OPTIMAL NIPAH VIRUS (NIV) SPREAD CONTROL DYNAMICS

ARINZE LUKE OZIOKO1∗, REMIGIUS OKEKE AJA2, SUNDAY EMMANUEL FADUGBA3, KEKANA MALESELA4, GODWIN CHRISTOPHER E. MBAH5

1Department of mathematics, Federal University Lokoja, Kogi State, Nigeria
2Department of Mathematics, Michael Okpara University of Agriculture, Umudike, Nigeria
3Department of Physical Sciences, Mathematics Programme, Landmark University, Omu-Aran, Nigeria
4Department of Mathematics and Statistics, Tshwane University of technology, Pretoria, South Africa
5Department of Mathematics, University of Nigeria, Nsukka, Nigeria

Copyright © 2023 the author(s). This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Abstract. In this work, we look at the vaccine and condom Nipah virus model using an optimum control analysis. We implemented measures to limit infection dissemination and control. We examine four distinct controls: personal protection, rapid testing, burying infected pigs, and therapy control. We construct an ideal control model and demonstrate the mathematical results using the suggested controls. The results of optimum control suggest that measures can be useful in decreasing infected individuals and increasing the health of society.

Keywords: Nipah virus; optimal control; numerical results; protection.

2020 AMS Subject Classification: 00A71,92B05, 68U20.

1. INTRODUCTION

The Nipah Virus (NiV) is a transmissible from animal virus which may trigger deadly encephalitis and serious lung conditions in humans. It is a contagious virus that primarily affects Pteropodidae fruit bats, but it can also impact swine and humans. During an epidemic among

∗Corresponding author
E-mail address: arinze.luke@fulokoja.edu.ng
Received June 08, 2023
Malaysian swine producers in 1999, the Nipah virus was detected. There have been no new cases recorded in Malaysia since 1999. It was discovered in Bangladesh in 2001, and outbreaks have occurred practically every year thereafter. East India has also been ravaged by the illness on a regular basis. The virus has been discovered in the recognized native reservoir (Pteropus bat species) as well as a variety of additional bat species in Cambodia, Ghana, Indonesia, Madagascar, the Philippines, and Thailand [14].

Humans are affected with the virus through interaction with sick animals especially pigs or their bodily secretions, or through ingestion of contaminated food items. Close contact with an infected person may result in from person to person spread, particularly in hospital settings. According to Tan et al [15], patients hospitalized to the University Hospital in Kuala Lumpur and their family members served as the study’s subjects. 110 people from 14 houses were analyzed. Asymptomatic Nipah infection was seen in 30 out of 110 (27%) of the household members.

Although no drugs or vaccines are presently available for treatment, a phase 1 clinical research of a Nipah virus vaccine candidate (HeV-sG-V) began in February 2020 [13]. The vaccine will be administered to normal individuals aged 18 to 49 to test its effectiveness and safety in triggering an immune response [13].

During NiV epidemics in South Asian nations, interactions between animals, people, and the environment were very important [2]. Numerous variables influence human-animal interactions, including prolonged droughts, reduced animal habitats as a result of deforestation, manmade fires that destroy forests in Indonesia, and pig rearing mixed with farmland. [1].

For the study of the dynamics of disease spread, researchers have developed mathematical models like the one in [7], [8], [6], which has changed our knowledge of these contagious illnesses and aided in the development of sufficient and effective countermeasures. Biswas investigated disease mechanisms by employing the SIR fundamental mathematical model. He investigated this model further and investigated potential control and avoidance techniques with an optimum solution [10], [9] and [3]. Sultana [4] used optimum control theory to create a quantitative study of Nipah viral infections. Control tactics in their work included raising consciousness and providing treatment. They proved the presence of optimum controls, and the ideal controls
are defined using Pontryagin’s utmost concept. According to the numerical modeling, the optimum control method is far more effective at reducing infectious people and the associated costs of both measures. Furthermore, Mondal et al[16] propose and evaluate a mathematical model for Nipah viral management with vital mechanics. They [11], [16] include the quarantine of contagious people based on the existence of isolation facilities alongside monitoring coverage. According to the numerical modeling, better sanitation and confinement of infectious people are sufficient to contain Nipah viral spread. As Nipah virus control plans, Omede et al [12] weighed avoidance measures to keep people in the vulnerable area from coming into contact with the virus, Nipah virus treatment for people in the area that is infectious compartment, and Nipah virus treatment for people in the curative area.

The fundamental purpose of this research is to investigate the four control techniques: personal prevention (pp), rapid testing, burying infected piglets, and therapy control in the vaccines and condoms Nipah virus model. This paper is structured as follows: Section 2, Methodology of NiV model. In Section 3, Existence of the optimal control of NiV. Section 4, optimal control numerical simulation. Section 5, discussion and conclusion.

2. Methodology of NiV Model

From the humans and pigs population, we have $S_p(t)$: the number of pigs who are not yet infected with the NiV at time $t$, but may get it if they come into contact with other infected pigs or eat contaminated fruits, $E_p(t)$: the number of pigs that have come into contact with the infectious agent or pathogen that causes the Nipah virus, $I_p(t)$: the number of pigs that are capable of transmitting the virus to others including human, $S(t)$: susceptible with respect to human beings, $S_v(t)$: the susceptible persons who are vaccinated, $S_u(t)$: the susceptible persons who are not yet vaccinated, $S_{vc}(t)$: the susceptible persons who are vaccinated and use condoms, $S_{vn}(t)$: the susceptible persons who are vaccinated and do not use condoms, $S_{uc}(t)$: the susceptible persons who are not yet vaccinated and use condoms, $S_{un}(t)$: the susceptible persons who are not yet vaccinated and do not care for condoms, $E(t)$: people that are in touch with the infectious agent (human and pigs) or pathogen that causes the Nipah virus, $I(t)$: people that are capable of transmitting the virus to others, $C(t)$: they are people who have been infected with the virus but do not develop any symptoms of the disease, and still carry and
transmit the virus to others, $I_i(t)$: they are isolated individuals undergoing treatment who are capable of transmitting the virus to others, $I_e(t)$: they are not isolated but undergoing treatment as individuals that are capable of transmitting the virus to others, $R(t)$: they are individuals who have recovered from the Nipah virus and are capable of contacting the virus again, $D(t)$: the bodies of those who died due to the virus.

