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Personal protective strategies for dengue disease: Simulations in two coexisting virus serotypes scenarios

Artur M.C. Brito da Cruz[a,c,*], Helena Sofia Rodrigues[b,c]

[a] *Escola Superior de Tecnologia de Setúbal, Instituto Politécnico de Setúbal, Portugal*
[b] *Escola Superior de Ciências Empresariais, Instituto Politécnico de Viana do Castelo, Portugal*
[c] *CIDMA - Centro de Investigação e Desenvolvimento em Matemática e Aplicações, Departamento de Matemática, Universidade de Aveiro, Portugal*

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Abstract

Dengue fever is a common mosquito-borne viral infectious disease in the world and is widely spread, especially in tropical and subtropical regions. At this moment, one of the best ways to fight the disease is to prevent mosquito bites. In this study, we present a mathematical model that carefully considers personal protection for humans. It is an epidemiological model that translates the dengue disease through a system of differential ordinary equations which takes in consideration the dynamics of the disease between human and mosquito populations. This model incorporates a parameter that simulates personal protection measures, namely insect repellent, special clothes, or bed nets, and a parameter that asserts the effectiveness of public awareness to the importance of using personal protective equipment.

In 2012 there was a dengue disease outbreak in Madeira Island, in Portugal, and this study not only tries to predict what could happen if a second outbreak occurs, where it is considered that there are two serotypes of Dengue disease, but also tries to predict the effects and the importance of taking personal protection measures.

The results show that the level of personal measures and the time that people are compelled to use them have a significant impact to prevent dengue disease.

Keywords: Dengue; Personal protection; Coexistence; Epidemiology; Repellent; Bed net

1. Introduction

Dengue is a mosquito-borne disease and is a major public health issue in the tropics and subtropics namely in the Madeira Island. Dengue is a viral infection transmitted primarily by the Aedes aegypti mosquito, which is found mostly in tropical regions. The mosquito lives in urban habitats and breeds mostly in man-made containers. Ae. aegypti is a day-time feeder and its peak biting periods are early in the morning and in the evening before sunset. Female Aedes aegypti frequently feed multiple times between each egg-laying period. Once a female has laid her eggs, these eggs can remain viable for several months, and will hatch when they are in contact with water [34].

* Corresponding author at: Escola Superior de Tecnologia de Setúbal, Instituto Politécnico de Setúbal, Portugal.
E-mail addresses: artur.cruz@estsetubal.ips.pt (A.M.C. Brito da Cruz), sofiarodrigues@esce.ipvc.pt (H.S. Rodrigues).

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Dengue Fever is transmitted by dengue viruses that are members of the genus Flavivirus and family Flaviviridae. Four immunologically distinct but antigenically similar DENV-1, DENV-2, DENV-3, and DENV-4 serotypes cause dengue [33,35].

Infection with a dengue serotype results in life-long immunity to that type. However, in subsequent infections, it may have a higher chance to catch the more dangerous forms of dengue, Dengue Hemorrhagic Fever (DHF) and Dengue Shock Syndrome (DSS). The fatality rate of patients with these symptoms is larger and there is not yet a proper treatment for Dengue [34]. The reason for this disease escalation is due to the effects of antibody-dependent enhancement (ADE) [30]. In that way, dengue strategies should be effective against all dengue serotypes.

There is no particular treatment for dengue disease and clinical management depends on supportive therapy, mainly cautious monitoring of intravascular volume replacement. The recently licensed dengue vaccine, Dengvaxia (CYD–TDV) made by Sanofi Pasteur, has been approved, but still needs more improvements [29]. Until the results are not completely satisfactory to the population, dengue prevention and control rely on interventions targeting the vector. Basic control strategies intent to keep out mosquitoes from egg-laying habitats through the application of suitable insecticides or predators to outdoor water storage containers; other control strategies are the use of personal and household protections such as open space spray of insecticide during dengue outbreak [24].

Several mathematical models have been formulated to investigate the effects of dengue on population [2,7,10–12,21,25,30,32,35]. Mathematical epidemiology studies about interaction models between host-vector and human populations for dengue disease transmission were proposed in [1,5,36]. The focus was on the study of the basic reproductive rate from the stability analysis of equilibrium points using systems of ordinary differential equations (ODEs). There is a large number of studies using mathematical models and computer simulations that discuss the vector control methods [4,6] and inefficient vaccines [15,26] as human protection tools. Some of these models combine the use of larvicide, adulticide and vaccination strategies to combat the host-vector and the virus in humans. They use two control strategies: one for mosquito population reduction and the other for human immunization. Hence, modeling dengue disease is of great importance to help us understand the disease's dynamics and, therefore, interfering with its spreading though control methods verified mathematically.

The protection against mosquito bites could also be analyzed as a control of the disease. Aedes mosquitoes have diurnal biting activities in both indoor and outdoor environments. Therefore, personal protection measures should be applied all day long and especially during the hours of highest mosquito activity (mid-morning, late afternoon to twilight).

In this work, the main focus goes to the personal protective measures, to reduce/eliminate mosquito bites with the final aim of prevent dengue disease. Protective measures adopted by individuals not only help in protecting themselves against mosquito bites, but also help in reducing the mosquito population by denying the blood meal essential for nourishment of the mosquito eggs of the female anopheles mosquito.

Some of these personal protective measures are clothes that minimizes skin exposure during daylight hours , when mosquitoes are most active and, therefore, afford some protection from the bites of dengue vectors. Besides, there are repellents, ideally the ones that contain DEET, that could be applied to the exposed skin and/or clothing [23,33]. Also, insecticide-treated mosquito nets can afford good protection for those who sleep during the day (e.g. infants, the bedridden and night-shift workers) and can be another way to prevent bites.

The application of these measures could contribute to the decrease the burden cost of this disease [18]. According to these authors, the economic effect of dengue on households, including lost workdays, is substantial.

When studying the time where individuals use personal protective equipment, one has to consider two prominent factors: the duration of the protection (e.g. a can of repellent spray had a short term, when compared with the use of a bed net) and the willingness to use these measures through awareness and publicity campaigns. Both aspects are contemplated in our model.

The paper is composed of five sections. In Section 2, the mathematical model is proposed, including the variables, parameters and the set of differential equations. The numerical results are shown in Section 3, where a series of simulations using distinct measures of personal protection are carried out. Finally, in Section 4, the main conclusions and some future directions are presented.

