Education

Lassa fever model with variability in susceptibility due to awareness level

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Abstract

This paper modifies a mathematical model for the transmission dynamics of Lassa fever that accounted for awareness level due susceptibility. The modified model classifies the susceptible individuals by their level of Lassa fever awareness and further expands the number of key factors that can affect the Lassa fever dynamics. The effect of these factors on the associated reproduction number of the model is considered. The model is analysed by using stability theory of differential equations. The model analysis shows that the spread of Lassa fever disease can be controlled by using awareness programmes. The simulation analysis of the model confirms the analytical results.

Keywords: infectious disease; lassa fever; awareness level; modelling; stability

Introduction

Infectious diseases have always been a major public health threat to human life and health. We face the challenge of Lasa fever (LF) recently. LF is an acute viral illness cause by Lassa virus which belongs to the member of Arenavirus family. The disease was first described in the 1950s and the virus was identified in 1969, when two missionary nurses died from it in the town of Lassa in Borno state, Nigeria [2]. Lassa fever is endemic in West African countries such as Guinea, Liberia, Sierra Leone and Nigeria. The animal host of the Lassa virus is the rodents called Mastomys Natalensis [3]. Lassa fever can be transmitted through ingestion of food that is contaminated with infected rodent's saliva, urine or excreta, inhalation of the aerosol as occurs during the sweeping of an area where the droppings are present, contaminated needles or exposure to an infected aerosol in health care setting and person-to-person transmission occurs through body fluid exchange [10]. The symptoms of LF take up to three weeks to manifest [1]. They start with a lower fever, tiredness, body ache, sore throat and headache, nausea, vomiting and even diarrhea, high fever, swelling of the face, bleeding from the eyes or nose, breathing difficulties, severe pain in the back, chest and abdomen, etc. [4]. There is no approved vaccine for Lassa fever but it can be treated using Ribavirin which is effective during early stage of infectiousness [7]. Even though fatality is high, LF is still preventable especially through public health education awareness.

Effective public health education is a cornerstone in the primary prevention and control of infectious disease and can reduce the social burden of the disease [6]. In recent years, with the impact of public health education on epidemic diseases, many mathematical models have been proposed, which focus on studying the impact of control mechanisms on LF, by either stochastic differential equation model or a deterministic model. However, these models did not provide in-depth information on variability in susceptibility due to awareness level has been published. Awareness is the ability to directly know and perceive, to feel, or to be cognizant of events. More broadly, it is the state of being conscious of something. Another definition describes it as a state wherein a subject is aware of some information when that information is directly available to bring to bear in the direction of a wide range of behavioural processes [8]. The concept is often synonymous to consciousness and is also understood as being consciousness itself [9]. The states of awareness are also associated with the states of experience so that the structure represented in awareness is mirrored in the structure of experience. In general, awareness may also refer to public or common knowledge or understanding about a social, scientific, or political issue, and hence many movements try to foster awareness of a given subject, that is, raising awareness. Examples include AIDS or Lassa fever awareness. In this context, awareness would mean level of education (knowledge or consciousness) about Lassa fever disease and its preventive measures. Here, we will be based on the model of Obasi and Mbah [6] and build a new compartment model that takes into account the effect of awareness level, discuss how this can affect the spread of the LF epidemic disease.

2. The Model Formulation

The original idea of this model was partially motivated by the work of [6]. In this control model we assumed that susceptible individuals are divided into two groups depending on their level of education/awareness of the disease (any treatment policy); the low level of education (high risk) group, S_{h1} and the high level of education (low risk) group, S_{h2}. The S_{h1} class is educated at the per capita rate a and thereafter move into the S_{h2} class. Lassa virus can invade the S_{h1} and S_{h2} classes, depending on the efficacy of the education programme. The programme is assumed to reduce the likelihood of infection by a factor of $\partial(0 \le \partial \le 1)$. The case $\partial = 0$ signifies a completely

effective education programme, while $\partial = 1$ models the situation where the education programme is totally ineffective. It was further assumed that the education programme produces temporary immunity at the per capital rate b. Hence, b measures the rate at which those in the S_{h2} class return to the S_{h1} due to forgetfulness caused by lack of continuous exposure to the enlightenment programme while disease persists in the community. Thus, the Lassa fever model with variability in susceptibility due to awareness level is given in the following system of equations:

