Menemui Matematik (Discovering Mathematics)
Vol. 44, No. 2: 139-151 (2022)

The COVID-19 Outbreak Transmission Dynamic Prediction with SIR Model using Runge-Kutta Method

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ABSTRACT

The COVID-19 disease has been going on for almost three years since it emerged in December 2019. COVID-19 has become the deadliest contagious virus in the world, and the situation is still serious everywhere. Therefore, accurate epidemic predictions are required to find a suitable and efficient prevention measure. To comprehend the transmission of this disease, this research examines the Susceptible Infected Recovered Model (SIR) using actual data based on Malaysian cases. The 4th order Runge-Kutta method was utilised to formulate and solve differential equations numerically. The model has been studied theoretically and through computer simulations using MATLAB. As a result, the rate of COVID-19 transmission from susceptible to infected will increase the number of affected populations. The pace of recovery of COVID-19 transmission from infected to recovered will result in a decline in infected populations. By observing the data, the COVID-19 outbreak transmission dynamics had a longer incubation period and recovery phase. The 4th order Runge-Kutta numerical method approximates the value depicting the virus's movement or transmission. It may be utilised to investigate numerical solutions in the SIR model and analyse the movement of the COVID-19 outbreak. The described model can be used in other countries, a vital strategy when considering COVID-19 transmission.

Keywords: Coronavirus, COVID-19, Malaysia, Runge-Kutta method, SIR Model.

INTRODUCTION

The World Health Organization, known as WHO, identified a rare pneumonia disease that originated in Wuhan, Coronavirus disease 2019 (COVID-19), before it became an outbreak in other nations (Zhang et al., 2020). Pandemic COVID-19 is a contagious disease that significantly impacts worldwide, affecting more than 200 countries and regions (Mohammed et al., 2021). Malaysia is one of the nations that has been struck by this outbreak recently. Over 4,505,059 confirmed cases have been recorded in the region up to this point. A high number of people have died as a result of the epidemic (Abdul Taib et al., 2022). As our nation enforced Movement Control Order (MCO), the lockdown caused a slew of disasters, including health, economic, and financial collapse, as well as a collapse in the industrial and educational activity. Although there were concerns about the MCO's effectiveness initially, the COVID -19 cases have dropped (Tang, 2022). Many sectors were affected by the MCO and social distancing, which were established as control measures. The landscape has now successfully decreased the number of affected persons. Since the onset of the COVID-19 outbreak in China, based on epidemiological modelling, recent researchers have employed numerous models to predict the future of the pandemic and its period of peak (Alenezi et al., 2021; Duan & Nie, 2022; Haq et al., 2022; Zhu & Shen, 2021).

This study aims to forecast Malaysia's COVID-19 outbreak's transmission dynamics using the Susceptible-Infected-Recovery epidemic model (SIR). The SIR model may be applied to monitor disease spreading and forecast the number of infected, removed, and recovered populations and the population's mortality. Numerous diseases, including HIV and tuberculosis, have been estimated using the SIR model (Abueldahab & Mutombo, 2021; Azizan et al., 2022; Sokolov & Sokolova, 2019). The most basic version of the SIR approach, which is effective for epidemic diseases, is defined as follows: Susceptible (S), Infected (I), and Recovered (R) are the three factors that SIR combines to determine the overall population (Ergen et al., 2015). The entire healthy population, yet at risk of contracting an infection, is classified as susceptible. The population that is either mildly or seriously sick is said to be infected. Recovered is the sum of all individuals who survived the outbreak and developed immunity, including those who have since passed away.

The 4^{th} order Runge-Kutta technique is applied to define and solve a system of nonlinear differential equations. Data for the analysis were collected from 25^{th} March 2020 in a population of 33.80 million (Ministry of Health Malaysia, n.d.). Mathematical modelling becomes an instrument that can assist in resolving real-world issues. The epidemiological forecast based on mathematical modelling is critical for understanding the epidemic's progress and proposing appropriate disease-control methods. The primary goal of this analysis is to predict the progression for the spread of COVID-19 outbreak in Malaysia. We set 25 March 2020 as $t = 0$. Therefore, we chose MATLAB as one of the applications to help us conduct this study. Using MATLAB, we will get an idea of the distribution pattern of COVID-19 disease in the future. The result of this study will show whether the number of infected people will increase or decrease in the upcoming months, so that the authority will be aware of some backup strategies that can control and eradicate the infection. Thus, by predicting this COVID-19 case, it can have many positive effects on a country.

