Lab - 6

Krunal Lukhi (201901449)[*] and Dhwanil Shah (201901450)[†]
Dhirubhai Ambani Institute of Information & Communication Technology,
Gandhinagar, Gujarat 382007, India
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In this lab, we attempt to study spread of Malaria in closed a close system. We first developed a basic mathematical model that captures the spread of Malaria. Then, we vary different parameters of basic model to observe their effect on system. Finally, we apply Malaria model to study effect of fumigation on Dengue outbreak at DAIICT. At last, we presents our conclusions based on our analysis of this model.

I. INTRODUCTION

Malaria is spread by Anopheles mosquitoes which become infected when they bit an already infected human host. These infected mosquitoes are called vectors. Vectors spreads Malaria by biting uninfected humans. Actual process of transmission of Malaria-causing Plasmodium is very complex. We make some assumption to make our job simple.

- We assume that the population of humans is closed with no births, no immigration, and no deaths except from Malaria.
- As soon as a vector bites a human, the individual becomes a host.
- No immunity exists for uninfected individuals, and no incubation period occurs.
- Some human hosts eventually become immune and others die, while still others recover and become susceptible again.
- The death rates for infected and uninfected mosquitoes are identical.
- At birth, a mosquito is uninfected.
- An infected mosquito immediately becomes a host that can infect humans.

Based on these assumptions, we divide humans and mosquitoes into different compartments.

1. **Susceptible Humans (S_h):** who are susceptible to Malaria infection
2. **Human host (I_h):** who have Malaria and can infect mosquitoes that bite them
3. **Immune Humans (R_h):** who cannot get the disease again
4. **Uninfected mosquitoes (S_m):** which do not carry Plasmodium
5. **Vectors (I_m):** which carry Plasmodium

II. MODEL

Parameters of the model

1. r: recovery rate of humans
2. p: probability of mosquito bite
3. κ: rate of immunization of humans
4. d: death rate due to Malaria
5. α: birth rate of mosquitoes
6. β: death rate of mosquitoes

We come up with following model.

$$\frac{dS_h}{dt} = rI_h - \frac{pS_hI_m}{M} \tag{1}$$

$$\frac{dI_h}{dt} = \frac{pS_hI_m}{M} - (\kappa + d + r)I_h \tag{2}$$

$$\frac{dR_h}{dt} = \kappa I_h \tag{3}$$

$$\frac{dS_m}{dt} = \alpha(S_m + I_m) - \beta S_m - \frac{pS_mI_h}{N} \tag{4}$$

$$\frac{dI_m}{dt} = \frac{pS_mI_h}{N} - \beta I_m \tag{5}$$

To find the reproduction number using the next generation method we need two matrices F and V. The former represents the rates of flow from uninfected to infected class and the latter represents all the other flows to and from the infected classes. Both these Jacobian would be calculated at the equilibrium points.

[*]Electronic address: 201901449@daiict.ac.in
[†]Electronic address: 201901450@daiict.ac.in

The reproduction number (R_0) would be given as $\rho(FV^{-1})$. The following equation represents the value of the reproduction number R_0.

$$R_0 = \sqrt{\frac{p^2 \cdot S_m^2 \cdot S_h \cdot (S_h + R_h)}{(I_m + S_m)^2 \cdot (I_h + S_h + R_h)^2} \cdot \frac{1}{(r + \kappa + d) \cdot \beta}} \tag{6}$$

III. RESULTS

1. **Basic modeling of the differential equations (without interventions):** In this case we model the above differential equations graphically for the values of the parameters specified in the table below.

uninfected humans	300
human hosts	1
immune	0
prob_bit	0.3
recovery rate	0.3
immunity rate	0.01
Malaria induced death rate	0.005
mosquito birth rate	0.01
mosquito death rate	0.01
vectors	0
uninfected mosquitoes	300
prob_bite_human	0.3

We start with basic model which is shown fig. 1. We observe that number of the susceptible humans decreases as some of them get bit by vectors and some get recovered. Infected population first increases and then decreases because some of the people get immunized. Immune population strictly increases as rate of change of immune population is proportional to infected population which always positive. As the birth rate and death rate of mosquitoes are same, vector population follows the trend of host humans population. Population of unaffected mosquitoes decrease and then increases as opposite to vectors, because death rate and birth rate are same for mosquitoes.

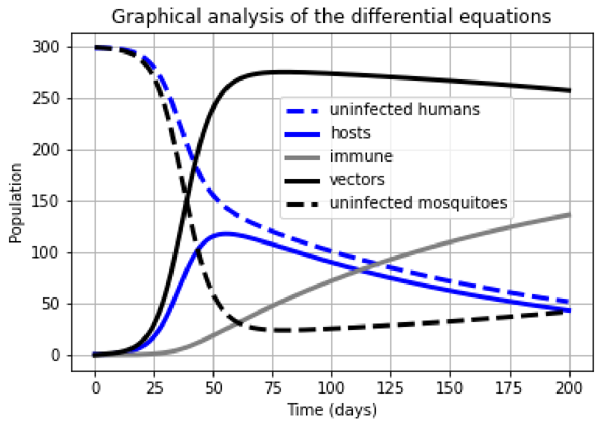

FIG. 1: Graph based on the above parameters

2. **Effect of vaccination:**

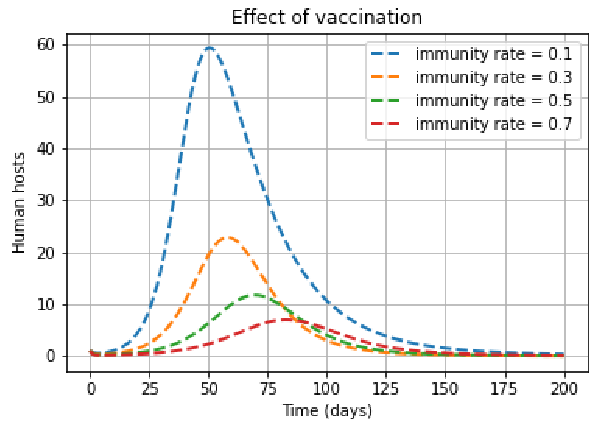

FIG. 2: Graph showing human hosts vs time when the effect of vaccination is considered