$$\begin{cases} \dfrac{dS_{h1}}{dt} = \Lambda_h + \xi\phi(1-\nu)I_h + \rho\psi R_h - \lambda_h S_{h1} + bS_{h2} - (\mu_h + a)S_{h1} \\ \dfrac{dS_{h2}}{dt} = (1-\xi)\phi(1-\nu)I_h + (1-\rho)\psi R_h - \partial\lambda_h S_{h2} + aS_{h1} - (\mu_h + b)S_{h2} \\ \dfrac{dE_h}{dt} = \lambda_h S_{h1} + \partial\lambda_h S_{h2} - (\kappa + \mu_h)E_h \\ \dfrac{dI_h}{dt} = \kappa E_h - (\phi + \delta + \mu_h)I_h \\ \dfrac{dR_h}{dt} = \phi\nu I_h - (\psi + \mu_h)R_h \\ \dfrac{dS_r}{dt} = \Lambda_r - \lambda_r S_r + \varphi R_r - \mu_r S_r \\ \dfrac{dI_r}{dt} = \lambda_r S_r - (\omega + \mu_r)I_r \\ \dfrac{dR_r}{dt} = \omega I_r - (\varphi + \mu_r)R_r \end{cases} \quad (1)$$

where $\lambda_h = \beta_1\sigma I_r + \beta_2\varepsilon I_h + \eta(1-e^{-rt})$; $\lambda_r = \beta_3\vartheta I_r$ is the force of infection. The description of the state variables and parameters of the model is shown in Tables 1 and 2.

Table 1: Description of the state variables of the model

Variable	Description
S_{h1}	Low level of education (high risk) susceptible group
S_{h2}	High level of education (low risk) susceptible group
E_h	Number of Exposed humans
I_h	Number of Infectious humans
R_h	Number of Recovered humans
S_r	Number of Susceptible rodents
I_r	Number of Infectious rodents
R_r	Number of Recovered rodents

Table 2: Description of the parameters of the basic Lassa fever model

Parameters	Description
Λ_h	Recruitment level of humans
Λ_r	Recruitment level of rodents
δ	Per capita Lassa-induced death rate
ψ	Recovered human loss of immunity
ϕ	Natural individual recovery
β_1	Transmission rate per contact by an infectious rodent
β_2	Transmission rate per contact by an infective through sexual activity
β_3	Transmission rate per contact by an infected rodent
η	Relative infectiousness of individuals with aerosol
μ_h	Natural mortality rate for humans
μ_r	Natural mortality rate for rodents
κ	Progression rate of human from exposed to infected
σ	Contact rate of rodent per human per unit time
ϑ	Relative human-to-rodent transmissibility of infected rodents
ε	Relative human-to-human transmissibility of infected humans
∂	Efficacy of the education programme
a, b	Immunity measures

ω	Recovery rate of rodents
φ	Recovered rodent loss of immunity
N_h	Total population of humans
N_r	Total population of rodents

2.1 Basic Properties of the Model

Since the model (1) monitors human population, all its associated parameters and state variables are assumed to be non-negative for all $t \geq 0$. Before analysing the model, it is instructive to show that the state variables of the model remain non-negative for all non-negative initial conditions. Thus, we claim the following result.

Theorem 1: Let the initial data be $S_{h1}(0), S_{h2}(0), E_h(0), I_h(0), R_h(0), S_r(0), I_r(0), R_r(0)$ be non-negative. Then, the solutions $(S_{h1}, S_{h2}, E_h, I_h, R_h, S_r, I_r, R_r)$ of model (1) are positive and bounded for all $t > 0$, whenever they exists.

Proof

Suppose $S_{h1}(0) \geq 0$. The first equation of system (1) can be written as:

$$\frac{d}{dt}\left[S_{h1}(t)\eta(t)\right] = \Lambda_h \eta(t),$$

where $\eta(t) = \exp\left(\int_0^t \left[\lambda_h(S_{h1}) + \mu_h\right] dS_{h1}\right) > 0$ is the integrating factor. Hence, integrating this last relation with respect to t, we have

$$S_{h1}(t)\eta(t) - S_{h1}(0) = \int_0^t \Lambda_h \eta(S_{h1}) dS_{h1},$$

so that the division of both side by $\eta(t)$ yields

$$S_{h1}(t) = \left[S_{h1}(0) - \int_0^t \Lambda_h \eta(S_{h1}) dS_{h1}\right] \times \eta^{-1}(t) > 0.$$

The same arguments can be used to prove that $S_{h2}, E_h(t), I_h(t), R_h(t), S_r(t), I_r(t), R_r(t) \geq 0$ for all $t > 0$.