SIR model is one of the mathematical models used to explore and explain the dynamics of infectious illness transmission in a particular region or region (Kousar et al., 2016). SIR is regarded as one of the most dependable basic instruments, with three compartments which are susceptible (S), infected (I), and recovered (R). Susceptible (S) is referred to the stage of the susceptible person at a time (t) which is when the spreading starts. At that time, all Malaysian populations became susceptible. Infected (I) is referred to the stage when a person gets infected by COVID-19. When that infected person has been identified, contact tracing will be examined. If they have tested positive for COVID-19, whether symptomatic or asymptomatic, they will be isolated and treated as if they are infected (I). They will subsequently be converted into a stage of recovery (R) person once they have recovered. This model contains 4^{th} order Runge-Kutta technique because they are ideally suited to solving the initial value problem which is known as (IVP) for ordinary differential equations (ODE). This approach is a numerical way to find solutions from the SIR model's basic equations. Finally, the 4^{th} order Runge-Kutta approach is the most excellent option to optimise SIR model predictions.

This paper is organised as follows: Section 2 explains the methodology of this research. Furthermore, Section 3 provides the outcomes and discussion. The last section concludes this article's findings and suggests future research.

METHODOLOGY

One of the best methods that can be used to approximate the analytical solution is the Runge-Kutta method. The Runge-Kutta technique is an improved version of the Euler method that provides a higher level of accuracy. Furthermore, the Runge-Kutta approach is more precise than the Euler method because it uses a higher number of slope weights at each time step. As a result, we used a numerical Runge-Kutta approach to solve this study's susceptible-infected-recovery (SIR) model. The Runge-Kutta formula is one of the most well-known and well-understood designs in numerical analysis (Adamu et al., 2019).

SIR Model for Transmission Dynamic of the COVID-19 Outbreak

The system is made up of three differential equations that split the population into three compartments based on the categorisation, which are Susceptible (S), Infected (I), and Recovered (R) (Law et al., 2020). Transmission rate (r) and recovery rate (a) determine the interaction between the categories. The Susceptible, Infected, and Recovery, known as SIR Model for COVID-19 outbreak, is described in the type of a line graphic as Fig. 1.

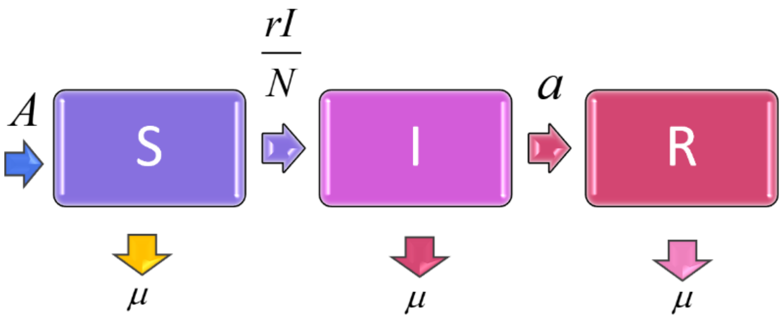

Figure 1: Schematic diagram of Susceptible, Infected and Recovery Model (SIR Model) for COVID-19 outbreak

Time (t), measured in months, is the independent variable, whereas the dependent variables are $(S, I$ and $R)$. Three sets of dependent variables are considered. The rate of change in the susceptible population, the rate of change in the infected population, and the rate of change in the recovered population are represented by equations (1), (2) and (3).

$$\frac{dS}{dt} = A - \mu S - \frac{rI}{N}S \tag{1}$$

$$\frac{dI}{dt} = \frac{rI}{N}S - (\mu + a)I \tag{2}$$

$$\frac{dR}{dt} = aI - \mu R \tag{3}$$

with $N = S + I + R$.

Table 1 below shows the parameters and the description used in the SIR model.

Table 1: Parameters and description used in the SIR model.

Parameters	Description
$\boldsymbol{S}$	Total of susceptible individuals in Malaysia at the period t
$\boldsymbol{I}$	Total of infected people in Malaysia at period t
$\boldsymbol{R}$	Total of recovered people in Malaysia at period t
$\boldsymbol{r}$	The rate at which the outbreak spreads from susceptible to infected people. $(0 \leq r \leq 1)$
$\boldsymbol{a}$	The recovery rate from the infected phase to the recovered phase
$\boldsymbol{A}$	The number of populations in Malaysia in 2020

μ	The rate of mortality in Malaysia

Assumptions

The following assumptions are used to simplify the analysis:

1. The overall population number (N) remains constant. Births, immigration, and natural death are all ignored. As a result, the rate of change of (N) will be zero. This will result in:

$$N = \text{Susceptible} + \text{Infected} + \text{Recovery} \tag{4}$$

$$\frac{dN}{dt} = \frac{dS}{dt} + \frac{dI}{dt} + \frac{dR}{dt} = 0 \tag{5}$$

2. The population is homogeneously distributed.
3. Individuals who have recovered become immune (hence remain in the removed compartment).
4. The persons who died from the disease are also included in the removed compartment.

