CHAPTER-9

DISCUSSION

9.1 Summary, and Conclusion

India has been one of the dengue endemic regions since ancient days. At present dengue is endemic in India in 23 states/Union Territories. Ngwa and Shu (2000) and Ngwa (2004) proposed an ordinary differential equation (ODE) compartmental model, a susceptible- exposed-infectious-recovered-susceptible (SEIRS) pattern for humans and a susceptible-exposed-infectious (SEI) pattern for mosquitoes. In this work, Ngwa (2004) model has been considered for further development. In fact, the Aedes aegypti mosquitoes, the principal vector for the spread of dengue, not only bite humans but also birds and animals. In this thesis, only human has been considered. An ordinary differential equation model called SPR_SODE has been created for the transmission of dengue. In this model a set of four equations for humans and three equations for mosquitoes has been created. Here, up to 17 parameters and 7 states have been defined. The model has been further simplified to fractional quantities to eliminate calculation difficulties. The model has been arbitrarily extended to many regions with valid assumptions. Further, the model has been analyzed. It has been shown that there exists a domain where the model is epidemiologically and mathematically well-posed. The existence and uniqueness of an equilibrium point with no disease (Disease free equilibrium point) $x_{nodis}$ has been proved. The existence of endemic equilibrium point has also been proved.

The reproductive number $R_0$ has been defined and that is epidemiologically accurate in the sense that it provides the expected number of new infections (in mosquitoes or humans) from one infectious individual (human or mosquito) over the duration of the infectious period, given that all other members of the population are susceptible. The asymptotic stability of the model has been discussed. If $R_0 < 1$, then the disease-free equilibrium point, $x_{nodis}$, is locally asymptotically stable, and if $R_0 > 1$, then $x_{nodis}$ is
unstable. That an endemic equilibrium point exists for all $R_0 > 1$ with a transcritical bifurcation at $R_0 = 1$ has been proved. The analysis and the numerical simulations have shown that for $\eta_h = 0$ (no disease-induced death), and for some small positive values of $\eta_h$, there is a supercritical transcritical bifurcation at $R_0 = 1$ with an exchange of stability between the disease-free equilibrium and the endemic equilibrium. For larger values of $\eta_h$, there is a subcritical transcritical bifurcation at $R_0 = 1$, with an exchange of stability between the endemic equilibrium and the disease-free equilibrium; and there is a saddle-node bifurcation at $R_0 = R^*_0$ for some $R^*_0 < 1$. Thus, for some values of $R_0 < 1$, there exist two endemic equilibrium points, the smaller of which is unstable, while the larger is locally asymptotically stable.

Although in general the endemic equilibrium point is unique and stable for $R_0 > 1$, numerical results for particular parameter sets suggest that there is a unique stable endemic equilibrium point for $R_0 > 1$. Also, all orbits of our dengue model are bounded. The possible existence of a subcritical bifurcation at $R_0 = 1$ and a saddle-node bifurcation at some $R^*_0 < 1$ can have implications for public health, when the epidemiological parameters are close to those of the defined values. Simply reducing $R_0$ to a value below 1 is not always sufficient to eradicate the disease; it is now necessary to reduce $R_0$ to a value less than $R^*_0$ to ensure that there are no endemic equilibria. The existence of a saddle-node bifurcation also implies that in some areas with endemic dengue, it may be possible to significantly reduce prevalence or eradicate the disease with small increases in control programs (a small reduction in $R_0$ so that it is less than $R^*_0$). In some areas where dengue has been eradicated it is possible for a slight disruption, like a change in environmental or control variables or an influx of infectious humans or mosquitoes, to cause the disease to reestablish itself in the population with a significant increase in disease prevalence.

To effectively guide public policy and public health decision making, the model and parameter values need to be tested against the data from dengue-endemic field sites. The sensitivity analysis, however, remains an important step toward comparing the effectiveness of different control strategies. As $R_0$ has an explicit expression, its sensitivity to the different parameter values can be analytically evaluated. The sensitivity of the endemic equilibrium to the parameter values is numerically evaluated. This allows us to
determine the relative importance of the parameters to disease transmission and prevalence. Two sets of baseline values have been considered: one for areas of high transmission and another one for low transmission. A stochastic simulation of the dengue model using the Gillespie algorithm has been performed and the results have been compared with the deterministic approach using MATLAB. As each dengue intervention strategy affects different parameters to different degrees, different control strategies for efficiency and effectiveness in reducing dengue mortality and morbidity can be compared. This analysis shows that dengue transmission is most sensitive to the mosquito biting rate, and prevalence is most sensitive to the mosquito biting rate and the human recovery rate.

9.2 Control measures & Suggestions

No eradication program is currently operational, but there are several steps individuals can take to reduce localized mosquito numbers. Because Ae. aegypti are container-inhabiting mosquitoes, one of the most successful and cost-effective methods to reducing populations is by preventing containers around the home from collecting water. By turning over empty flowerpots, properly maintaining swimming pools and removing unused tyres, the number of places mosquitoes have to lay eggs can be greatly reduced. Aerating birdbaths and making sure that gutters are free of blockages, cleaning pet bowls every day, and always emptying overflowing dishes for potted plants will go a long way in containing the explosion of mosquito population.

9.2.1 Vaccines

So far, there is no satisfactory vaccine and no immediate prospect of preventing the disease by immunization.

