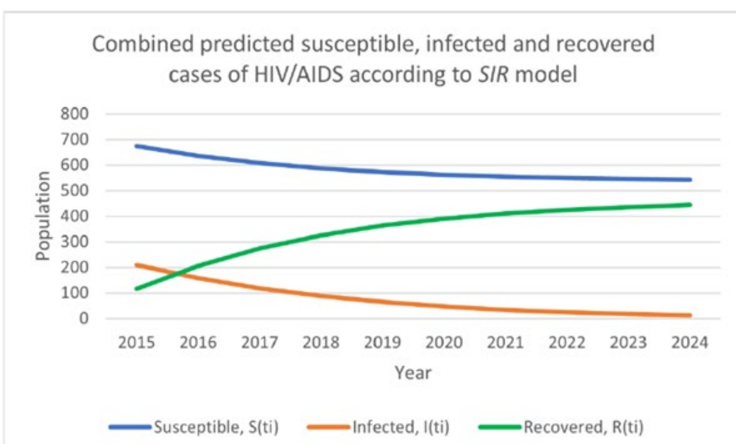

Figure 3: Predicted susceptible, infected and recovered cases of HIV/AIDS.

The predicted susceptible and infected cases are subsequently compared to the actual data. Tables 2 and 3 present the predicted and confirmed cases of susceptibility and infection.

Table 2: Predicted and confirmed susceptible cases of HIV/AIDS.

Year	Predicted Susceptible Case	Confirmed Susceptible Case
2015	675	740
2016	635	740
2017	607	750
2018	587	730
2019	572	710
2020	562	680
2021	555	-
2022	549	-
2023	546	-
2024	543	-

Table 3: Predicted and confirmed infected cases of HIV/AIDS.

Year	Predicted Infected Case	Confirmed Infected Case
2015	209	260
2016	159	260
2017	119	250
2018	88	270
2019	64	290
2020	47	320
2021	34	-
2022	25	-
2023	18	-
2024	13	-

As illustrated in Figure 4, we can conclude that the *SIR* model can provide reliable predictions for susceptible populations. However, for the confirmed infected case, the trends seem to be increases as shown in Figure 5.

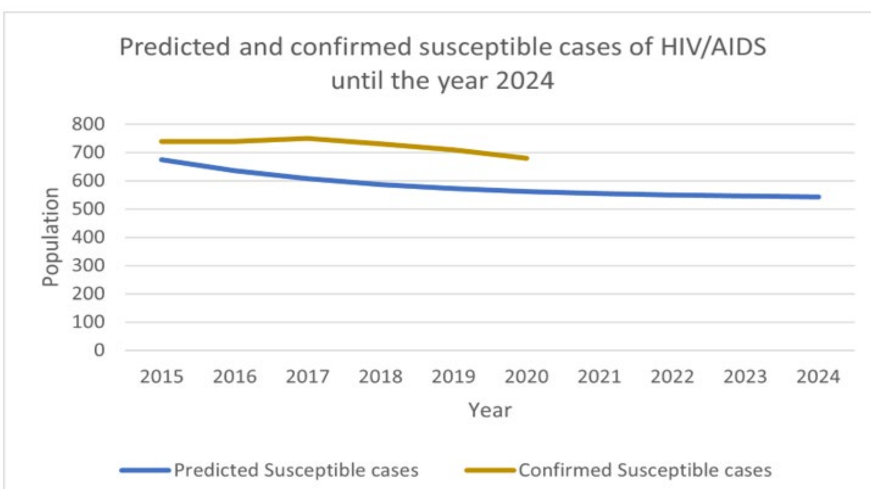

Figure 4: Predicted susceptible cases per 1000 population.

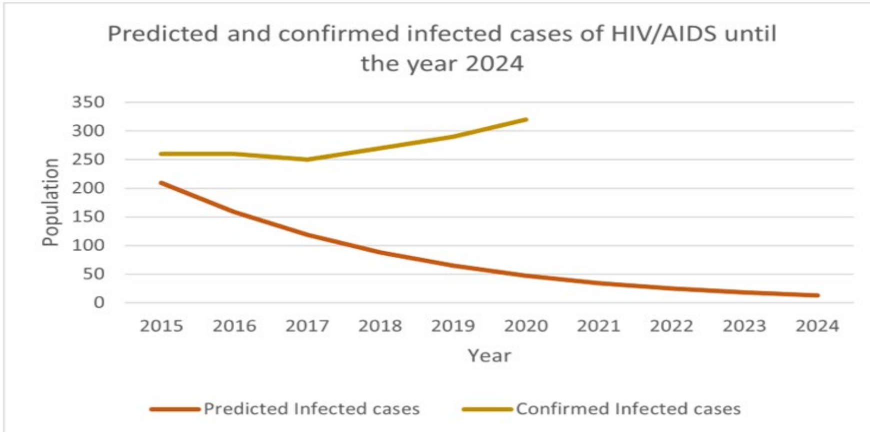

Figure 5: Predicted and confirmed infected cases of HIV/AIDS.

4 Conclusions

Based on the results and the discussion obtained, our estimated R_o for HIV/AIDS is 0.65116, which means the transmission is likely to decrease and indicates that disease spread is under relatively reasonable control. This also suggests that a preventive strategy based on healthcare personnel effectively combats the spread of HIV/AIDS. Next, this research collected HIV/AIDS data, including the number of susceptible, infected and recovered cases from 2015 to 2020, to predict the number of infections of HIV/AIDS. The SIR model can predict the HIV/AIDS pandemic well as it is the best model for the epidemic virus. The result shows that the prediction for the susceptible and infected HIV/AIDS cases will decrease while recovered HIV/AIDS cases will increase yearly. Lastly, we can analyze the spread of HIV/AIDS in Malaysia and compare the behaviour of the disease by comparing the predicted and confirmed cases for the three SIR model compartments susceptible, infected and recovered. From the observation, the susceptible and infected class from the SIR compartment started changing behaviour after 2017, before those two compartments remained constant from 2015.

Meanwhile, the population remains constant for the recovered class since ART is still ineffective in fully curing HIV/AIDS. However, the predicted SIR model shows different results compared to actual HIV/AIDS cases in Malaysia, where the number of susceptible and infected populations in the model is lower than the actual data. In contrast, the recovered population is higher than the real data.

Overall, the findings suggest that Malaysia could provide state-of-the-art ART as it consists of the most advanced ART medications and will essentially be distributed for free to the HIV-infected population through a unified and universal public health system. The treatment with HIV medications, known as ART, allows people living with HIV to live longer and healthier lives. Although ART cannot cure HIV, it can reduce the amount of HIV in the body, known as the viral load, to an undetectable level. Next, the health department needs to hold many effective prevention programmes throughout Malaysia targeting people living with HIV/AIDS to give awareness to people about the HIV/AIDS pandemic and ensure treatment is provided to people living with HIV AIDS. Besides, prevention in the health care setting is also essential such as preventing mother-to-child transmission and blood safety. Finally, mandatory HIV testing and individual counselling regarding HIV prevention are crucial for all individuals to ensure that they are aware of their status and can access prevention, treatment, care and support. The key is to target investment where it will have the most significant impact: test, treat and target shifting for harm reduction in new and current infections. As for future research, we recommend using the extended SIR model to provide a more accurate prediction. This result can assist in estimating future infection forecasts.

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