Runge-Kutta 4th Order Method

For a system of differential equations, the 4th order Runge-Kutta technique consists of following forms:

$$y_{r+1} = y_r + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4) \tag{6}$$

with

$$k_1 = hf(x_r, y_r)$$
$$k_2 = hf\left(x_r + \frac{1}{2}h, y_r + \frac{1}{2}k_1\right)$$
$$k_3 = hf\left(x_r + \frac{1}{2}h, y_r + \frac{1}{2}k_2\right)$$
$$k_4 = hf(x_r + h, y_r + k_3)$$

This approach is easy to programme, stable, and has minor cut and rounding errors. This study is an experimental study that examines theories about COVID-19 transmission models. The Runge-Kutta 4th order technique is utilised to come up with the numerical solution of the Susceptible, Infected and Recovery Model (SIR model). Then the SIR Model was analysed and generated using primary data for this study from the Government website and other sources in 2020 on the number of COVID-19 cases (Ministry of Health Malaysia, n.d.). MATLAB software was used to run the simulation. We set 25 March 2020 as $t = 0$. Figure 2 and Algorithm 1 display the flowchart of the model and the pseudocode of the program respectively.

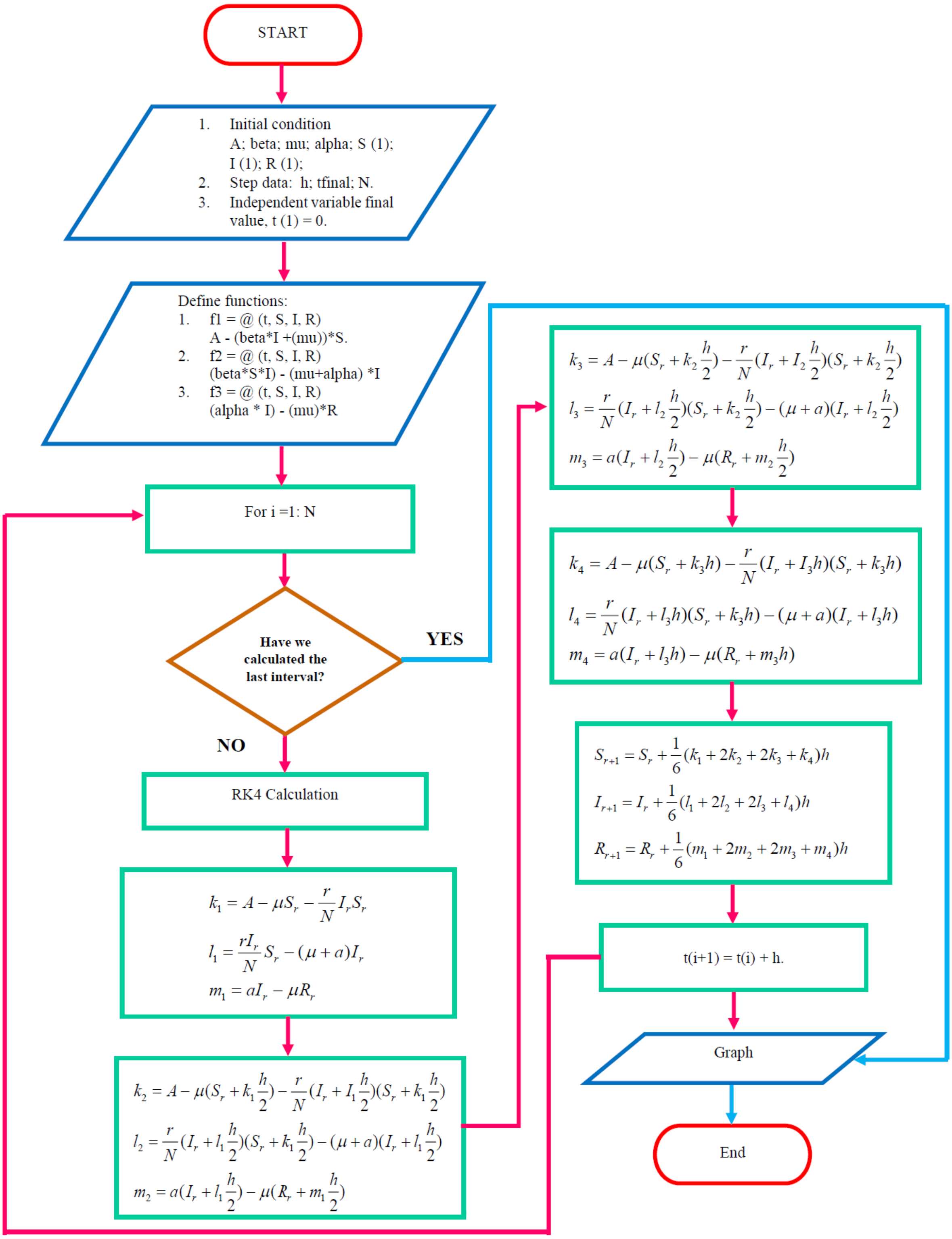

Figure 2: The flowchart of the model.

```
% Declare parameters used
A = 32365999; beta = 0.227750/32365999; mu = 0.00231060; alpha = 0.0247450;

% step size
h= 0.001;  tfinal = 100;
N = ceil(tfinal/h)  % Calculates upto y(100000) ceil(tfinal/h)

% the function as you desire
f1 = @(t,S,I,R)    A - (beta*I +(mu))* S;
f2 = @ (t,S,I,R)  (beta* S * I ) - (mu + alpha)*I
f3 = @ (t,S,I,R)  (alpha * I)  - (mu)*R

% initial conditions
t(1)=0; S(1)= 33364029/33365999 ; I(1)=1796/33365999; R(1)=174/33365999;