We assume the following: Natural sickness recovery can take place because of powerful antibodies[12]. Casual touching of the dead bodies will expose the individuals to the virus [17]. There is an interaction between the farmer and the infectious pigs[5]. Since they are continuously watched, medical personnel safeguard themselves against the virus, and infection can happen in a therapy class, isolated individuals do not aid in the spread of NiV[12]. The general public has easy access to and can afford condoms, an infected isolation facility, and vaccinations[5]. After some time, people who have recovered become susceptible to infection once more.

**Table 2.1. Describe the Variables**

<table>
<thead>
<tr>
<th>parameters</th>
<th>Parameter Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda_p$</td>
<td>The proportion of new pigs introduced</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Exposure rate of pigs</td>
</tr>
<tr>
<td>$\rho$</td>
<td>The rate at which infected pigs become exposed</td>
</tr>
<tr>
<td>$\Lambda$</td>
<td>Human resource recruitment level</td>
</tr>
<tr>
<td>$\chi_1$</td>
<td>Rate of vulnerable non-vaccinated people</td>
</tr>
<tr>
<td>$\chi_2$</td>
<td>Vaccination coverage among vulnerable populations</td>
</tr>
<tr>
<td>$\eta_1$</td>
<td>The fraction of unvaccinated vulnerable people who use condoms</td>
</tr>
<tr>
<td>$\eta_2$</td>
<td>The fraction of unvaccinated vulnerable people who do not use condoms.</td>
</tr>
<tr>
<td>$\tau_1$</td>
<td>The fraction of vaccinated people who use condoms</td>
</tr>
<tr>
<td>$\tau_2$</td>
<td>The fraction of vaccinated vulnerable people who do not use condoms</td>
</tr>
<tr>
<td>$\Gamma_3$</td>
<td>Infection force on $S_{nc}$</td>
</tr>
<tr>
<td>$\Gamma_4$</td>
<td>Infection force on $S_{un}$</td>
</tr>
<tr>
<td>$\Gamma_1$</td>
<td>Infection force on $S_{vc}$</td>
</tr>
<tr>
<td>$\Gamma_2$</td>
<td>Infection force on $S_{vn}$</td>
</tr>
</tbody>
</table>
The rate at which an exposed population becomes infected

\( \theta \) The proportion of the exposed population who becomes a NiV carrier

\( \psi_1 \) Rate of isolation of infected people having treatment

\( \psi_2 \) Treatment rate of infected persons

\( \gamma_1 \) Recovery rate from the disease therapy class

\( \gamma_2 \) Recovery rate from the infectious isolated undergoing treatment class

\( \gamma_3 \) The NiV carrier recovery rate

\( \gamma_4 \) The infectious recovery rate

\( \epsilon \) Rate of susceptibility among recovered persons

\( \delta_1 \) Illness-related death rate in NiV-Carriers

\( \delta_2 \) Illness-related death rate in infectious population

\( \delta_3 \) Illness-related death rate in infectious isolated people undergoing treatment

\( \delta_4 \) Illness-related death rate in infectious people undergoing treatment

\( \delta_d \) Illness-related death rate in infectious pigs

\( \mu_d \) The rate at which deceased bodies are disposed of (burial/cremation)

\( \mu_p \) Pig mortality rate

\( \mu \) Natural death rate

We assume the following: Natural sickness recovery can take place because of powerful antibodies [12]. Casual touching of the dead bodies will expose the individuals to the virus [17]. There is an interaction between the farmer and the infectious pigs[5]. Since they are continuously watched, medical personnel safeguard themselves against the virus, and infection can happen in a therapy class, isolated individuals do not aid in the spread of NiV [12]. The general public has easy access to and can afford condoms, an infected isolation facility, and vaccinations[5]. After some time, people who have recovered become susceptible to infection once more.

The above formulations and assumptions result in the deterministic system of nonlinear ordinary differential equations that characterize the dynamics of Nipah virus infection spread in two groups.
\[
\frac{dS}{dt} = \Lambda - (\chi_1 + \chi_2 + \mu)S + \varepsilon R
\]
\[
\frac{dS_v}{dt} = \chi_2 S - (\tau_1 + \tau_2 + \mu)S_v
\]
\[
\frac{dS_u}{dt} = \chi_1 S - (\eta_1 + \eta_2 + \mu)S_u
\]
\[
\frac{dS_{vc}}{dt} = \tau_1 S_v - (\Gamma_1 + \mu)S_{vc}
\]
\[
\frac{dS_{vn}}{dt} = \tau_2 S_v - (\Gamma_2 + \mu)S_{vn}
\]
\[
\frac{dS_{uc}}{dt} = \eta_1 S_u - (\Gamma_3 + \mu)S_{uc}
\]
\[
\frac{dS_{un}}{dt} = \eta_2 S_u - (\Gamma_4 + \mu)S_{un}
\]
\[
\frac{dE}{dt} = \Gamma_2 S_v + \Gamma_4 S_u + \Gamma_3 S_{uc} + \Gamma_1 S_{vc} - (\mu + \theta + \kappa)E
\]
\[
\frac{dC}{dt} = \theta E - (\gamma_3 + \mu + \delta_1)C
\]
\[
\frac{dI}{dt} = \kappa E - (\psi_1 + \psi_2 + \mu + \delta_2 + \gamma_4)I
\]
\[
\frac{dI_t}{dt} = \psi_1 I - (\gamma_2 + \mu + \delta_3)I_t
\]
\[
\frac{dI_t}{dt} = \psi_2 I - (\gamma_1 + \mu + \delta_4)I_t
\]
\[
\frac{dR}{dt} = \gamma_2 I_t + \gamma_4 I + \gamma_1 I_t + \gamma_3 C - \mu R - \varepsilon R
\]
\[
\frac{dD}{dt} = \delta_4 I_t + \delta_3 I_t + \delta_1 C + \delta_2 I - \mu_d D
\]
\[
\frac{dS_p}{dt} = \Lambda_p - (\sigma + \mu_p)S_p
\]
\[
\frac{dE_p}{dt} = \sigma S_p - (\rho + \mu_p)E_p
\]
\[
\frac{dI_p}{dt} = \rho E_p - (\mu_p + \delta_p)I_p
\]