2. The mathematical model

In this section, it is presented the compartmental model for dengue disease, when two of dengue serotypes coexist. It is based on the model presented in [25], which describes the relationship between human and mosquito

Table 1
Human variables.

S	–	Susceptible humans;
I_1	–	Infected humans with DENV-1;
I_j	–	Infected humans with DENV-j, with j = 2, 3, or 4;
R_1	–	Recovered humans from DENV-1;
R_j	–	Recovered humans from DEVN-j, with j = 2, 3, or 4;
I_{1j}	–	Infected humans with DEVN-j (with j = 2, 3, or 4;) after being infected with DEVN-1;
I_{j1}	–	Infected humans with DEVN-1 after being infected with DEVN-j, with j = 2, 3, or 4;
R	–	Recovered humans, after both infections.

Table 2
Mosquito variables.

S_m	–	Susceptible mosquitoes;
I_{1m}	–	Infected mosquitoes with DENV-1;
I_{jm}	–	Infected mosquitoes with DENV-j, with j = 2, 3, or 4.

populations in a simulation for Madeira Island in Portugal. In that work, the authors use a model for two types of viruses by allowing temporary cross-immunity and increased susceptibility to the second infection. Most of the human parameters used in this work are based on that paper (see Table 3 for more details).

In this work, it was considered that infections of two different serotypes exist at the same time: DENV-1 (the one that occurred in Madeira Island) and one of the other three, without specification. The idea is to predict what could happen when two strains coexist, namely we want to predict the number of deaths due to the cross-infection. The coexistence of two serotypes is already explored on other papers; the novelty of this paper is in the use of personal protective equipment as a way to fight the disease as well as the use of advertising campaigns to compel people to use these kinds of measures to avoid mosquito bites. Our epidemiological model splits human population into two main compartments: one for the population that uses protective equipment (protected population) and one for the other persons (unprotected population). These divided human compartments are based in the work of Demers et al. [9]. According to the previous authors [9], personal protection should be a control strategy operated and promoted by a National Health Agency. The use of mosquito repellents, protective clothing, and mosquito nets are important measures of personal protection against dengue. These are easy to use, safe, and they are not very expensive. However, these should be used regularly without fail, once bed nets wear down and DEET bottles run dry, the individuals lose protection. Therefore, it is necessary a fully commitment from the users. A well-implemented health promotion will motivate people to use or acquire access to personal protection. For this reason, in our model, human population is divided in several classes, as Table 1 shows.

There is a flow between protected and unprotected individuals, so each compartment of the Susceptible, Infected, and Recovered humans it is divided into two classes: the protected and unprotected individuals. To distinguish those classes we use the subscripts $_u$ and $_p$, respectively. There is the assumption of the homogeneity of the population, meaning that every individual of a compartment is homogeneously mixed with the other individuals. Immigration and emigration were ignored, as well as seasonality. As a final assumption, it was considered that an individual cannot be infected, at the same time, with both strains of the virus.

Humans and mosquitoes are assumed to be born susceptible. The mosquitoes are described by a SI model, where S_m are the susceptible ones, and I_m are the infected ones , as described in Table 2. It should be noted that there is not any variable state for cross-infected or recovered mosquitoes due to their short lifespan. An infected mosquito remains infected until its death [8,33]. Each mosquito has an equal probability to bite any host.

Therefore, there are 16 state variables related to humans and 3 related to mosquitoes, all of them mutually exclusive. The dynamics of the human population are defined by the following system of ODEs:

$$
\begin{cases}
\frac{dS_u}{dt} = -\kappa S_u + \gamma S_p + \mu_h N_h - \left(B\beta_{1mh}\frac{I_{1m}}{N_h} + B\beta_{jmh}\frac{I_{jm}}{N_h} + \mu_h \right) S_u \\
\frac{dS_p}{dt} = \kappa S_u - \gamma S_p - \left(B_p\beta_{1mh}\frac{I_{1m}}{N_h} + B_p\beta_{jmh}\frac{I_{jm}}{N_h} + \mu_h \right) S_p \\
\frac{dI_{1u}}{dt} = -\kappa I_{1u} + \gamma I_{1p} + B\beta_{1mh}\frac{I_{1m}}{N_h} S_u - (\eta_{1h} + \mu_h) I_{1u} \\
\frac{dI_{1p}}{dt} = \kappa I_{1u} - \gamma I_{1p} + B_p\beta_{1mh}\frac{I_{1m}}{N_h} S_p - (\eta_{1h} + \mu_h) I_{1p} \\
\frac{dI_{ju}}{dt} = -\kappa I_{ju} + \gamma I_{jp} + B\beta_{jmh}\frac{I_{jm}}{N_h} S_u - \left(\eta_{jh} + \mu_h\right) I_{ju} \\
\frac{dI_{jp}}{dt} = \kappa I_{ju} - \gamma I_{jp} + B_p\beta_{jmh}\frac{I_{jm}}{N_h} S_p - \left(\eta_{jh} + \mu_h\right) I_{jp} \\
\frac{dR_{1u}}{dt} = -\kappa R_{1u} + \gamma R_{1p} + \eta_{1h} I_{1u} - \left(\sigma B\beta_{jmh}\frac{I_{jm}}{N_h} + \mu_h \right) R_{1u} \\
\frac{dR_{1p}}{dt} = \kappa R_{1u} - \gamma R_{1p} + \eta_{1h} I_{1p} - \left(\sigma B_p\beta_{jmh}\frac{I_{jm}}{N_h} + \mu_h \right) R_{1p} \\
\frac{dR_{ju}}{dt} = -\kappa R_{ju} + \gamma R_{jp} + \eta_{jh} I_{ju} - \left(\sigma B\beta_{1mh}\frac{I_{1m}}{N_h} + \mu_h \right) R_{ju} \\
\frac{dR_{jp}}{dt} = \kappa R_{ju} - \gamma R_{jp} + \eta_{jh} I_{jp} - \left(\sigma B_p\beta_{1mh}\frac{I_{1m}}{N_h} + \mu_h \right) R_{jp} \\
\frac{dI_{1ju}}{dt} = -\kappa I_{1ju} + \gamma I_{1jp} + \sigma B\beta_{jmh}\frac{I_{jm}}{N_h} R_{1u} - \left(\mu_h + \mu_{dhf} + \eta_{jh}\right) I_{1ju} \\
\frac{dI_{1jp}}{dt} = \kappa I_{1ju} - \gamma I_{1jp} + \sigma B_p\beta_{jmh}\frac{I_{jm}}{N_h} R_{1p} - \left(\mu_h + \mu_{dhf} + \eta_{jh}\right) I_{1jp} \\
\frac{dI_{j1u}}{dt} = -\kappa I_{j1u} + \gamma I_{j1p} + \sigma B\beta_{1mh}\frac{I_{1m}}{N_h} R_{ju} - \left(\mu_h + \mu_{dhf} + \eta_{1h}\right) I_{j1u} \\
\frac{dI_{j1p}}{dt} = \kappa I_{j1u} - \gamma I_{j1p} + \sigma B_p\beta_{1mh}\frac{I_{1m}}{N_h} R_{jp} - \left(\mu_h + \mu_{dhf} + \eta_{1h}\right) I_{j1p} \\
\frac{dR_u}{dt} = -\kappa R_u + \gamma R_p + \eta_{jh} I_{1ju} + \eta_{1h} I_{j1u} - \mu_h R_u \\
\frac{dR_p}{dt} = \kappa R_u - \gamma R_p + \eta_{jh} I_{1jp} + \eta_{1h} I_{j1p} - \mu_h R_p
\end{cases}
\tag{1}
$$