%step size
for i=1:N;  % update loop

%update time
t(i+1) = t(i) + h;

%%%%% Stage One %%%%%
K_1S = f1( t(i) ,  S(i),  I(i) ,  R(i) );
K_1I = f2( t(i) ,  S(i),  I(i) ,  R(i) );
K_1R = f3( t(i) ,  S(i),  I(i) ,  R(i) );

%%%%% Stage Two %%%%%%
K_2S = f1( t(i) + (1/2)*h, S(i) + (1/2)*h*K_1S, I(i) + (1/2)*h* K_1I , R(i) + (1/2)*h* K_1R );
K_2I = f2( t(i) + (1/2)*h, S(i) + (1/2)*h*K_1S, I(i) + (1/2)*h* K_1I , R(i) + (1/2)*h* K_1R );
K_2R = f3( t(i) + (1/2)*h, S(i) + (1/2)*h*K_1S, I(i) + (1/2)*h* K_1I , R(i) + (1/2)*h* K_1R );

%%%%% Stage Three %%%%%
K_3S = f1( t(i) + (1/2)*h, S(i) + (1/2)*h*K_2S, I(i) + (1/2)*h* K_2I , R(i) + (1/2)*h* K_2R );
K_3I = f2( t(i) + (1/2)*h, S(i) + (1/2)*h*K_2S, I(i) + (1/2)*h* K_2I , R(i) + (1/2)*h* K_2R );
K_3R = f3( t(i) + (1/2)*h, S(i) + (1/2)*h*K_2S, I(i) + (1/2)*h* K_2I , R(i) + (1/2)*h* K_2R );

%%%%%  Stage Four %%%%%
K_4S = f1( t(i) + h, S(i) + h*K_3S, I(i) + h* K_3I , R(i) +  h*K_3R );
K_4I = f2( t(i) + h, S(i) + h*K_3S, I(i) + h* K_3I , R(i) +  h*K_3R );
K_4R = f3( t(i) + h, S(i) + h*K_3S, I(i) + h* K_3I , R(i) +  h*K_3R );

%%%%% Now, the main equations %%%%%
S(i+1) = S(i) + (1/6)*(K_1S+2*K_2S+2*K_3S+K_4S)*h;
I(i+1) = I(i) + (1/6)*(K_1I+2*K_2I+2*K_3I+K_4I)*h;
R(i+1) = R(i) + (1/6)*(K_1R+2*K_2R+2*K_3R+K_4R)*h;
End

%plot the solutions
%figure(1); clf(1)
%plot(t,S), %plot(t,I), %plot(t,R)
%legend('S(t)'), %legend('I(t)'), %legend('R(t)')
%  The function to plots all together\

plot(t,S,t,I,t,R)
legend('S(t)= Susceptible','I(t)= Infected', 'R(t)= Recovery')
xlabel('Time(months)')
ylabel('Populations')
set(gca,'Fontsize', 12)
```

Algorithm 1: The pseudocode of the program.