Such that
\[
\Gamma_1 = \beta_1 \left( \frac{a_1 I_p + a_2 C + a_3 I + a_4 I_t + a_5 D}{N_p} \right), \quad \Gamma_2 = \beta_2 \left( \frac{b_1 I_p + b_2 C + b_3 I + b_4 I_t + b_5 D}{N} \right).
\]
\[
\Gamma_3 = \beta_3 \left( \frac{q_1 I_p + q_2 C + q_3 I + q_4 I_t + q_5 D}{N_p} \right), \quad \Gamma_4 = \beta_4 \left( \frac{z_1 I_p + z_2 C + z_3 I + z_4 I_t + z_5 D}{N} \right).
\]
2.1. Optimal Control Procedure. The Nipah viral model is subjected to optimum management theory given in (2.1). We examine four distinct controls to reduce Nipah viral infection and further spread in the population. The following definition applies to these controls: The safety control $u_1$ calls for reducing interaction with contagious persons, including dead victims of the Nipah virus, cleaning hands frequently, using hand sanitizer, and wearing masks. Further, avoid meeting and limit their movement in areas with a high number of cases. Rapid testing of people in the vulnerable stage to detect Nipah virus carriers ($C$) and symptomatic individuals constitutes the second control $u_2$. To further reduce the infection, the people should be isolated or confined to their house after recognition through testing. The control $u_3$ is burying infected piglet. The fourth control $u_4$ is the therapy control. The use of Ribavirin and any other substances that can boast immune system especial different species of vegetables. Also bitter kola could also be very relevant. Following is a system of optimal control issue that may result from the talk above:

\[
\begin{align*}
\frac{dS}{dt} &= \Lambda - (\chi_1 + \chi_2 + \mu)S + \varepsilon R \\
\frac{dS_v}{dt} &= \chi_2 S - (\tau_1 + \tau_2 + \mu)S_v \\
\frac{dS_u}{dt} &= \chi_1 S - (\eta_1 + \eta_2 + \mu)S_u \\
\frac{dS_{vc}}{dt} &= \tau_1 S_v - (\Gamma_1 + \mu)S_{vc} \\
\frac{dS_{vn}}{dt} &= \tau_2 S_v - (\Gamma_2 + \mu)S_{vn} \\
\frac{dS_{uc}}{dt} &= \eta_1 S_u - (1 - u_1)\Gamma_3 S_{uc} - \mu S_{uc} \\
\frac{dS_{un}}{dt} &= \eta_2 S_u - (1 - u_1)\Gamma_4 S_{un} - \mu S_{un} \\
\frac{dE}{dt} &= \Gamma_2 S_{vn} + (1 - u_1)\Gamma_4 S_{un} + (1 - u_1)\Gamma_3 S_{uc} + \Gamma_1 S_{vc} - (u_2 + \mu + \theta + \kappa)E \\
\frac{dC}{dt} &= (u_2 + \theta)E - (u_4 + \gamma_3 + \mu + \delta_1)C \\
\frac{dI}{dt} &= \kappa E - (\psi_1 + \psi_2 + \mu + \delta_2 + \gamma_4 + u_4)I \\
\frac{dI_t}{dt} &= \psi_1 I - (u_4 + \gamma_2 + \mu + \delta_3)I_t
\end{align*}
\]
\[
\begin{align*}
\frac{dI_t}{dt} &= \psi_2 I - (u_4 + \gamma_1 + \mu + \delta_4)I_t \\
\frac{dR}{dt} &= (I_t + I_{it} + I)u_4 + \gamma_2 I_{it} + \gamma_4 I + \gamma_1 I_t + \gamma_3 C - \mu R - \varepsilon R \\
\frac{dD}{dt} &= \delta_1 I_t + \delta_2 I_{it} + \delta_1 C + \delta_2 - \mu_d D \\
\frac{dS_p}{dt} &= \Lambda_p - (1 - u_3)\sigma S_p - \mu_p S_p \\
\frac{dE_p}{dt} &= (1 - u_3)\sigma S_p - (\rho + \mu_p)E_p \\
\frac{dI_p}{dt} &= \rho E_p - (\mu_p + \delta_p)I_p
\end{align*}
\]

with the initial conditions \( S(0) \geq 0, S_u(0) \geq 0, S_v(0) \geq 0, S_{uc}(0) \geq 0, S_{wu}(0) \geq 0, S_w(0) \geq 0, S_{vn}(0) \geq 0, E(0) \geq 0, C(0) \geq 0, I(0) \geq 0, I_{it}(0) \geq 0, I_t(0) \geq 0, D(0) \geq 0, R(0) \geq 0, S_p(0) \geq 0, E_p(0) \geq 0, I_p(0) \geq 0 \)

Our goals are to decrease the overall number of contagious people in the community and the costs associated with protective gear, vaccine production and dissemination, quick testing, and treatment at predetermined intervals. We reduce the target function provided by,

\[(2.3)\]

\[
J(u_i, \Omega_1) = \int_0^T \left( A_1 E + A_2 C + A_3 I + A_4 I_{it} + A_5 I_t + A_6 D + \frac{1}{2} [k_1 u_1^2 + k_2 u_2^2 + k_3 u_3^2 + k_4 u_4^2] \right) dt
\]

where \( i = 1, 2, 3, 4 \), and \( T \) is final time, \( \Omega_1 \) stands for the collection of all contagious compartments, \( A_i, i = 1, \ldots, 6 \) represents the sections’ non-negative weight values \( E, C, I, I_{it}, I_t, D \) respectively and \( k_1, k_2, k_3, k_4 \) are the weight constant for the control variable \( u_1, u_2, u_3, u_4 \) respectively. The weights \( k_1, k_2, k_3, k_4 \) which are constant parameters for \( u_1, u_2, u_3, u_4 \) will standardized using the optimal control condition.