The mosquito population is modeled by the following differential system:

$$
\begin{cases}
\frac{dS_m}{dt} = & \mu_m N_m - \left(\frac{+B\beta_{jhm}(I_{ju}+I_{1ju})+B_p\beta_{jhm}(I_{jp}+I_{1jp})}{N_h} \right) S_m \\
& - \left(\frac{B\beta_{jhm}(I_{ju}+I_{1ju})+B_p\beta_{jhm}(I_{jp}+I_{1jp})}{N_h} + \mu_m \right) S_m \\
\frac{dI_{1m}}{dt} = & \left(B\beta_{1hm}\frac{I_{1u}+I_{j1u}}{N_h} + B_p\beta_{1hm}\frac{I_{1p}+I_{j1p}}{N_h} \right) S_m - \mu_m I_{1m} \\
\frac{dI_{jm}}{dt} = & \left(B\beta_{jhm}\frac{I_{ju}+I_{1ju}}{N_h} + B_p\beta_{jhm}\frac{I_{jp}+I_{1jp}}{N_h} \right) S_m - \mu_m I_{jm}
\end{cases}
\tag{2}
$$

The differential equations are subject to the initial conditions that are described in the next section. The parameters used in the model are described in Table 3.

The flow diagram that depicts this model is shown in Fig. 1.

Notice that the human population is not constant, death rate is higher that birth rate, because the Dengue Hemorrhagic Fever (DHF). There is evidence that a secondary infection could lead to a more severe situation and increases the risk of developing DHF, which could lead to death. This can be explained by the ADE phenomenon (Antibody-Dependent Enhancement) [31].

After recovering from one serotype of dengue, the immune system responds by producing antibodies to the virus, gaining lifelong immunity against that serotype. However, when a new serotype of dengue is contracted, the same antibodies that protect against the previous serotype, facilitate the entry of the new virus into host cells, enhancing the infection. This makes the viral infection much more acute.

Table 3
Parameters of the epidemiological model.

Parameter	Description	Range	Used values	Source
N_h	Human population		112 000	[17]
$\frac{1}{\kappa}$	Average time an unprotected individual remains unprotected (efficacy of an awareness campaign) (per day)	[0, 365]	15, 30, 90	
$\frac{1}{\gamma}$	Average time that a person remains protected for a specific product (per day)	[0, 365]	15, 30, 90	[9]
$\frac{1}{\mu_h}$	Average lifespan of humans (in days)		79 × 365	[17]
B	Average number of bites on an unprotected person (per day)	$\frac{1}{3}$	$\frac{1}{3}$	[25,27]
B_p	Average number of bites on a protected person (per day)	$\frac{1}{27}$	$\frac{1}{27}$	
β_{1mh}, β_{jmh}	Transmission probability from $I_{1m,Ijm}$ (per bite)	[0.25, 0.33]	0.25	[13]
$\frac{1}{\eta_{1h}}, \frac{1}{\eta_{jh}}$	Average infection period on humans (per day)	[4, 15]	7	[8]
σ	ADF phenomenon index	[0, 5]	1.1	[22]
μ_{dhf}	DHF probability of death	[0.001, 0.1]	0.02	[7,33]
$\frac{1}{\mu_m}$	Average lifespan of adult mosquitoes (in days)	[8, 45]	15	[14,16,19]
N_m	Mosquito population	$6 \times N_h$	672 000	[28]
β_{1hm}, β_{jhm}	Transmission probability from I_1, I_j (per bite)	[0.25, 0.33]	0.25	[13]