9.2.2 Other measures

Isolation under bed nets during the first few days; individual protection against mosquitoes. The personal prophylactic measures are wearing of full sleeves shirts and pants; use of mosquito repellent creams, liquids, coils, mats, etc., use of bed nets for sleeping infants and children during day time to prevent mosquito bite. The environmental measures are detection and elimination of mosquito breeding places, management of roof tops, porticos and sunshades, proper covering for stored water, observation of weekly dry day, etc.
Use electric insecticide devices using repellent treated pads indoor or in enclosed areas.

Use mosquito coils, or candle heated or gas operated devices using insecticide treated pads for patio and veranda or relatively sheltered or low wind outdoor situations.

9.2.3 Eliminate potential breeding sites

- Ensure roof gutters drains freely so that pools of water are not left at any low points. Throw a small amount of methoprene pellets on to the roof above problem gutters.
- Fishponds with fish do not breed mosquitoes. Tadpoles do not eat mosquito larvae. Keep fishponds and frog ponds stocked with fish and do not spray surface spray onto or at the edge of fishponds.
- Other predators include dragonfly naiads, which consume mosquito larvae in the breeding waters, adult dragonflies, which eat adult mosquitoes. The adult dragonfly (scientific name is Odonata. Odonata is an order of carnivorous insects, encompassing dragonflies) likes to eat gnats, mayflies, flies, mosquitoes and other small flying insects. Adult dragonflies eat just about anything that is edible and can be caught. They are a treasure for humanity because they keep mosquito populations under strict control by feasting on them when they are in abundance.
- Two species of fungi are currently also being used for killing adult mosquitoes: Metarhizium anisopliae and Beauveria bassiana.
- Scientists have created spermless male mosquitoes and are experimenting with methods of introducing the sterile males into the environment in the hope of reducing overall mosquito numbers. Another approach under investigation for the control of the mosquito species Aedes aegypti uses a strain that is genetically modified to require the antibiotic Tetracycline to develop beyond the larval stage. Modified males raised in a laboratory will develop normally as they are supplied with this chemical and can be released into the wild. However, their subsequent offspring will lack tetracycline in the wild and will never develop into adults. In recent years, control of mosquitoes by genetic methods like sterile male technique, cytoplasmic incompatibility, chromosomal translocations, sex distortion, and gene replacement has been explored. Their use is still in research phase. They are cheaper, more efficient and not subject to vector resistance.
Larva-eating fish: Dr. Hanson implemented this method in large water containers with significant success in Peru. Over “three hundred thousand fish” were distributed as larvae consumers in the campaign. Effective biocontrol agents include predatory fish that feed on mosquito larvae such as mosquito fish (Gambusia affinis), and some cyprinids (carps and minnows) and killifish. Tilapia will also consume mosquito larvae. Direct introduction of tilapia and mosquito fish into ecosystems around the world has had disastrous consequences. Adult mosquito biological control by means of frogs has also been employed by various agencies.

A simple synthesis for environmentally benign carbon nanoparticles that could be used to control mosquito populations has been demonstrated by scientists in India.

The fight to stop the breeding of these deadly mosquitoes is in the process, precautionary measures are being taken, fogging machines are purchased and extra staff members have been brought in to carry out fogging drives. They will identify and work with the areas severely hit by dengue. Special teams will be formed to find out the vulnerable areas and spread awareness to prevent the spread of Dengue. There is an urgent need of sensitization, as the public needs to be more responsible for preventing dengue.

9.3 Future Work

The dengue transmission is not just based on the human and mosquito parameters alone. Many other improvements and extensions of the model are possible. To compare control strategies with more certainty, there are numerous additions that can be included to our model. There are so many social and environmental factors causing the spread. One example is the addition of seasonal dependence. Mosquitoes are very active in summer seasons whereas their growth is significantly higher at the end of the rainfall seasons due to improper storage of water and drainages. Hence, the above said model can be improved by including temperature, humidity, the mosquito birth rate, and the incubation period in mosquitoes as parameters. Another extension is to add more states to the model. For example a more accurate model might divide the human states by age and gender. The reproductive number $R_0$ plays a vital role in the decision making on the disease spread. Instead of using a classical and general method for deriving $R_0$ when the population is divided into discrete, disjoint cases especially, it may be a good thinking to use the next generation operators. It can be used for models with underlying age structure or spatial
structure. The effects of the incidence rate on the period of immunity can be included which plays an important part in the spread of dengue.

The model can be extended to include the effects of the environment on the spread of dengue. Some parameters, such as the mosquito birth rate and the incubation period in mosquitoes, depend on seasonal environmental factors such as rainfall, temperature, and humidity. These effects can be included by modeling these parameters as periodic functions of time. To improve the entomological sub-model, juvenile mosquito stages can be added. We would like to explore this periodically forced model for features not seen in the autonomous model, including the modifications to the definition of the reproductive number and the endemic states. This would provide a more accurate picture of dengue transmission and prevalence than that obtained from models using parameter values that are averaged over the seasons. An increase in ambient temperature, with high relative humidity and rainfall, increases the emergence rate of mosquitoes, lengthens the life span of adult mosquitoes, and reduces the latency period in mosquitoes, resulting in a multidimensional increase in dengue transmission levels. Other planned improvements to the model include the addition of age and spatial structure. An ultimate goal is to validate this model by applying it to a particular dengue endemic region of the world to compare the predicted endemic states with the prevalence data.

Finally, the relationship between the parameters in our model and the intervention strategies used to control dengue can be quantified. A quantitative relationship would then allow us to directly relate the cost of each strategy to the reduction in disease burden and allow for the definite comparison of the efficiency and cost-effectiveness of different intervention strategies on reducing dengue morbidity and mortality.