The variables defined above have bounds on Lebesgue integrable functions. We strive for optimum settings \( u_i^* \) for \( i=1,\ldots,4 \), such that \( J(u_i^*) = \min(J(u_i, \Omega_1)) \) where \( u_i \in U \) the control set defined as

\[(2.4)\]

\[
U = \{(u_i) : [\sigma, T] \rightarrow [0, 1], (u_i), is \ Lebesgue \ measureable\}
\]
We explain the terms in the integrand in (2.3) above as follows: The term $A_1 E + A_2 C + A_3 I + A_4 I_{it} + A_5 I + A_6 D$ indicates the expense involved with tracking infectious people. The term $k_1 u_1^2 + k_3 u_3^2$ reflects the expense of all kinds of protection against infectious people and pigs. The term $k_2 u_2^2$ reflects the expense of all types of rapid testing of exposed people. The term $k_4 u_4^2$ indicates the total expense of all kinds of therapy for all infected people in the infectious groups.

3. Existence of the Optimal Control for Nipah Virus Model

3.1. Existence of the State. From the equation (2.2), we have

\[
\frac{dN}{dt} = \Lambda - \mu S - \mu S_u - \mu S_v - \mu S_{uc} - \mu S_{un} - \mu S_{vn} - \mu E - \mu C - \delta_1 C - \mu I
\]
\[
- \delta_2 I - \mu I_{it} - \delta_3 I_{it} - \mu I_t - \delta_4 I_t - \mu R
\]
\[
= \Lambda - \mu N - \delta_4 I_t - \delta_1 C - \delta_3 I_{it} - \delta_2 I
\]

\[ (3.1) \leq \Lambda - \mu N(t), \]

(3.2)
\[
\frac{dD}{dt} = \delta_4 I_t + \delta_3 I_{it} + \delta_1 C + \delta_2 I - \mu_d D
\]

Solving (3.1), we obtain

\[ N(t) \leq \frac{\Lambda}{\mu} + \left( N(0) - \frac{\Lambda}{\mu} \right) e^{-\mu t} \]

(3.3)

where the $N(0) = N_0$ is the initial value of the total populations. As $t \rightarrow \infty$ in (3.3), the population size $N(t)$ approaches $\frac{\Lambda}{\mu}$, ie

\[ 0 \leq N(t) \leq \frac{\Lambda}{\mu} \]

\[ S(t) + S_u(t) + S_v(t) + S_{uc}(t) + S_{un}(t) + S_{vn}(t) + E(t) + C(t) + I(t) + I_{it}(t) + I_t(t) + R(t) \leq \frac{\Lambda}{\mu} \Rightarrow S(t) \leq \frac{\Lambda}{\mu}, \ldots, I(t) \leq \frac{\Lambda}{\mu}, I_{it}(t) \leq \frac{\Lambda}{\mu}, I_t(t) \leq \frac{\Lambda}{\mu}, \ldots, R(t) \leq \frac{\Lambda}{\mu} \] as $t \geq 0$. 

Therefore,
\[
\frac{dD}{dt} = \delta_4 I_t + \delta_3 I_{it} + \delta_1 C + \delta_2 I - \mu_d D
\]
(3.4)
\[
\leq (\delta_4 + \delta_3 + \delta_1 + \delta_2) \frac{\Lambda}{\mu} - \mu_d D
\]
implies \( D(t) \leq (\delta_4 + \delta_3 + \delta_1 + \delta_2) \frac{\Lambda}{\mu} \) and
\[
\frac{dN_p}{dt} = \Lambda_p - \mu_p S_p - \mu_p E_p - \mu_p I_p - \delta_p I_p
\]
(3.5)
\[
\leq \Lambda_p - \mu_p N_p(t) - \delta_p I_p
\]
implies \( N_p(t) \leq \frac{\Lambda_p}{\mu_p} \).

Finally the system (2.2) is bounded and the solutions exist.

3.2. Existence of the Objective Functional. Pontryagin’s optimal concept reduces the state system (2.2) to an issue of reducing the Lagrangian \( L \) and Hamiltonian \( H \) with regard to \((u_1, u_2, u_3, u_4)\) at each position. The integrand of the goal functional makes up the Lagrangian of the management problem, which is the Hamiltonian enhanced with penalty terms for control restrictions and is given by
\[
L = A_1 E + A_2 C + A_3 I + A_4 I_{it} + A_5 I + A_6 D + \frac{1}{2} [k_1 u_1^2 + k_2 u_2^2 + k_3 u_3^2 + k_4 u_4^2]
\]

We look for the lagrangian’s minimal number. This can be done by specifying the Hamiltonian \( H \) for the control problem, comprised of the integrand of the function with the goal and the result of the inner product of the right hand sides of the state equations and the co-state variables or adjoint variables \( \lambda_i, \ i = 1, \ldots, 17 \) with respect to state variable as
\[
H = A_1 E + A_2 C + A_3 I + A_4 I_{it} + A_5 I + A_6 D + \frac{1}{2} [k_1 u_1^2 + k_2 u_2^2 + k_3 u_3^2 + k_4 u_4^2]
\]
+ \( \lambda_1 \{A - (\chi_1 + \chi_2 + \mu)S + \varepsilon R\} \) + \( \lambda_2 \{\chi_2 S - (\tau_1 + \tau_2 + \mu)S_v\} \)
+ \( \lambda_3 \{\chi_1 S - (\eta_1 + \eta_2 + \mu)S_u\} \) + \( \lambda_4 \{\tau_1 S_v - (\Gamma_1 + \mu)S_{vc}\} \)
+ \( \lambda_5 \{\tau_2 S_v - (\Gamma_2 + \mu)S_{vn}\} \) + \( \lambda_6 \{\eta_1 S_u - (1 - u_1)\Gamma_3 S_{uc} - \mu S_{uc}\} \)
+ \( \lambda_7 \{\eta_2 S_u - (1 - u_1)\Gamma_4 S_{un} - \mu S_{un}\} \)
(3.6)
+ \lambda_8 \{ \Gamma_2 \varsigma + (1 - u_1)\Gamma_4 \varsigma\mu + (1 - u_1)\Gamma_3 \varsigma + \Gamma_1 \varsigma \theta + (u_2 + \mu + \theta + \kappa)E \} \\
+ \lambda_9 \{(u_2 + \theta)E - (u_4 + \gamma_3 + \mu + \delta_1)C \} + \lambda_{10} \{ \kappa E - (\psi_1 + \psi_2 + \mu + \delta_2 + \gamma_4 + u_4)I \} \\
+ \lambda_{11} \{ \psi_1 I - (u_4 + \gamma_2 + \mu + \delta_3)I_a \} + \lambda_{12} \{ \psi_2 I - (u_4 + \gamma_1 + \mu + \delta_4)I_t \} \\
+ \lambda_{13} \{ (I + I_t + I_u)u_4 + \gamma_2 I_{tt} + \gamma_4 I + \gamma_1 I_t + \gamma_3 C + u_2 C - \mu R - \varepsilon R \} \\
+ \lambda_{14} \{ \delta_4 I_t + \delta_3 I_{tt} + \delta_1 C + \delta_2 I - \mu_d D \} \\
+ \lambda_{15} \{ \Lambda_p - (1 - u_3)\sigma S_p + \mu_p S_p \} + \lambda_{16} \{ (1 - u_3)\sigma S_p - (\rho + \mu_p)E_p \} \\
+ \lambda_{17} \{ \rho E_p - (\mu_p + \delta_p)I_p \}