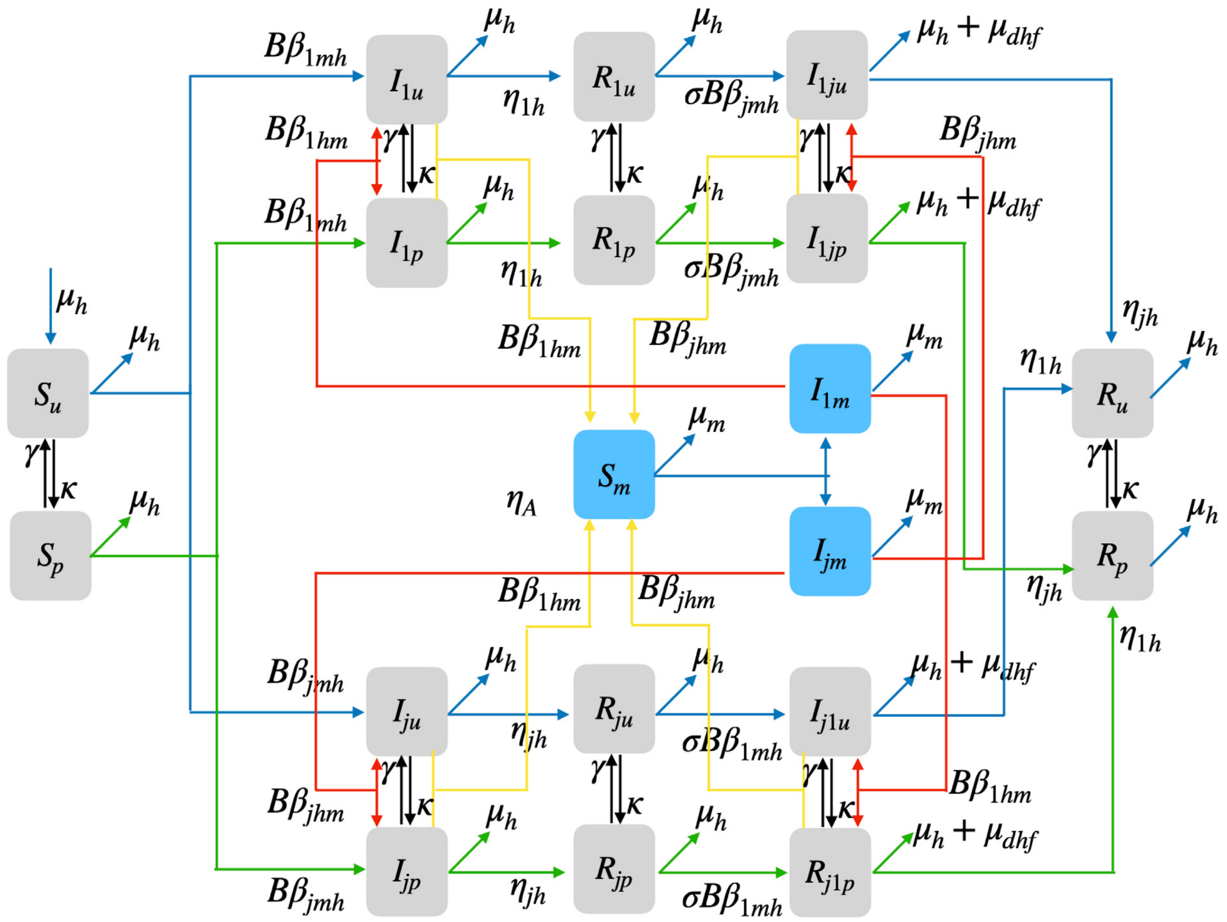

Fig. 1. Flow Diagram of Dengue model with two serotypes and personal protection control.

Applying various vector control interventions to different types of hosts allows us to quantify the effects of these intervention strategies [3]. In the model, we divide the host population into two distinct categories: protected and unprotected ones. The protection could vary, from a simple application of repellent, going through protective clothes or insecticide-treated nets (ITN). The parameter γ describes this protection according to the product lifetime and used correctly (different values of γ are used to predict short, medium, and long term protection).

These personal protection measures are only effective if a huge percentage of the population is knowledgeable of this preventive measures and uses them. That way, public awareness should be promoted for the prevention and control of dengue fever. The parameter κ describes the effort to lead people to use personal protection to prevent bite of the mosquitoes.

In the next section, a set of simulations is carried out to analyze distinct scenarios of prevention, using personal protective measures.

3. Numerical results

To run the model, it was used GNU Octave software (version 5.2.0), a high-level programming language for numerical computations. The numerical solutions were found using the ode45 GNU Octave solver based on the well known explicit Dormand–Prince method of order 4. The simulations done, are considering one year ($t_f = 365$), and they are divided into different goals, corresponding distinct targets to achieve. First, it is important to understand the impact of protective measures, at the beginning of the spread disease, simulating different initial conditions for the percentage of people that are protected. Then, it is important to understand the impact of awareness campaigns on the use of correctly protective measures (κ). Finally, the simulation of distinct personal protections, with their respective time of protection, are also simulated (γ).

3.1. Simulation with distinct initial conditions

Personal protection measures against mosquito bites are some of the prophylactic tools against dengue. The use of personal protective measures has been advocated as an effective tool in the control of mosquito-borne diseases. The idea of this subsection is to understand what is the impact of a well-informed population and, at the same time, the propensity to take personal protection initiatives.

Table 4 resume the initial conditions used in the simulations. The values related to the human population are mirroring the situation on Madeira Island after the first outbreak with DEN-1, where 2151 individuals became infected and no deaths occurred. Another assumption, frequently used in the research, was to consider mosquito population six times greater than the human population, i.e. it was used $N_m = 6N_h$.

In this subsection, we consider four distinct initial conditions, simulating different use of personal protective measures. The first one, which is called no control, happens when people do not use any personal protective measures during the whole year of the simulation study (0%). The other three simulations imply that 5%, 25% and 50% of the population is using protective measures, splitting each compartment (susceptible, infected, recovered) in protected and unprotected population.

Notice that, for people that already had DEN-1, it was considered that this group of people are more sensitized to the disease, and therefore have a greater predisposition to protect themselves; this way we increased each one of the compartments after the first infection with more 10% of persons that use protective equipment (for example, for the second scenario of 5% of population protected, the percentage of the population implementing personal protecting measures after recover of serotype 1 is 15%).

For all these initial conditions, it was considered $\frac{1}{\gamma} = 15$, $\frac{1}{\kappa} = 30$ (Case A - Fig. 2), describing using a small protection factor of 15 days, and $\frac{1}{\gamma} = 180$, $\frac{1}{\kappa} = 30$ (Case B - Fig. 3) using a longest protection factor, with different percentages of the population protected. The graphics of all compartments of case A are included in the Appendix (Fig. 7) because in all cases the shape of the curves is similar. Here it is only presented the main conclusions related to the total of recovered individuals, giving the information about the number of persons that had the disease all over the time, and the total of the population, giving the information of death caused by severe dengue.

In the Appendix, it is possible to see that the peak of the infections of one serotype (1 or j) occurs before the 100 days of the outbreak, while the second infection has a delay. In the compartments with protection, of course, there is no one in the curve of no control, but it is possible to analyze that the peak of the infection is 4 times smaller when compared with the similarly unprotected compartments. In all graphics, regarding the compartments without protection, the willingness of population taking preventive measures of personal protection has a considerable impact

Table 4
Initial conditions of the model.