RESULTS AND DISCUSSION

Numerical Solution of SIR Model for COVID-19 Outbreak by Fourth Order Runge-Kutta Method

The SIR model for COVID-19 transmission, as shown in equations (1) – (3), will be transformed into ordinary differential equations, as shown in equations (7) – (9):

$$\frac{dS}{dt} = f(t, S, I, R) = A - \mu S - \frac{rl}{N} S \tag{7}$$

$$\frac{dI}{dt} = g(t, S, I, R) = \frac{rl}{N} S - (\mu + a) I \tag{8}$$

$$\frac{dR}{dt} = i(t, S, I, R) = aI - \mu R \tag{9}$$

Runge-Kutta 4th Order technique can be applied to solve the equation (7) – (9) above according to the equation (6) using substitution. Hence we get the numerical solutions of the SIR model for COVID-19 outbreak transmission using equation (10) – (12) as follows:

$$S_{r+1} = S_r + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4)h \tag{10}$$

$$I_{r+1} = I_r + \frac{1}{6}(l_1 + 2l_2 + 2l_3 + l_4)h \tag{11}$$

$$R_{r+1} = R_r + \frac{1}{6}(m_1 + 2m_2 + 2m_3 + m_4)h \tag{12}$$

where

$$k_1 = A - \mu S_r - \frac{r}{N} I_r S_r$$
$$k_2 = A - \mu(S_r + k_1 \frac{h}{2}) - \frac{r}{N}(I_r + I_1 \frac{h}{2})(S_r + k_1 \frac{h}{2})$$
$$k_3 = A - \mu(S_r + k_2 \frac{h}{2}) - \frac{r}{N}(I_r + I_2 \frac{h}{2})(S_r + k_2 \frac{h}{2})$$
$$k_4 = A - \mu(S_r + k_3 h) - \frac{r}{N}(I_r + I_3 h)(S_r + k_3 h)$$

where

$$l_1 = \frac{rI_r}{N} S_r - (\mu + a) I_r$$
$$l_2 = \frac{r}{N}(I_r + l_1 \frac{h}{2})(S_r + k_1 \frac{h}{2}) - (\mu + a)(I_r + l_1 \frac{h}{2})$$
$$l_3 = \frac{r}{N}(I_r + l_2 \frac{h}{2})(S_r + k_2 \frac{h}{2}) - (\mu + a)(I_r + l_2 \frac{h}{2})$$
$$l_4 = \frac{r}{N}(I_r + l_3 h)(S_r + k_3 h) - (\mu + a)(I_r + l_3 h)$$

where

$$m_1 = aI_r - \mu R_r$$
$$m_2 = a(I_r + l_1 \frac{h}{2}) - \mu(R_r + m_1 \frac{h}{2})$$
$$m_3 = a(I_r + l_2 \frac{h}{2}) - \mu(R_r + m_2 \frac{h}{2})$$
$$m_4 = a(I_r + l_3 h) - \mu(R_r + m_3 h)$$

SIR Model Simulation Using Application of MATLAB Software

Table 2 shows the parameters that we used and the initial values for the SIR model for Covid-19 transmission where $S(0), I(0)\ R(0)$ are obtained from (Ministry of Health Malaysia, n.d.). Meanwhile, r, a and μ are obtained from (Ahmad Zuber et al., 2021).

Table 2: The Initial Condition of Susceptible, Infected and Recovery Model (SIR model).

Variable/Parameter	Value
$\boldsymbol{S(0) = S(2020)}$	$\frac{33,364,029}{33,365,999}$
$\boldsymbol{I(0) = I(2020)}$	$\frac{1796}{33,365,999}$
$\boldsymbol{R(0) = R(2020)}$	$\frac{174}{33,365,999}$
$\boldsymbol{N = A}$	32,365,999
$\boldsymbol{r}$	0.2277500
$\boldsymbol{a}$	0.0247450
$\boldsymbol{\mu}$	0.00231060

The Susceptible, Infected and Recovery Model (SIR model) are formulated for the COVID-19 transmission in Malaysia as in equations (13) – (15).