Furthermore, let $N = S_{h1} + S_{h2} + E_h + I_h + R_h$. Then,

$$\begin{aligned}
&\dot{N}(t) = \dot{S}_{h1} + \dot{S}_{h2} + \dot{E}_h + \dot{I}_h + \dot{R}_h \\
&= \Lambda_h + \xi\phi(1-\nu)I_h + \rho\psi R_h - \lambda_h S_{h1} + bS_{h2} - (\mu_h + a)S_{h1} + (1-\xi)\phi(1-\nu)I_h + (1-\rho)\psi R_h - \lambda_h S_{h2} + aS_{h1} - (\mu_h + b)S_{h2} \\
&+ \lambda_h S_{h1} + \partial\lambda_h S_{h2} - (\kappa + \mu_h)E_h + \kappa E_h - (\phi + \delta + \mu_h)I_h + \phi\nu I_h - (\psi + \mu_h)R_h \\
&\leq \Lambda_h - \mu_h N_h - \delta I_h, \ \delta = 0
\end{aligned}$$

This implies that as $t \to \infty, \sup N_h \leq \frac{\Lambda_h}{\mu_h}$. Also from (1), we have that as: $t \to \infty, \sup S_r(t) \leq \frac{\Lambda_r}{\mu_r}$.

This completes the proof.

Combining Theorem 1 with the trivial existence and uniqueness of a local solution for the model (1), we have established the following theorem which ensures the mathematical and biological well-posedness of system (1).

Theorem 2: The dynamics of model (1) is a dynamical system in the biological feasible compact set

$$\Gamma := \left\{(S_{h1}, S_{h2}, E_h, I_h, R_h, S_r, I_r, R_r) \in \mathbb{R}_+^8 : N_h \leq \frac{\Lambda_h}{\mu_h}, N_r \leq \frac{\Lambda_r}{\mu_r}\right\} \quad (2)$$

3. Reproduction Number and LAS of the DFE

The model (1) has a disease-free equilibrium (DFE), obtained by setting the right hand sides of the equations in the model to zero, given by

$$\xi_0 = \left(S_{h1}^0, S_{h2}^0, E_h^0, I_h^0, R_h^0, S_r^0, I_r^0, R_r^0\right) = \left(\frac{\Lambda_h}{T-H}, \frac{a}{G}\left(\frac{\Lambda_h}{T-H}\right), 0, 0, 0, \frac{\Lambda_r}{\mu_r}, 0, 0\right) \quad (3)$$

Where,

$$G = \eta\partial\left(1-e^{-rt}\right) + \mu_h + b, \ H = \eta\left(1-e^{-rt}\right) + \mu_h + a, \ T = \frac{ab}{G}$$

The stability of ξ_0 can be established using the next generation operator method on the system (1). Using the notations in [6], the matrices F and V, for the new infection terms and the remaining transfer terms respectively, are given by

$$F = \begin{pmatrix} 0 & \beta_2\varepsilon S_{h1}^0 + \beta_2\varepsilon\partial S_{h2}^0 & \beta_1\sigma S_{h1}^0 + \beta_1\sigma\partial S_{h2}^0 \\ 0 & 0 & 0 \\ 0 & 0 & \beta_3\vartheta S_r^0 \end{pmatrix}$$

and

$$V=\begin{pmatrix}(\kappa+\mu_h) & 0 & 0\\ -\kappa & (\phi+\mu_h+\delta) & 0\\ 0 & 0 & (\omega+\mu_r)\end{pmatrix}$$

In the calculation of matrices F and V, we took the infection variables to be E_h, I_h and I_r as explained in [6]. Thus

$$R_{alc}=R_h+R_r=\frac{\beta_2\kappa\varepsilon\left(S_{h1}^0+\partial S_{h2}^0\right)}{(\kappa+\mu_h)(\phi+\mu_h+\delta)}+\frac{\beta_3\vartheta\Lambda_r}{\mu_r(\omega+\mu_r)} \quad (4)$$

where R_{alc} is obtained from $\rho\left(FV^{-1}\right)$ with ρ being the spectral radius of the matrix FV^{-1}. The following result follow from Theorem 2 in [6]:

Lemma 1: The DFE of the model (1), ξ_0, is locally asymptotically stable if $R_{alc}<1$ and unstable if $R_{alc}>1$. The threshold quantity R_{alc} is the effective reproduction number under awareness campaign control for the Lassa fever model. Biologically speaking, Lemma (1) implies that Lassa fever can be eliminated from the community (when $R_{alc}<1$) if the initial sizes of the subpopulation of the model are in the basin of attraction of ξ_0 in the presence of awareness campaign.
Assuming the of presence of awareness campaign can reduce the basic reproduction number R_0 by a factor q, i.e.