Human population			
0%	5%	25%	50%
$S_u(0) = 1\,009\,789$	$S_u(0) = 104\,300$	$S_u(0) = 82\,342$	$S_u(0) = 54\,895$
$S_p(0) = 0$	$S_p(0) = 5489$	$S_p(0) = 27\,447$	$S_p(0) = 54\,894$
$I_{1u}(0) = 20$	$I_{1u}(0) = 19$	$I_{1u}(0) = 15$	$I_{1u}(0) = 10$
$I_{1p}(0) = 0$	$I_{1u}(0) = 1$	$I_{1u}(0) = 5$	$I_{1u}(0) = 10$
$I_{ju}(0) = 20$	$I_{ju}(0) = 19$	$I_{ju}(0) = 15$	$I_{ju}(0) = 10$
$I_{jp}(0) = 0$	$I_{ju}(0) = 1$	$I_{ju}(0) = 5$	$I_{ju}(0) = 10$
$R_{1u}(0) = 2151$	$R_{1u}(0) = 1828$	$R_{1u}(0) = 1398$	$R_{1u}(0) = 860$
$R_{1p}(0) = 0$	$R_{1p}(0) = 323$	$R_{1p}(0) = 753$	$R_{1p}(0) = 1291$
$R_{ju}(0) = 0$	$R_{ju}(0) = 0$	$R_{ju}(0) = 0$	$R_{ju}(0) = 0$
$R_{jp}(0) = 0$	$R_{jp}(0) = 0$	$R_{jp}(0) = 0$	$R_{jp}(0) = 0$
$I_{1ju}(0) = 20$	$I_{1ju}(0) = 17$	$I_{1ju}(0) = 13$	$I_{1ju}(0) = 8$
$I_{1jp}(0) = 0$	$I_{1ju}(0) = 3$	$I_{1ju}(0) = 7$	$I_{1ju}(0) = 12$
$I_{j1u}(0) = 0$	$I_{j1u}(0) = 0$	$I_{j1u}(0) = 0$	$I_{j1u}(0) = 0$
$I_{j1p}(0) = 0$	$I_{j1p}(0) = 0$	$I_{j1p}(0) = 0$	$I_{j1p}(0) = 0$
$R_u(0) = 0$	$R_u(0) = 0$	$R_u(0) = 0$	$R_u(0) = 0$
$R_p(0) = 0$	$R_p(0) = 0$	$R_p(0) = 0$	$R_p(0) = 0$
Mosquito population			
$S_m(0) = 670\,000$			
$I_{1m}(0) = 1000$			
$I_{jm}(0) = 1000$			

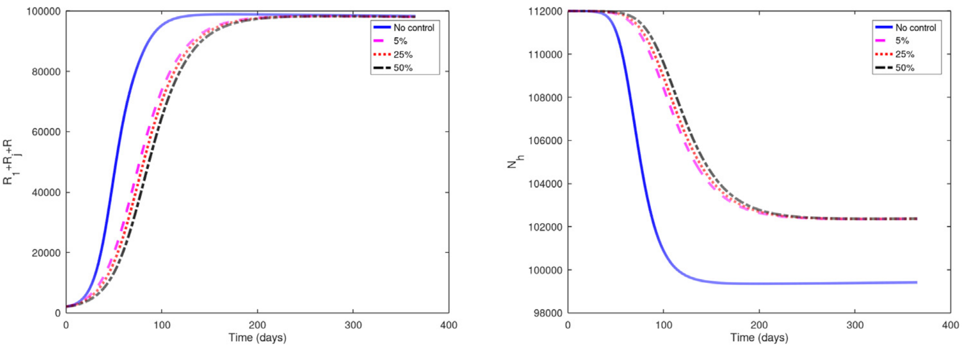

Fig. 2. Case A: scenarios with different percentage of the protected population, since the beginning of the outbreak (with $\frac{1}{\gamma} = 15$, $\frac{1}{\kappa} = 30$).

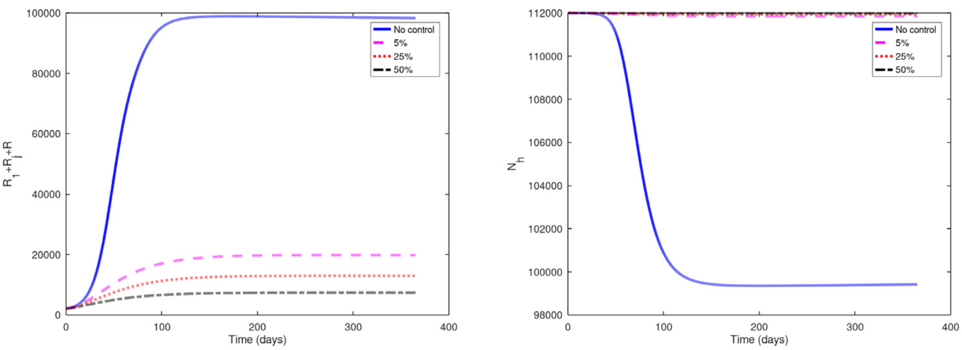

Fig. 3. Case B: scenarios with different percentage of the protected population, since the beginning of the outbreak ($\frac{1}{\gamma} = 180$, $\frac{1}{\kappa} = 30$).

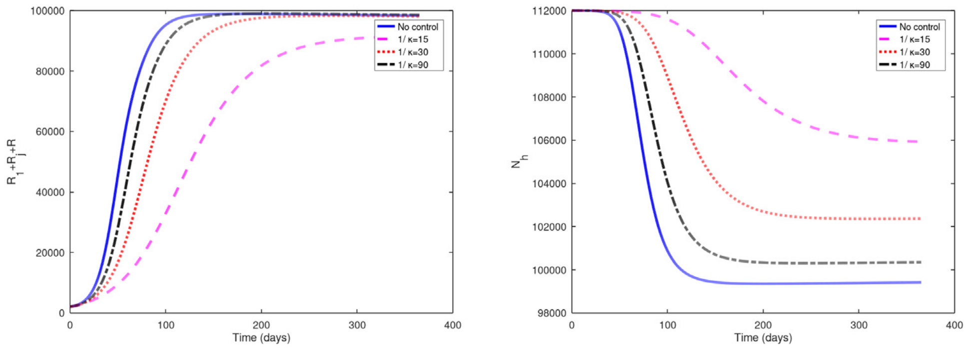

Fig. 4. Case C: scenarios with different values of κ, $\frac{1}{\kappa} = 15, 30, 90$ (with $\frac{1}{\gamma} = 15$ and 25% of the population with initial protection).

in slowing the spread of the infection. When the curve of an epidemic is flattened, it gives health systems time to adapt human and logistics resources, and absorb the new patients, ensuring that everyone is treated in a proper way.