The system’s state and control variables \((2.2)\) have positive values. Convex and closed characterize the control set \(U\). The presence of optimal control is demonstrated by Corollary 4.1 in [18] because the integrand of the objective cost function \(U\) given by \((2.2)\) is a convex function of \((u_1, u_2, u_3, u_4)\) on the control set \(U\). As a result, there are positive integers \(\xi_1, \xi_2\) and \(\varsigma\) such that

\[
J(u_1, u_2, u_3, u_4) \geq \xi_1 \left( |u_1|^2 + |u_2|^2 + |u_3|^2 + |u_4|^2 \right)^{\varsigma} - \xi_2
\]

where \(\xi_1, \xi_2 > 0\), and \(\varsigma > 1\)

Since the answers are bounded, the state system’s Lipschitz condition is satisfied. Considering that the state variables are constrained, this proves the presence of an optimum control.

### 3.3. An Optimal Control’s Characteristics.

The essential criteria for Pontryagin’s Optimal Concept serves as the foundation for the important standards for optimal management [19]. The systems \((2.2)\) and \((2.1)\) are reduced by this idea. to the problem of reducing a Hamiltonian \(H\) pointwise with respect to the constraints \(u_i; i = 1, 2, 3, 4\). The set of adjoint equations can be derived using the correct partial derivatives of \(H\) with regard to the state variables.

**Theorem 3.1.** The given optimal controls \(u_i^*\) and solutions \(S(t)^*, S_v(t)^*, S_u(t)^*, S_v(t)^*, S_{un}(t)^*, S_{uc}(t)^*, S_{un}(t)^*, E(t)^*, C(t)^*, I(t)^*, I_{tt}(t)^*, I_t(t)^*, R(t)^*, D(t)^*, S_p(t)^*, E_p(t)^*, I_p^*\) of the control system \((4.409)-(4.425)\) that minimizes \(J(u_i^*)\) over \(U\). Then there exists adjoint variables \(\lambda_i\) satisfying

\[
\frac{\partial \lambda_i}{\partial t} = -\frac{\partial H}{\partial i}
\]
with the transversality conditions,

$$\lambda_i(T) = 0$$  \hspace{1cm} (3.9)

$$i = S(t), S_v(t), S_u(t), S_{vc}(t), S_{vn}(t), S_{wc}(t), S_{wm}(t), E(t), C(t), I(t), I_{it}(t), I_{i}(t), R(t),$$

$$D(t), S_p(t), E_p(t), I_p$$

The optimality condition is given by

$$\frac{\partial H}{du_i} = 0, \quad i = 1, 2, 3, 4$$  \hspace{1cm} (3.10)

Furthermore, we have the controls $u_i^*$,

$$u_1^* = \min \left\{ 1, \max \left[ 0, \frac{\lambda_{18} (S_{uc} \Gamma_3 + S_{un} \Gamma_4) - S_{uc} \lambda_6 \Gamma_3 - S_{un} \lambda_7 \Gamma_4}{k_1} \right] \right\}$$  \hspace{1cm} (3.11)

$$u_2^* = \min \left\{ 1, \max \left[ 0, \frac{E(\lambda_{18} - \lambda_9) - \lambda_{13} C}{k_2} \right] \right\}$$  \hspace{1cm} (3.12)

$$u_3^* = \min \left\{ 1, \max \left[ 0, \frac{S_p \sigma (\lambda_{16} - \lambda_{15})}{k_3} \right] \right\}$$  \hspace{1cm} (3.13)

$$u_4^* = \min \left\{ 1, \max \left[ 0, \frac{I_{17} (1 - u_1) (\Gamma_3 + \mu) - \lambda_{13} (I + I_{it} + I_{i})}{k_4} \right] \right\}$$  \hspace{1cm} (3.14)

Proof. The findings from the [18] cases provide proof that an optimal control issue exists. Differentiating $H$ with regard to each state variable results in the system ruling the adjoint variables. Consequently, the adjoint system is expressed as,

$$\lambda_1 = -\frac{\partial H}{\partial S} = \lambda_1 (\chi_1 + \chi_2 + \mu) - \chi_1 \lambda_3 - \chi_2 \lambda_2$$

$$\dot{\lambda}_2 = -\frac{\partial H}{\partial S_v} = \lambda_2 (\mu + \tau_1 + \tau_2) - \lambda_4 \tau_1 - \lambda_5 \tau_2$$

$$\dot{\lambda}_3 = -\frac{\partial H}{\partial S_u} = \lambda_3 (\eta_1 + \eta_2 + \mu) - \eta_1 \lambda_6 - \eta_2 \lambda_7$$