Due to vaccination, immunization rate improves. Look at fig. 2, We can conclude that, vaccination controls the peak human host population. Vaccination at higher rate significantly flattens curve. It also suggests that vaccination is very effective measure to fight against Malaria outbreak.

3. **Effect of mosquito repellents:**

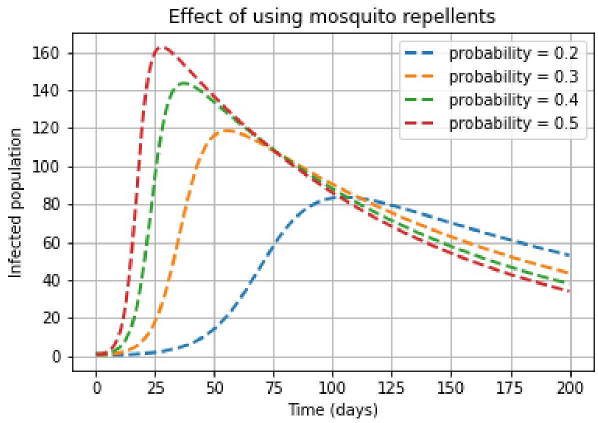

FIG. 3: Graph showing infected population of humans vs time when the effect of mosquito repellents is considered

Mosquito repellent creams reduce probability of bit. Fig. 3 presents the effect of change in probability of bit on human host population. We observe that, lower probability of bit leads to lower peak host population. When probability is decreased from 0.3 to 0.2, we observed almost 33% decrease in peak host population. So, applying mosquito repellent cream on skin turns out to be good measure to avoid Malaria.

4. **Effect of Fumigation:**

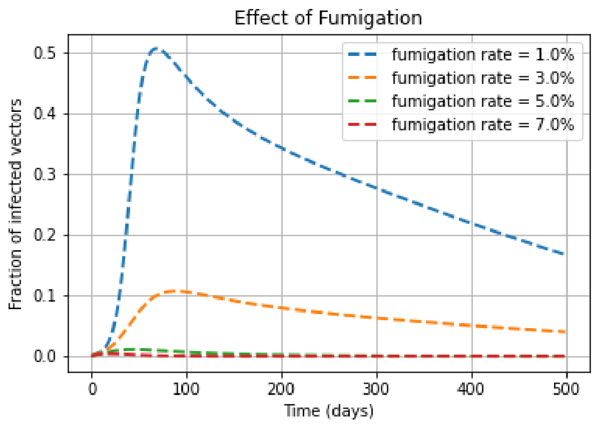

FIG. 4: Graph showing the effect of fumigation on the infected vectors

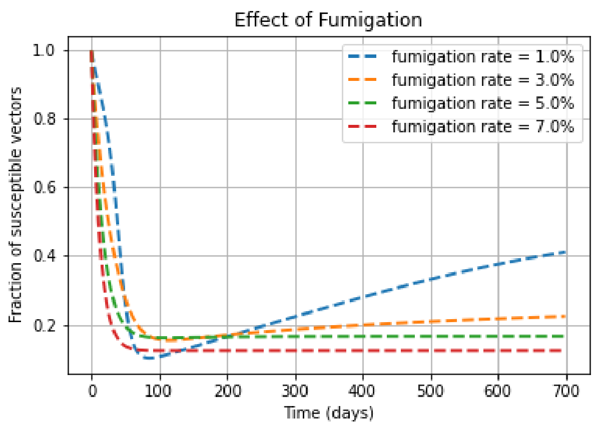

FIG. 5: Graph showing the effect of fumigation on the susceptible vectors

Fumigation leads to sudden death of vectors. Due to sudden death, less number of mosquitoes get infected, that leads to decrease in human host population. Peak human host population depends on fumigation rate. Look at fig. 4 and 5, When fumigation is less, we don't see much change in population of vectors. When we increase fumigation rate up to significant value, we observe noticeable decrease in population of vectors, because more fumigation kills more numbers of vectors. Decrease in vector population directly affects the population of human hosts, which also decreases. Hence, fumigation can apply sudden break spread of Malaria. This quite effective measure to stop spreading Malaria.

IV. CONCLUSIONS

We start with basic model without any health interventions. Then, we tweak out model to incorporate effect of three different health interventions such as vaccination, fumigation and mosquito repellents. We observe that all of them are quite effective measures. In real life scenarios, vaccination is slow process and It may not always be possible to vaccinate everybody in short period of time. So, our other two measures fumigation and mosquito repellents become crucial. We observe that fumigation shows sudden results. So, in emergency situations, It is very good option. But again, there is issue of availability and scaling. Taking about Dengue outbreak at DAIICT, given the fact that we have the facility of fumigation, this should work very well as we have seen on fig. 4 and 5. Mosquito repellents are generally available to everybody and it is the best health measure when population is very large and other two measure are not widely available.