$R_{alc}=(1-q)R_0$, we obtain that

$$\frac{R_{alc}}{R_0}=\frac{1}{T-H}\left(1+\frac{\partial a}{G}\right)\left(\eta\left(1-e^{-rt}\right)+\mu_h\right)=0.07001\Rightarrow R_{alc}=(1-q)R_0$$

$$\therefore 1-q=0.07001\Rightarrow q=0.9299$$

Thus, introduction of awareness campaign significantly reduces the transmission of LF required for successful eradication of the disease (requirement of at least 92.9% effectiveness). This means that the awareness reproduction number R_{alc} is 92.9% smaller than the basic reproduction number R_0, indicating that introduction of awareness campaign as a control strategy is 92.9% effective in reducing LF transmission. This model predicts that awareness campaign control can reduce the population level transmission by up to 92.9% alone without existing interventions.

Theorem 3: Model (1) has a unique endemic (positive) equilibrium when (special case, $\psi=\eta=\phi=0$) whenever $R_{iqc}>1$.

To establish the existence of endemic equilibria of model (1), for the special case $\psi=\eta=\phi=0$ let $\xi_1=\left(S_{h1}^*,S_{h2}^*,E_h^*,I_h^*,R_h^*,S_r^*,I_r^*,R_r^*\right)$ represent any arbitrary endemic equilibrium of model (1). The equations in (1), with $\psi=\eta=\phi=0$, are solved in terms of the force of infection at the steady state to give

$$\begin{aligned}
S_{h1}^*&=\frac{\Lambda_h\left(\partial\lambda_h^*+\mu_h+b\right)}{\left(\lambda_h^*+\mu_h+a\right)\left(\partial\lambda_h^*+\mu_h+b\right)-ab},\\
S_{h2}^*&=\frac{a\Lambda_h}{\left(\lambda_h^*+\mu_h+a\right)\left(\partial\lambda_h^*+\mu_h+b\right)-ab},\\
E_h^*&=\frac{\Lambda_h\lambda_h^*}{(\kappa+\mu_h)}\left[\frac{\left(\partial\lambda_h^*+\mu_h+b\right)+a\partial}{\left(\lambda_h^*+\mu_h+a\right)\left(\partial\lambda_h^*+\mu_h+b\right)-ab}\right],\\
I_h^*&=\frac{\kappa\Lambda_h\lambda_h^*}{(\phi+\delta+\mu_h)(\kappa+\mu_h)}\left[\frac{\left(\partial\lambda_h^*+\mu_h+b\right)+a\partial}{\left(\lambda_h^*+\mu_h+a\right)\left(\partial\lambda_h^*+\mu_h+b\right)-ab}\right],\\
R_h^*&=\frac{\kappa\Lambda_h\lambda_h^*}{\mu_h(\delta+\mu_h)(\kappa+\mu_h)}\left[\frac{\left(\partial\lambda_h^*+\mu_h+b\right)+a\partial}{\left(\lambda_h^*+\mu_h+a\right)\left(\partial\lambda_h^*+\mu_h+b\right)-ab}\right],\\
S_r^*&=\frac{\lambda_r^*\Lambda_r(\varphi+\mu_r)}{\left(\left(\lambda_r^*+\mu_r\right)(\varphi+\mu_r)(\omega+\mu_r)+\omega\varphi\lambda_r^*\right)}\left(\frac{\lambda_r^*}{\omega+\mu_r}\right),\\
I_r^*&=\frac{\lambda_r^*\Lambda_r(\varphi+\mu_r)}{\left(\lambda_r^*+\mu_r\right)(\varphi+\mu_r)(\omega+\mu_r)+\omega\varphi\lambda_r^*},\\
R_r^*&=\frac{\lambda_r^*\Lambda_r(\varphi+\mu_r)}{\left(\left(\lambda_r^*+\mu_r\right)(\varphi+\mu_r)(\omega+\mu_r)+\omega\varphi\lambda_r^*\right)}\left(\frac{\omega}{\varphi+\mu_r}\right).
\end{aligned} \quad (5)$$