$$\dot{\lambda}_4 = -\frac{\partial H}{\partial S_{vc}} = \lambda_4 (\Gamma_1 + \mu) - \lambda_8 \Gamma_1$$

$$\dot{\lambda}_5 = -\frac{\partial H}{\partial S_{vn}} = \lambda_5 (\Gamma_2 + \mu) - \lambda_8 \Gamma_2$$

$$\dot{\lambda}_6 = -\frac{\partial H}{\partial S_{wc}} = \lambda_6 (1 - u_1) (\Gamma_3 + \mu) - \lambda_8 (1 - u_1) \Gamma_3$$
\begin{align*}
\dot{\lambda}_7 &= -\frac{\partial H}{\partial S_{un}} = \lambda_7 (1 - u_1) (\Gamma_4 + \mu) - \lambda_8 (1 - u_1) \Gamma_4 \\
\dot{\lambda}_8 &= -\frac{\partial H}{\partial E} = -A_1 - \lambda_{10} \kappa + \lambda_8 (\kappa + \mu + \theta + u_2) - \lambda_9 (\theta + u_2) \\
\dot{\lambda}_9 &= -\frac{\partial H}{\partial C} = -A_2 - \delta_1 \lambda_{14} - (\gamma_3 + u_4) \lambda_{13} \\
&\quad - \lambda_8 \left( \frac{\text{Suc}\beta_3 q_2 (1 - u_1)}{N} + \frac{\text{Sun}\beta_4 z_2 (1 - u_1)}{N} + \frac{\text{Svca}\beta_1 \lambda_4}{N} + \frac{\text{Svn}\beta_2 \lambda_5}{N} \right) + \lambda_9 (\delta_1 + \gamma_3 + u_4 + \mu) \\
&\quad + \frac{\text{Suc}\beta_3 \lambda_6 q_2 (1 - u_1)}{N} + \frac{\text{Sun}\beta_4 \lambda_{7} z_2 (1 - u_1)}{N} + \frac{\text{Svca}\beta_1 \lambda_4}{N} + \frac{\text{Svn}\beta_2 \lambda_5}{N} \\
\dot{\lambda}_{10} &= -\frac{\partial H}{\partial I} = -A_3 - \delta_2 \lambda_{14} - (\gamma_4 + u_4) \lambda_{13} + \lambda_1 (\delta_2 + \gamma_4 + u_4 + \mu + \psi_1 + \psi_2) - \lambda_{11} \psi_1 \\
&\quad - \lambda_{12} \psi_2 - \lambda_8 \left( \frac{\text{Suc}\beta_3 q_3 (1 - u_1)}{N} + \frac{\text{Sun}\beta_4 z_3 (1 - u_1)}{N} + \frac{\text{Svca}\beta_1 \lambda_4}{N} + \frac{\text{Svn}\beta_2 \lambda_5}{N} \right) \\
&\quad + \frac{\text{Suc}\beta_3 \lambda_6 q_3 (1 - u_1)}{N} + \frac{\text{Sun}\beta_4 \lambda_{7} z_3 (1 - u_1)}{N} + \frac{\text{Svca}\beta_1 \lambda_4}{N} + \frac{\text{Svn}\beta_2 \lambda_5}{N} \\
\dot{\lambda}_{11} &= -\frac{\partial H}{\partial I_p} = -A_4 - \delta_3 \lambda_{14} - (\gamma_2 + u_4) \lambda_{13} + \lambda_{11} (\delta_3 + \gamma_2 + u_4 + \mu) \\
\dot{\lambda}_{12} &= -\frac{\partial H}{\partial I} = -A_5 - \delta_4 \lambda_{14} - (\gamma_1 + u_4) \lambda_{13} + \lambda_{12} (\delta_4 + \gamma_1 + u_4 + \mu) \\
&\quad - \lambda_8 \left( \frac{\text{Suc}\beta_3 q_4 (1 - u_1)}{N} + \frac{\text{Sun}\beta_4 z_4 (1 - u_1)}{N} + \frac{\text{Svca}\beta_1 \lambda_4}{N} + \frac{\text{Svn}\beta_2 \lambda_5}{N} \right) \\
&\quad + \frac{\text{Suc}\beta_3 \lambda_6 q_4 (1 - u_1)}{N} + \frac{\text{Sun}\beta_4 \lambda_{7} z_4 (1 - u_1)}{N} + \frac{\text{Svca}\beta_1 \lambda_4}{N} + \frac{\text{Svn}\beta_2 \lambda_5}{N} \\
\dot{\lambda}_{13} &= -\frac{\partial H}{\partial R} = \epsilon \lambda_1 + \lambda_{13} (\epsilon + \mu) \\
\dot{\lambda}_{14} &= -\frac{\partial H}{\partial D} = -A_6 + \lambda_{14} \mu_3 - \lambda_8 \left( \frac{\text{Suc}\beta_3 q_5 (1 - u_1)}{N} + \frac{\text{Sun}\beta_4 z_5 (1 - u_1)}{N} + \frac{\text{Svca}\beta_1 \lambda_4}{N} + \frac{\text{Svn}\beta_2 \lambda_5}{N} \right) \\
&\quad + \frac{\text{Suc}\beta_3 \lambda_6 q_5 (1 - u_1)}{N} + \frac{\text{Sun}\beta_4 \lambda_{7} z_5 (1 - u_1)}{N} + \frac{\text{Svca}\beta_1 \lambda_4}{N} + \frac{\text{Svn}\beta_2 \lambda_5}{N} \\
\dot{\lambda}_{15} &= -\frac{\partial H}{\partial S_p} = \lambda_{15} (\mu_2 + \sigma (1 - u_3)) - \lambda_{16} \sigma (1 - u_3) \\
\dot{\lambda}_{16} &= -\frac{\partial H}{\partial E_p} = \lambda_{16} (\mu_2 + \rho) - \lambda_{17} \rho \\
\dot{\lambda}_{17} &= -\frac{\partial H}{\partial I_p} = \lambda_{17} (\delta_5 + \mu_2) - \lambda_8 \left( \frac{\text{Suc}\beta_3 q_1 (1 - u_1)}{N p} + \frac{\text{Sun}\beta_4 z_1 (1 - u_1)}{N p} + \frac{\text{Svca}\beta_1 \lambda_4}{N p} + \frac{\text{Svn}\beta_2 \lambda_5}{N p} \right) \\
&\quad + \frac{\text{Suc}\beta_3 \lambda_6 q_1 (1 - u_1)}{N p} + \frac{\text{Sun}\beta_4 \lambda_{7} z_1 (1 - u_1)}{N p} + \frac{\text{Svca}\beta_1 \lambda_4}{N p} + \frac{\text{Svn}\beta_2 \lambda_5}{N p} \\
\end{align*}