$$\frac{dS}{dt} = 32365999 - 0.00231060S - \frac{0.2277500}{32365999}IS \tag{13}$$

$$\frac{dI}{dt} = \frac{0.2277500}{32365999}IS - (0.00231060 + 0.0247450)I \tag{14}$$

$$\frac{dR}{dt} = 0.0247450I - 0.00231060R \tag{15}$$

Figures 3, 4, 5 and 6 demonstrate the outcomes of simulation equations (10) - (12) considering month-to-month time intervals, time steps, also initial conditions in the type of input parameters and actual value, as shown in Table 2:

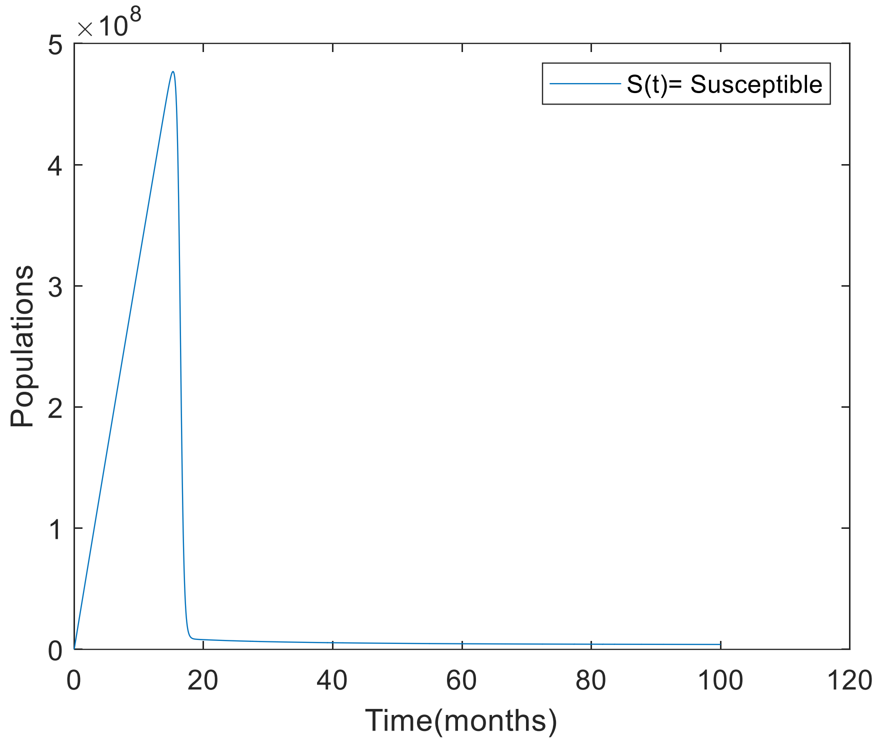

Figure 3: Total Number of Susceptible Population using SIR Model of COVID-19.

According to Fig. 3, the susceptible population is 33,364,029 individuals from 33,365,999 individuals, which is the population in 2020. During the next fifteen months, it increases until reaching a peak of a suspected population of 4,768,440,000 population. The increment is due to the fact that the total population and the initial value that we used, were more than the number of populations that declined in the suspected population of COVID-19 transmission rate from suspect to infected, as well as the mortality rate for the susceptible class. The curve will eventually converge to one point after reaching the peak point, indicating that the susceptible population will drop at some time in the future. It is shown that the transmission rate for COVID-19 to be spread is low in the future because the number of susceptible populations was moved to the infected population.