In Figs. 2 and 3, in the left side we have the recovered individuals and it is possible to observe the importance of people being predisposed to use protection, since the beginning of the outbreak. The number of recovered individuals is important because it accumulates the total of infections all over the outbreak. In Case B, using the longest protection, the number of recovered decreases from 100 000 to 20 000, when only the smallest percentage of the population is protected from the beginning. This information is crucial because health authorities could advise people through educational campaigns, influencing population behavior in advance, to prevent mosquito bites. This kind of awareness campaign could occur before the first infected individual gets to the hospital; it could occur when some specific climate conditions (temperature and humidity) are favorable to the increase of mosquitoes, or other factors related to the human behaviors. Nevertheless, regarding the number of deaths in both figures (right side of the figures), the values are similar in each kind of personal protection, having a distinct number between no protection and some protection since the beginning of the infections. Table 5 presents the numbers for each compartment after one year.

3.2. Simulation with distinct awareness campaigns efficacy

Educational campaigns are an important tool to make the community aware of the severity of this disease, leading people to take precautionary measures to prevent the disease. Madeira et al. [20] verified that students who had the opportunity to watch explanations about dengue, its vector and related preventive measures, were more able to recognize *A. aegypti* life stages and which measures should be considered the most viable to prevent the occurrence of the mosquito, leading that in their houses had half as mosquito breeding sites as when compared with other students without this kind of information.

In this study, several scenarios were simulated, using different times of awareness campaign exposure. The variation of κ translates the efficacy of the campaign: the more time that the campaign needs to be effective, means that the individual takes more time to perceive the benefits of personal protection and to adopt protective behaviors.

It was considered campaigns lasting 15, 30, and 90 days since the beginning of the outbreak. It was considered that 25% of the population takes personal protection measures since the beginning of the outbreak (scenario with initial conditions of 25% of protection). Case C (Fig. 4) shows different levels of efficacy. If the individual takes 90 days, counted from the moment that the outbreak is declared, to make the decision to apply an individual protection measure, its effectiveness is low because the peak infected persons occurs in the first 100 days. This means that the campaigns must be intensive and effective in the first 30 days of the outbreak, in order to reduce the number of infected individuals and the number of deaths.

In case D (Fig. 5), the scenarios are even more dramatic, when the personal protection measures are long-lasting. The number of infected drops significantly (more than 85 000) when people take the decision to protect themselves in the first 30 days; even if the population takes the decision late, there is a considerable number of fewer infections. The behavior of the curves related to recovered and total population are very similar for $\frac{1}{\kappa} = 30$ and $\frac{1}{\kappa} = 90$. In these two scenarios, the numbers of deaths are residual (see Table 5).

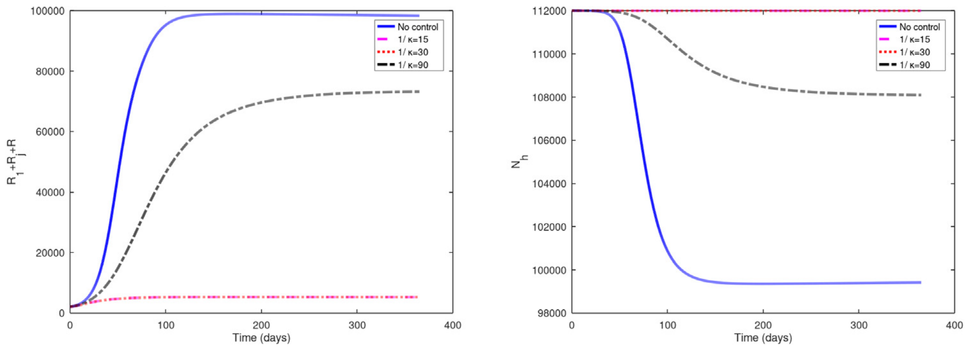

Fig. 5. Case D: scenarios with different values of κ, $\frac{1}{\kappa} = 15, 30, 90$ (with $\frac{1}{\gamma} = 180$ and 25% of the population with initial protection).

Table 5
Recovered cases and deaths in one year.

			$R_1(t_f)$	$R_j(t_f)$	$R(t_f)$	Total recovered	Deaths
No control			4119	4330	89 876	98 325	12 583
Protected population (varying initial conditions)							
Case A	5%	$\frac{1}{\gamma} = 15$, $\frac{1}{\kappa} = 30$	14 365	14 824	68 857	98 046	9640
	25%		14 389	14 846	68 820	98 055	9635
	50%		14 412	14 868	68 789	98 069	9630
Case B	5%	$\frac{1}{\gamma} = 180$, $\frac{1}{\kappa} = 30$	9957	8758	1103	19 818	154
	25%		7079	5475	456	13 010	64
	50%		4581	2664	143	7388	20
Efficacy of awareness campaigns (κ variation)							
Case C	$\frac{1}{\kappa} = 15$	$\frac{1}{\gamma} = 15$	23 558	24 542	43 380	91 510	6073
	$\frac{1}{\kappa} = 30$		14 389	14 846	68 820	98 055	9635
	$\frac{1}{\kappa} = 90$		7544	7817	83 225	98 586	11 651
Case D	$\frac{1}{\kappa} = 15$	$\frac{1}{\gamma} = 180$	3612	1586	69	5267	10
	$\frac{1}{\kappa} = 30$		7079	5475	456	13 010	64
	$\frac{1}{\kappa} = 90$		22 391	22 921	27 883	73 195	3904
Personal protective measures (γ variation)							
Case E	$\frac{1}{\gamma} = 15$	$\frac{1}{\kappa} = 30$	14 389	14 846	68 820	98 055	9635
	$\frac{1}{\gamma} = 180$		7079	5475	456	13 010	64
	$\frac{1}{\gamma} = 365$		5792	3995	274	10 061	38

3.3. Simulation with distinct personal protective measures

Personal protection technologies, such as repellent, insecticide-treated clothing, or insecticide-treated mosquito nets have been used to reduce bites from disease vectors, as well as reduce the prevalence of some vector-borne diseases. As the clothing or repellent can be worn when an individual is outside of their home during the day, it has the potential to provide long-term protection from day-biting mosquitoes; bed nets could give protection to persons that are sleeping, specially for babies or people with labor shifts that need to sleep during the day.