With the transversality conditions at time $T$: $\lambda_1(T) = \lambda_2(T) = \ldots = \lambda_{17}(T) = 0$
For \( t \in [0, T] \), the optimal controls \( u_1, u_2, u_3, \) and \( u_4 \) can be solved from the optimality condition

\[
\frac{\partial H}{\partial u_i} = 0, \quad i = 1, 2, 3, 4
\]

\[
\frac{\partial H}{\partial u_1} = \text{Suc}\lambda_6\Gamma_3 + \text{Sun}\lambda_7\Gamma_4 + 1.0k_1u_1 - \lambda_8(Suc\Gamma_3 + \text{Sun}\beta_3) = 0
\]

\[
\frac{\partial H}{\partial u_2} = C\lambda_13 - E\lambda_8 + E\lambda_9 + 1.0k_2u_2 = 0
\]

\[
\frac{\partial H}{\partial u_3} = Sp\lambda_{15}\sigma - Sp\lambda_{16}\sigma + 1.0k_3u_3 = 0
\]

\[
\frac{\partial H}{\partial u_4} = -C\lambda_9 - I\lambda_{10} - It\lambda_{11} - It\lambda_{12} + 1.0k_4u_4 + \lambda_{13}(I + It + It) = 0
\]

where

\[
\Gamma_3 = \beta_3\left(\frac{Ipq_1}{Np} + \frac{Cq_2 + Dq_5 + Itq_3 + Itq_4}{N}\right)
\]

\[
\Gamma_4 = \beta_4\left(\frac{Ipz_1}{Np} + \frac{Cz_2 + Dz_5 + Iz_3 + Itz_4}{N}\right)
\]

Substituting \( u_1 = u_1^*, u_2 = u_2^*, u_3 = u_3^*, u_4 = u_4^* \)

and solving for the optimal control \((u_1^*, u_2^*, u_3^*, u_4^*)\) we obtain

\[
u_1^* = \frac{\lambda_8(Suc\Gamma_3 + \text{Sun}\Gamma_4) - \text{Suc}\lambda_6\Gamma_3 - \text{Sun}\lambda_7\Gamma_4}{k_1}
\]

\[
u_2^* = \frac{E(\lambda_8 - \lambda_9) - \lambda_{13}C}{k_2}
\]

\[
u_3^* = \frac{Sp\sigma(\lambda_{16} - \lambda_{15})}{k_3}
\]

\[
u_4^* = \frac{I\lambda_{10} + I_6\lambda_{11} + I_7\lambda_{12} - \lambda_{13}(I + It + It)}{k_4}
\]

Hence, the required optimal control condition is obtained as

\[
u_1^* = \min \left\{ 1, \max \left\{ 0, \frac{\lambda_8(Suc\Gamma_3 + \text{Sun}\Gamma_4) - \text{Suc}\lambda_6\Gamma_3 - \text{Sun}\lambda_7\Gamma_4}{k_1} \right\} \right\}
\]

\[
u_2^* = \min \left\{ 1, \max \left\{ 0, \frac{E(\lambda_8 - \lambda_9) - \lambda_{13}C}{k_2} \right\} \right\}
\]

\[
u_3^* = \min \left\{ 1, \max \left\{ 0, \frac{Sp\sigma(\lambda_{16} - \lambda_{15})}{k_3} \right\} \right\}
\]
\[ u_4^* = \min \left\{ 1, \max \left[ 0, \frac{I\lambda_{10} + I_t\lambda_{11} + I_t\lambda_{12} - \lambda_{13}(I + I_t + I_{tt})}{k_4} \right] \right\} \]

It is discovered that the optimality requirements derived by considering the derivatives of the Hamiltonian (3.6) with regard to the controls only hold in the innermost regions of the control set \( U \).

4. **Optimal Control Model Numerical Simulations**

The Python programming language is used in this part to implement numerical answers to the optimum system. We looked at four factors that rely on the neighbors of the state variables: \( u_1, u_2, u_3, \) and \( u_4 \). We run the model both with and without supervision, and then we contrast the outcomes. Because the limits are not completely effective, we took into account their number values between zero(0) and one(1): \( u_1, u_2, u_3, \) and \( u_4 \). The parameter values used in the models are displayed in Tables 4.1 and 4.2. The visually optimized system’s numerical answer, obtained using Python software, is displayed below. Unlike state variables, which have starting conditions, adjoint variables have final conditions \([5], [9]\).
Figure 4.1. The solution of the model
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi_1$</td>
<td>0.33</td>
<td>Estimated</td>
</tr>
<tr>
<td>$\chi_2$</td>
<td>0.62</td>
<td>[5]</td>
</tr>
<tr>
<td>$\theta$</td>
<td>0.486</td>
<td>[5]</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>0.715</td>
<td>[5]</td>
</tr>
<tr>
<td>$\tau_1$</td>
<td>0.008</td>
<td>Estimated</td>
</tr>
<tr>
<td>$\tau_2$</td>
<td>0.019</td>
<td>Estimated</td>
</tr>
<tr>
<td>$\eta_1$</td>
<td>0.45</td>
<td>Estimated</td>
</tr>
<tr>
<td>$\eta_2$</td>
<td>0.39</td>
<td>Estimated</td>
</tr>
<tr>
<td>$\psi_1$</td>
<td>0.825</td>
<td>Estimated</td>
</tr>
<tr>
<td>$\psi_2$</td>
<td>0.342</td>
<td>Estimated</td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>0.8</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$\gamma_2$</td>
<td>0.5</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$\gamma_3$</td>
<td>0.09</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$\gamma_4$</td>
<td>0.1</td>
<td>[9]</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>0.1134</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>0.3969</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>0.4455</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>0.7209</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$\delta_1$</td>
<td>0.02</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.56</td>
<td>[5]</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>0.75</td>
<td>[5]</td>
</tr>
</tbody>
</table>