Substituting into the force of infection in the rodent, gives $a_0\lambda_r^* + b_0 = 0$ where,

$$a_0 = (\varphi + \mu_r)(\omega + \mu_r) + \omega\varphi$$
$$b_0 = \mu_r(\varphi + \mu_r)(\omega + \mu_r) - \beta_3\vartheta\Lambda_r(\varphi + \mu_r) = \mu_r(\varphi + \mu_r)(\omega + \mu_r)(1 - R_{alc})$$

The coefficient a_0 is always positive, the coefficient b_0 is positive (negative) if R_{alc} is less than (greater than) unity. Furthermore, there is no positive endemic equilibrium if $b_0 \geq 0$. If $b_0 < 0$ then there is a unique endemic equilibrium (given by $\lambda_r = {}^{b_0}\!/_{a_0}$). This result is summarized below.

Hence, a unique endemic equilibrium (for special case, $\psi = \eta = \phi = 0$) exists whenever $R_{alc} > 1$.

3.1 Global Asymptotic Stability: Special case with $\sigma = \eta = 0$.

Consider the model (1) with $\sigma = \eta = 0$. We claim the following:

Theorem 4: The DFE of the model (1) with $\sigma = \eta = 0$ is globally-asymptotically stable (GAS) whenever $R_{alc} < 1$.

Proof. Consider the model (1) with $\sigma = \eta = 0$. Further, consider the following linear Lyapunov function $F = \kappa E_h + (\kappa + \mu_h) I_h$ with Lyapunov derivative (where a dot represents differentiation with respect to *t*)

$$\begin{aligned}
\dot{F} &= \kappa\dot{E}_h(t) + (\kappa + \mu_h)\dot{I}_h(t) \\
&= \kappa(\lambda_h S_{h1} + \partial\lambda_h S_{h2} - (\kappa + \mu_h)E_h) + (\kappa + \mu_h)(\kappa E_h - (\phi + \delta + \mu_h)I_h) \\
&= (\kappa + \mu_h)(\phi + \delta + \mu_h)\left[\frac{\beta_2\varepsilon\kappa(S_{h1}^0 + \partial S_{h2}^0)}{(\kappa + \mu_h)(\phi + \delta + \mu_h)} - 1\right] I_h \\
\dot{F} &\leq (\kappa + \mu_h)(\phi + \delta + \mu_h)[R_{alc} - 1] I_h
\end{aligned} \tag{6}$$

Hence, $\dot{F} \leq 0$ if $R_{alc} \leq 1$ with $\dot{F} = 0$ if and only $I_h = 0$. Therefore F is a Lyaponuv function in Γ and it follows Salle's Invariance Principle [6], that every solution to the equations in (1) (with $\sigma = \eta = 0$) with initial conditions in Γ converges to ξ_0 as $t \to \infty$. i.e.,

Theorem 5: If $R_{alc} > 1$, then endemic equilibrium point of the model (1) is globally asymptotically stable if $S_{h1} = S_{h1}^*, S_{h2} = S_{h2}^*, E_h = E_h^*, I_h = I_h^*, R_h = R_h^*$ and unstable if $R_{alc} < 1$.

Proof

Consider the following Lyaponuv function,

$$V(S_{h1}, S_{h2}, E_h, I_h, R_h) = \frac{1}{2}(S_{h1} - S_{h1}^*)^2 + \frac{1}{2}(S_{h2} - S_{h2}^*)^2 + \frac{1}{2}(E_h - E_h^*)^2 + \frac{1}{2}(I_h - I_h^*)^2 \tag{7}$$