In this subsection, three different personal protective measures were considered that have different protection terms. For $\frac{1}{\gamma} = 15$, it was simulated taking in mind the use of a bottle of repellent with a long-lasting of 15 days. The simulation $\frac{1}{\gamma} = 180$ was done for insecticide-treated clothing that is losing its effect due to use and washing. Finally, it was considered a full-year protection ($\frac{1}{\gamma} = 365$) for the use of a bed net treated with insecticide.

Fig. 6 shows the simulations obtained for these three scenarios, using a awareness campaign $\frac{1}{\kappa} = 30$. The use of long-lasting protection measures has a huge impact on the numbers of the disease. The use of only one repellent

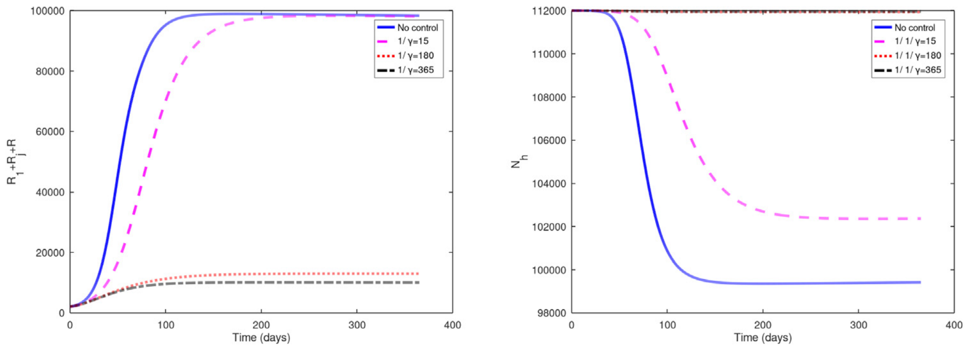

Fig. 6. Case E: scenarios with different values of γ, $\frac{1}{\gamma} = 15, 180, 365$ (with $\frac{1}{\kappa} = 30$ and 25% of the population with initial protection).

for 15 days is not enough to fight the outbreak. Even so, it has an impact on the number of lives saved in one year. But the long-lasting measures well-used, such as insecticide-treated clothing and bed net, represent a big help to combat the disease.

In Table 5, we have resumed the total number of recovered persons and deaths after one year of the appearance of an hypothetical dengue outbreak with two serotypes of dengue and 25% of the population with initial protection). There are big differences between the infected with serotype 1 or another j, since the number of recovered infected by one specific serotype have the same weight in the outbreak. The three scenarios where there was less than 10 000 infected persons, and as a consequence, the lowest number of deaths, happened when the highest level of willingness of adopting personal protection at the beginning of the epidemic (initial conditions with 50% of population protected) or rapid change of the individuals from unprotected to protected ($\frac{1}{\kappa} = 15$), and finally, when the choice of the type of protection gives us long-lasting protection.

4. Conclusions

In this research, we have analyzed the importance of personal protection during an outbreak of dengue. Sixteen scenarios help us to understand the evolution of the epidemiological curves. It was shown that awareness of the population is one of the keys to defeating the disease. The adoption of safety measures, right from the start of the outbreak, can reduce the number of infected individuals and deaths: if 50% of the population protects themselves, only 10% contract the disease when compared with no measures of control. This way, the population perception to protect from the bites, at the beginning or during the outbreak, is an important key to prevent dengue.

At the same time, these kinds of scenarios can be a powerful tool so that health authorities can grasp the importance of spending time and money to promote awareness campaigns since more efficient campaigns, have an impact on the spreading of the disease. In this paper, it was shown that the adoption of individual protective measures in the first fifteen days or ninety days of the outbreak, can be the difference between having less than 6000 or 74 000 infected persons, respectively, if they apply correctly the long-lasting protections.

Another important conclusion is the necessity of creating conditions to develop and improve the research in repellent impregnated tissues, for clothing or bed nets. These products are more durable than a bottle of repellent and have a significant impact in the fight against the mosquito bite. We showed that if these protective measures have a duration of at least half a year, the numbers drop down to 10% of infected humans and deaths related to the disease.

In future work, a functional should be added so we can make an optimal control analysis. We want to understand the burden cost of the disease taking into account the number of infected individuals and costs related to personal protective measures.