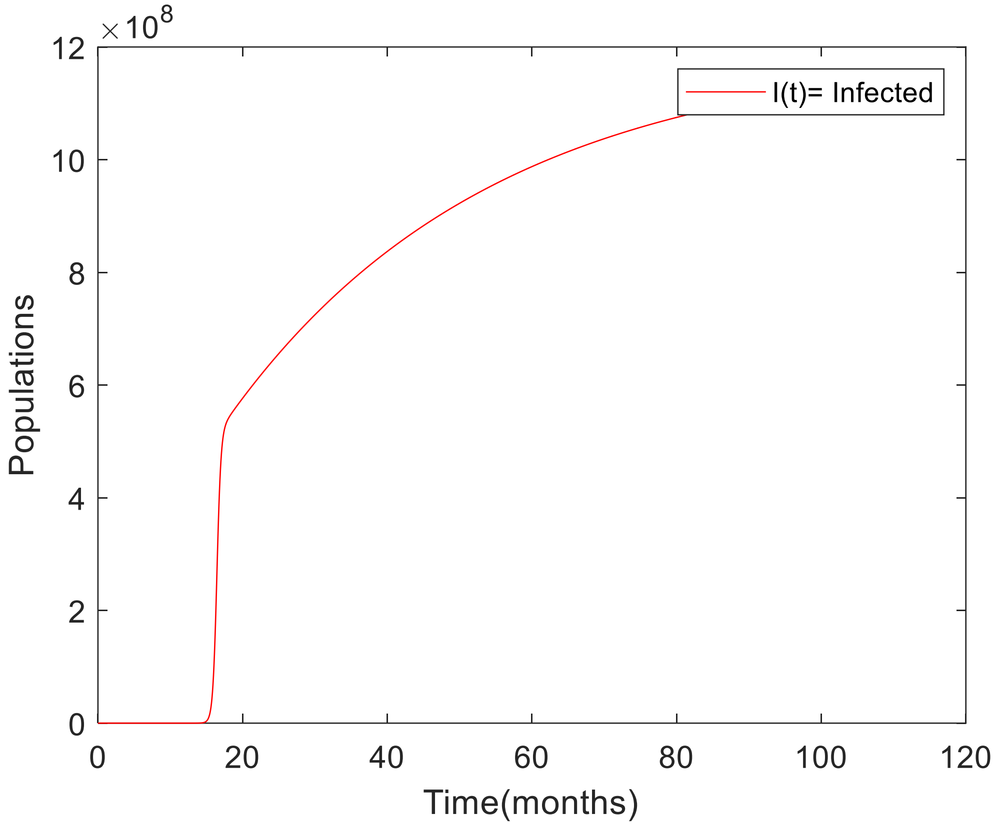

Figure 4: Total Number of Infected Population using SIR Model of COVID-19.

The number of infected populations at first is 1796 from 33,365,999, but as we can see from Fig. 4, the number of infected increased dramatically by 517,181,00 until the seventeen-month peaked. It is because, at that time, the transmission rate of COVID-19 from a susceptible to an infectious state was greater than the recovery rate from the infected phase to the recovery phase and mortality rate of the infected phase. The population in infected phases started to increase steadily after $t = 100$, and the graph line will converge to a certain point later.

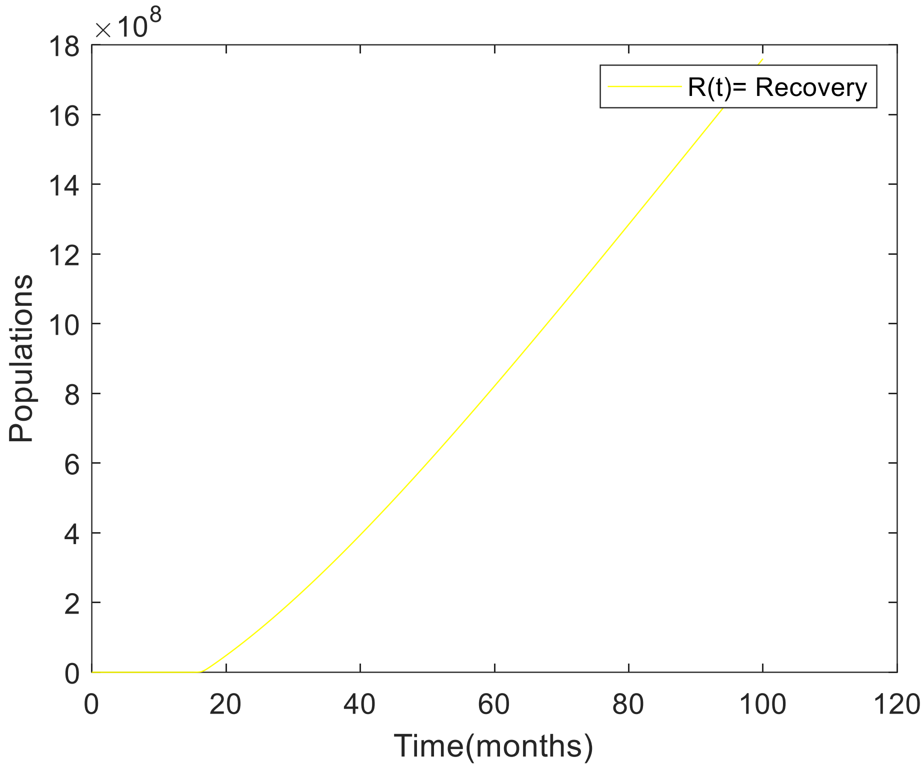

Figure 5: Total Number of Recovered Population using SIR Model of COVID-19.