**Table 4.1.** Description of the parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta_2$</td>
<td>0.15</td>
<td>[9]</td>
</tr>
<tr>
<td>$\delta_3$</td>
<td>0.0171</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$\delta_4$</td>
<td>0.2</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$a_1$</td>
<td>0.58</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$a_2$</td>
<td>0.513</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$a_3$</td>
<td>0.486</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$a_4$</td>
<td>0.513</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$a_5$</td>
<td>0.000288</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$b_1$</td>
<td>0.69</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$b_2$</td>
<td>0.522</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$b_3$</td>
<td>0.513</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$b_4$</td>
<td>0.504</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$b_5$</td>
<td>0.000324</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$q_1$</td>
<td>0.75</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$q_2$</td>
<td>0.4617</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$q_3$</td>
<td>0.531</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$q_4$</td>
<td>0.513</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$q_5$</td>
<td>0.000648</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>0.03</td>
<td>Estimated</td>
</tr>
<tr>
<td>$z_2$</td>
<td>0.4374</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$z_3$</td>
<td>0.504</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$z_4$</td>
<td>0.513</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$z_5$</td>
<td>0.000648</td>
<td>Inferred from [9]</td>
</tr>
<tr>
<td>$\mu_p$</td>
<td>0.00081</td>
<td>Estimated</td>
</tr>
<tr>
<td>$\mu$</td>
<td>0.0003421</td>
<td>[17]</td>
</tr>
</tbody>
</table>

**Table 4.2.** Description of the parameter
Figure 4.2. Simulations Showing The Effect of Controls $u_1, u_2, u_3, u_4$ on Infectious Human Population $I$
(A) Protection control
\[ u_1 \neq 0, u_2 = u_3 = u_4 = 0 \]

(B) Rapid testing \( u_2 \neq 0 \), \( u_1 = u_3 = u_4 = 0 \)

(C) Burying infected pigs \( u_3 \neq 0, u_1 = u_2 = u_4 = 0 \)

(D) Therapy control \( u_4 \neq 0, u_1 = u_3 = u_2 = 0 \)

(E) Combing controls \( u_2 = u_1 = u_3 = u_4 \neq 0 \)

**Figure 4.3.** Simulations Showing The Effect of Controls \( u_1, u_2, u_3, u_4 \) on NiV carriers (Asymptotic) Population C
(A) Protection control
\[ u_1 \neq 0, u_2 = u_3 = u_4 = 0 \]

(B) Rapid testing \( u_2 \neq 0 \), \( u_1 = u_3 = u_4 = 0 \)

(C) Burying infected pigs \( u_3 \neq 0, u_2 = u_4 = 0 \)

(D) Therapy control \( u_4 \neq 0, u_1 = u_3 = u_2 = 0 \)

(E) Combing controls \( u_2 = u_1 = u_3 = u_4 \neq 0 \)

Figure 4.4. Simulations Showing The Effect of Controls \( u_1, u_2, u_3, u_4 \) on Dead bodies Population I
Figure 4.1 depicts the schematic solutions of the model system. Figures 4.1(A) and 4.1(C) plainly show the importance of vaccine in a vulnerable community. Furthermore, figure 4.1(C) shows the fact that combining vaccine and condom use are beneficial management strategy for reducing NiV transmission. Furthermore, as demonstrated in figure 4.1(D), asymptomatic people are more infectious than symptomatic persons. This is because infectious people are more likely to go for healthcare assistance and be diagnosed with the illness, which can help hinder further spread of the disease through treatment or isolation measures, whereas asymptomatic people are more likely to interact with others without taking precautions or visiting a doctor because they do not show symptoms figure 4.1(E). This shows that, without vaccination and the use of condom, so many people are exposed to disease

Figures 4.2, 4.3 and 4.4 depict the impact of various control measures, including therapy controls, burying sick piglets, fast testing, and protection, on the infectious population $I$ and NiV carriers (asymptomatic) population $C$, respectively. Each measure helps to contain the spread of NiV by lowering the population’s proportion of NiV carriers (asymptomatic) and infectious individuals and dead bodies population. However, as shown in figure 4.2(E), 4.3 (e) and 4.4 (e), there is a substantial effect when combining the four controls at once. Such results are also experienced when apply to the exposed $E$ as it drastically reduces the exposed individuals.

4.1. Conclusion and Recommendation. Public health policymakers, especially those in Cambodia, Ghana, Indonesia, Madagascar, the Philippines, and Thailand who are at risk for infection due to confirmation that the virus has been discovered in known natural reservoirs (Pteropus bat species) and many other bat species, will benefit from the availability of methods that can be used to determine the best way to stop the spread of Nipah Virus [14].

In this study, we investigated the optimal combination of personal protection, quick testing, burying sick pigs, and therapy control methods to restrict infection spread in the vaccine and condom Nipah virus model. The goal function of the optimal control issue was then defined. We create a vaccine and condom Nipah virus model and display the pictorial results. The four control strategy have been examined in the form of personal protection control(prevention) which involves minimizing the contact among the infectious people including death body of
Nipah virus individuals, restrict traveling where the cases are high, washing hands regularly using sanitizer and masks. Secondly, rapid testing of individuals to identify the Nipah virus carriers (C) and the infectious individuals for isolation and treatment. Thirdly, is burying sick pigs and finally the therapy control. We explored the presence of optimum control and then used the Hamiltonian and the Pontryagin’s maximum principle to accomplish our goal. A contrast between a control plan with and without one is being watched. The impact of control factors is very noticeable in decreasing the number of infected people and controlling disease dynamics. The models show that the optimum combination of the four controls is very important for Nipah virus eradication. However, we recommend fast production of vaccine and its implementation with the use of condom.

**Conflict of Interests**

The authors declare that there is no conflict of interests.

**References**