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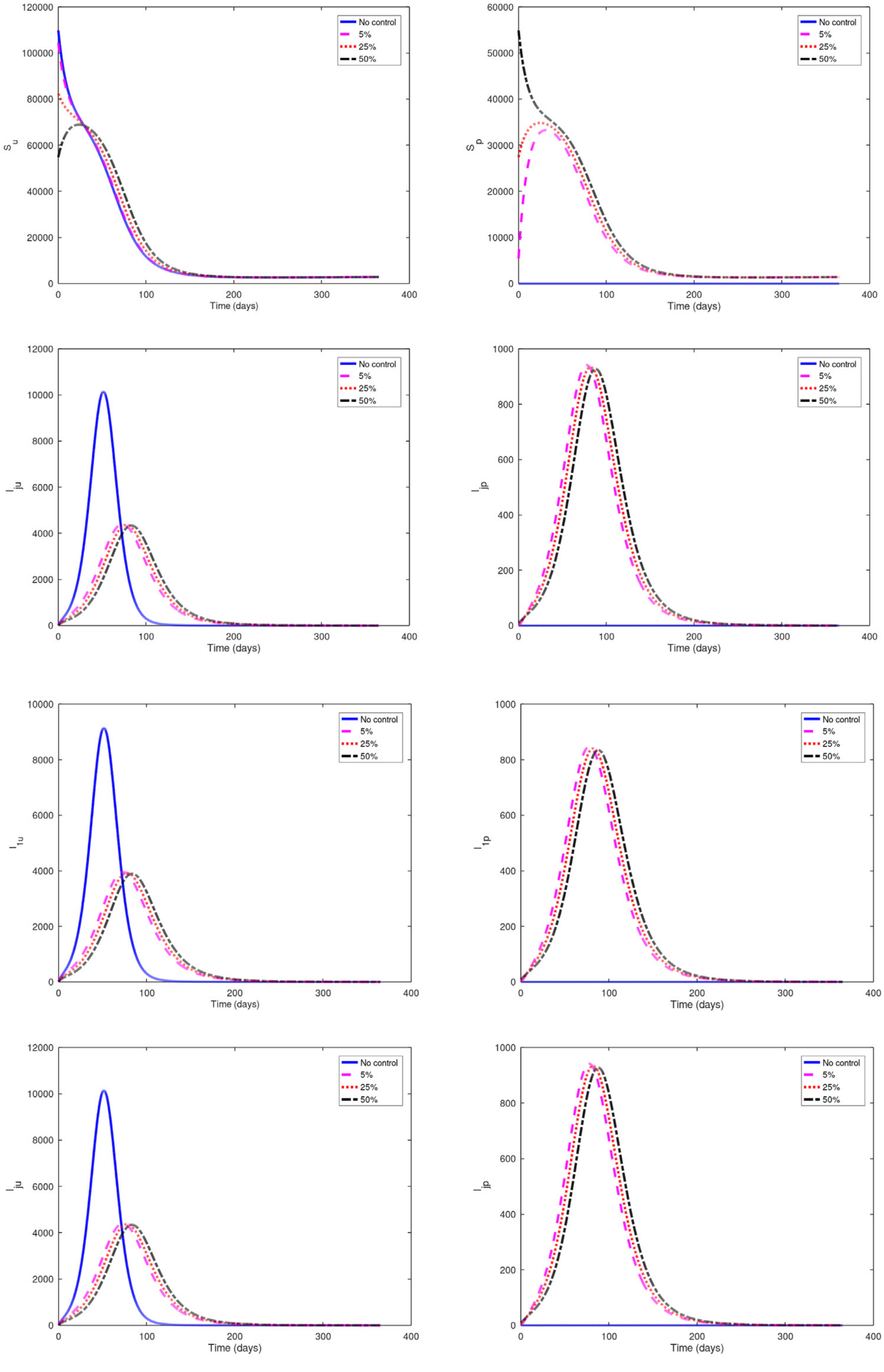

Fig. 7. Case A - $\frac{1}{\gamma} = 15$, $\frac{1}{\kappa} = 30$ with different percentage of the population protected.

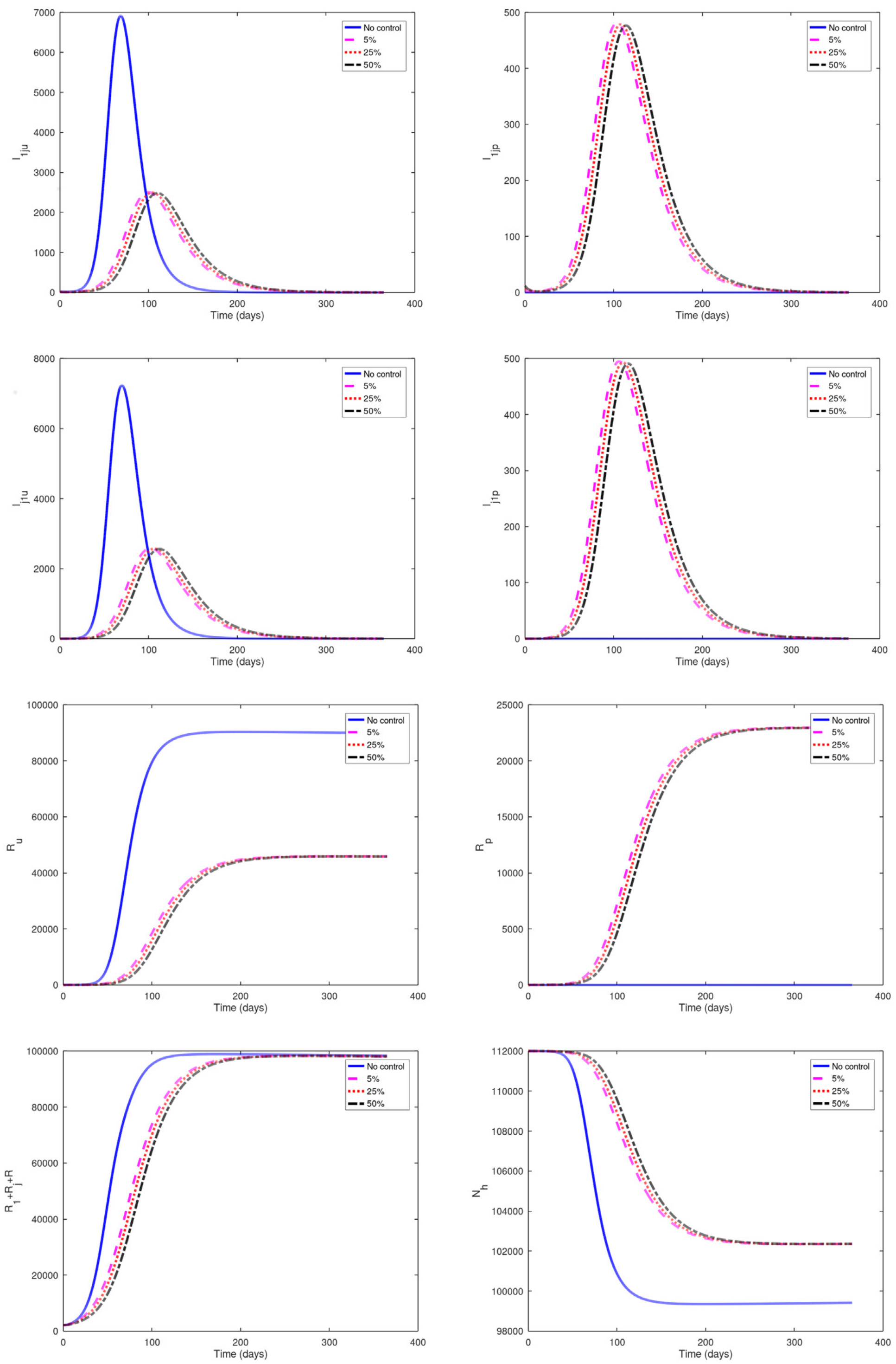

Fig. 7. (*continued*).

Appendix. Graphics for all compartments of Case A

See Fig. 7

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