Differentiating with respect to *t*,

$$\begin{aligned}
\frac{dV}{dt} &= (S_{h1} - S_{h1}^* + S_{h2} - S_{h2}^* + E_h - E_h^* + I_h - I_h^*)(S_{h1}'(t) + S_{h2}'(t) + E_h'(t) + I_h'(t)) \\
&= (S_{h1} - S_{h1}^* + S_{h2} - S_{h2}^* + E_h - E_h^* + I_h - I_h^*)\begin{pmatrix} \Lambda_h + \phi(1-\nu)I_h + \psi R_h + bS_{h2} + aS_{h1} \\ -(\mu_h + a)S_{h1} - (\mu_h + b)S_{h2} - \mu_h E_h - (\phi + \delta + \mu_h)I_h \end{pmatrix}
\end{aligned}$$

$$\therefore \quad \frac{dV}{dt} = -(S_{h1} - S_{h1}^* + S_{h2} - S_{h2}^* + E_h - E_h^* + I_h - I_h^*)(H - W)$$

where

$H = (\mu_h + a)S_{h1} + (\mu_h + b)S_{h2} + \mu_h E_h + (\phi + \delta + \mu_h)I_h$; $W = \Lambda_h + \phi(1-\nu)I_h + \psi R_h + bS_{h2} + aS_{h1}$ Hence we have $\frac{dV}{dt} = 0$ if $S_{h1} = S_{h1}^*, S_{h2} = S_{h2}^*, E_h = E_h^*, I_h = I_h^*, R_h = R_h^*$, also $\frac{dV}{dt} < 0$ if $H > W$.

Thus, it is clear that the endemic equilibrium point of the model (1) is globally asymptotically stable. So the proof is completed.

4. Numerical Simulations

In this section, we use a numerical example to support the theoretical analysis above in this paper. By extracting some values from [6]. The simulations are produced by MATLAB. See Tables 1 and 2 in [6] for the description of parameters and their based line or range value.