According to Fig. 5, the initial number of the recovered population is 174 from 33,365,999 residents. The recovered population are deemed to be increased over time. It showed that the number of people to be as healthy as ever is increasing. This increment is due to the fact that the rate of recovery which is from being infected to being recovered is more than the mortality rate of the recovered populations and the incapability of the rate of COVID-19 transmission from being exposed to being infected. As the number of recovered populations increases, the number of infected populations will decrease in the future. Hence, the rate of the transmission COVID-19 will be slow.

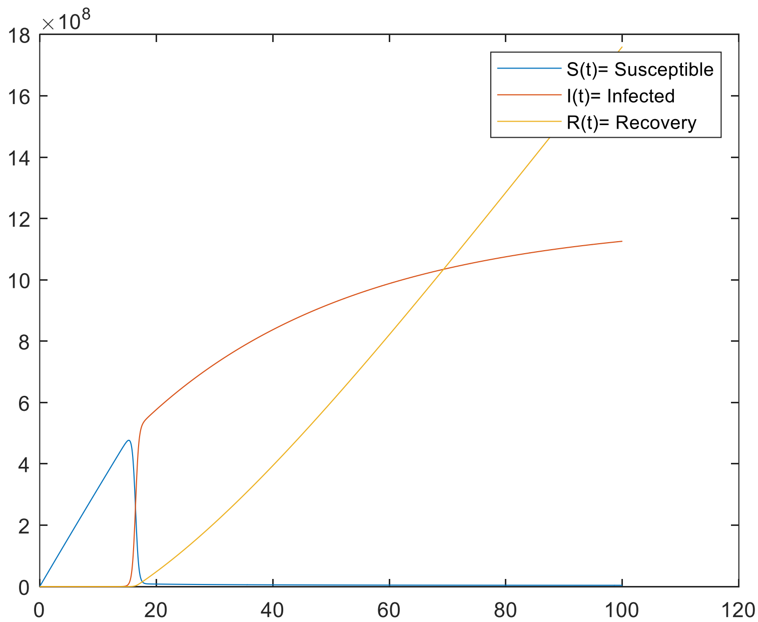

Figure 6: Total Number of Susceptible, Infected and Recovery Population using (SIR Model) of COVID-19.

According to Fig. 6, the number of susceptible decreased from $15.373 < t < 18.156$ months after achieving a high point, and then the susceptible population decreased to almost zero, we can say that because some populations are moved from the susceptible class to the infectious class. The infected group was increased until finally converging at subsequent times. We can say that because some populations moved to the recovered classes throughout many aspects, one of them is healing from COVID-19 disease. The recovery rate for the recovering class has grown from the first to the sixteenth month, indicating that the recovery rate has increased through time, indicating that more individuals are becoming healthy as previously. Analysing SIR models can be used to determine the transmission dynamics of the COVID-19 outbreak situation in any area by applying data simulation from certain areas we want. The simulation findings show that the COVID-19 transmission dynamic significantly influences the model and that COVID-19 in Malaysia reduces or might eliminate if the essential production number is fewer than 1, implying that the illness will not increase or will finally die out. The SIR model analysis and 4^{th} order Runge-Kutta technique is proven to provide a significant solution in this study.

CONCLUSION

The findings of the Susceptible, Infected and Recovery (SIR) model on the transmission dynamics of the COVID-19 outbreak by the Runge-Kutta 4^{th} order technique demonstrate that the daily transmission rate. It was obtained by fitting predicted data from the SIR model to real COVID-19 data from Malaysia, which we set to begin on 25 March 2020. The number of infected populations will be having an increment because of the amount of transmission of the COVID-19 from susceptible to infected. The number of infected populations will be reduced due to the rate of recovery of the transmission of the COVID-19 from infected to recovered. Furthermore, the COVID-19 outbreak transmission dynamic has a higher incubation period and recovery phase than the average data observed. Since large intervals are used, the motion of the suspected, infected and recovered categories can be seen. There is an increment in the susceptible, infected, and the most increased is in the recovered populations. However, the susceptible population will decline after reaching its peak. Nevertheless, the infected and recovered populations will move steadily at a later period, showing that the virus spread is getting slow. The numerical method used in this study which is 4^{th} order Runge-Kutta, could be applied to investigate numerical solutions in the SIR model and analyse the movement of the COVID-19 outbreak transmission dynamic because this numerical method gives the approximated value that shows the movement or the transmission of the viruses. Therefore, the presented model may be used by other nations, which is an essential addition to suggesting COVID-19 strategies.

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