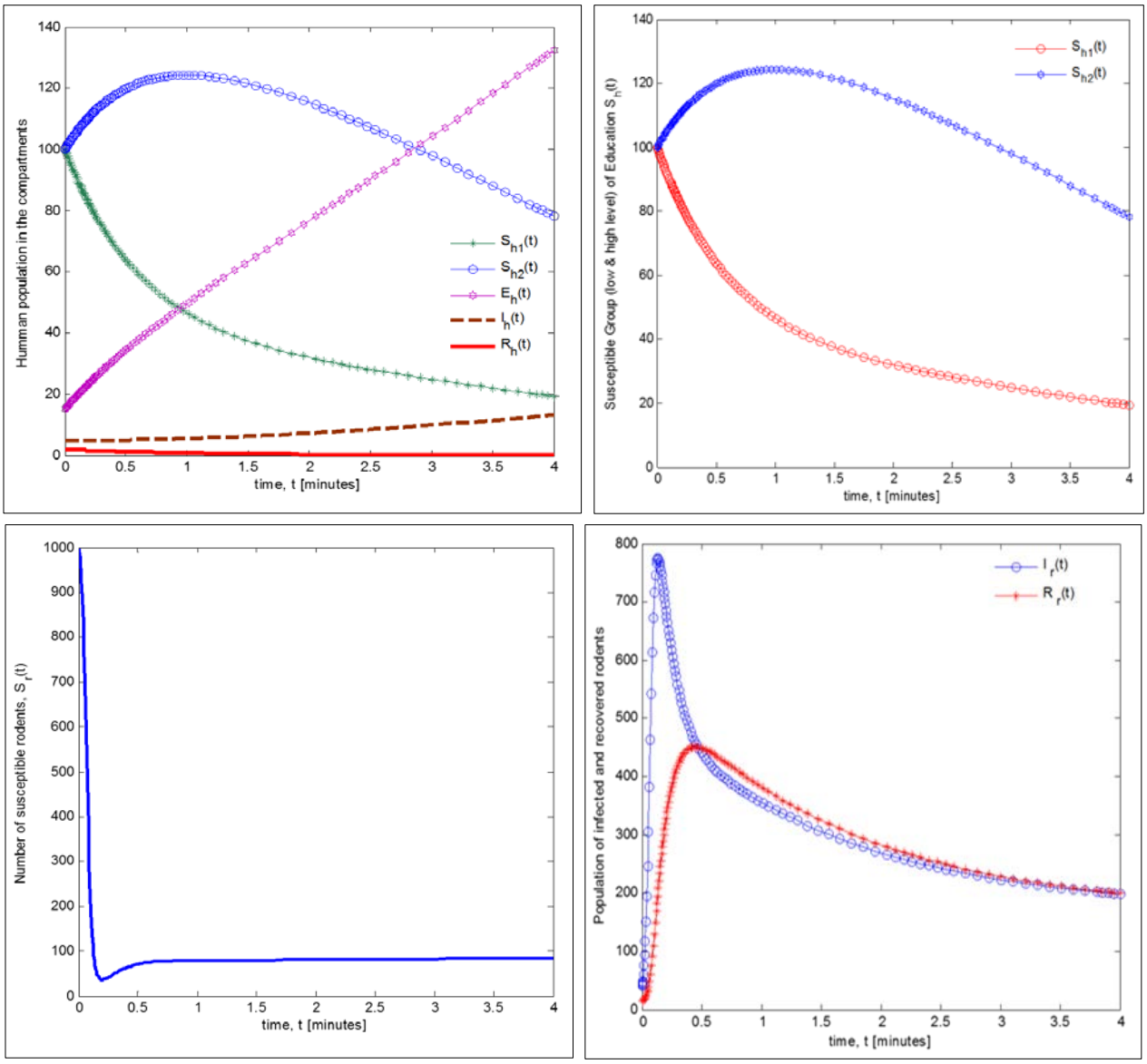

Fig 1: Simulation results showing the general dynamics of the model

From Figure 1, we can observe that infected individuals reduce in the presence of awareness campaign. This figure illustrates that the spread of Lassa fever disease can be controlled by using awareness programmes.

Concluding Remarks

In this paper, an extended mathematical model of Lassa fever disease transmission dynamics incorporating awareness campaign controls was presented. The disease-free and endemic equilibrium points were established. The effective reproduction number R_{iqc} of the model was obtained. By constructing a suitable Lyapunov functional, the global stability of the disease endemic equilibrium of the model was obtained for R_{iqc}. It was shown that if $R_{iqc} > 1$, then the model has a unique endemic equilibrium, which is locally asymptotically stable. The result showed that efficacy of awareness campaign in preventing infection and rate of educating susceptible individuals will have a positive impact in reducing the burden of LF in the community. Thus, introduction of awareness campaign significantly reduces the transmission of LF required for successful eradication of the disease (requirement of at least 92.9% effectiveness). This means that the awareness reproduction number R_{alc} is 92.9% smaller than the basic reproduction number R_0, indicating that introduction of awareness campaign as a control strategy is 92.9% effective in reducing LF transmission. This model predicts that awareness campaign control can reduce the population level transmission by up to 92.9% alone without existing interventions. The model analysis shows that the spread of Lassa fever disease can be controlled by using awareness programmes. The simulation analysis of the model confirms the analytical results.

References

1. Carrillo-Bustamante P, Thi Huyen Tram Nguyen, Lisa Oestereich, Stephan Günther, Jeremie Guedj, Frederik Graw. Determining ribavirin's mechanism of action against Lassa virus infection. Scientific Reports, 2017; 7(1):11693.
2. Central Intelligence Agency. *World fact book for the year*

2014. Retrieved on 20 February 2016 from, 2015. http:/www.cia/library/publication/the-worldfactbook/geos/ni.htm

3. Farrington CP, Kanaan MN, Gay NJ. Estimation of the basic reproduction number for infectious diseases from age-stratified serological survey data. Appl. Statist., 2001; 50(Part 3):251-292.
4. Fisher-Hoch SP, Tomori O, Nasidi A, Perez-Oronoz GI, Fakile Y, Hutwagner L. Review of cases of nosocomial Lassa fever in Nigeria: The high price of poor medical practice. Biomedical Journal, 1995; 311:857–869.
5. McCormick JB, *et al*. Lassa fever. Effective therapy with ribavirin. The New England Journal of Medicine. 1986; 314:20–26.
6. Obasi C, Mbah GCE. On the basic reproduction number of Lassa fever epidemics and its relationship with inter-epidemic period. Journal of the Nigerian Society for Mathematical Biology, 2019; 2:69–79.
7. Ogbu OE, Ajuluchukwu CJ, Uneke CJ. Lassa fever in West Africa sub-region: An overview. Journal of Vector Borne Diseases, 2007; 44:1-11.
8. Chalmers D. *The conscious mind: In search of a fundamental theory*. Oxford: Oxford University Press, 1997.
9. Amir H, Igor A, Leslie S, Allan B, Ron R, Vassilis C. Brain inspired cognitive systems. New York: Springer, 2009.
10. World Health Organization. Centre for disease control. Imported Lassa fever. Morbidity Mortal Weekly Reports, 2004; 53(38):894-897.