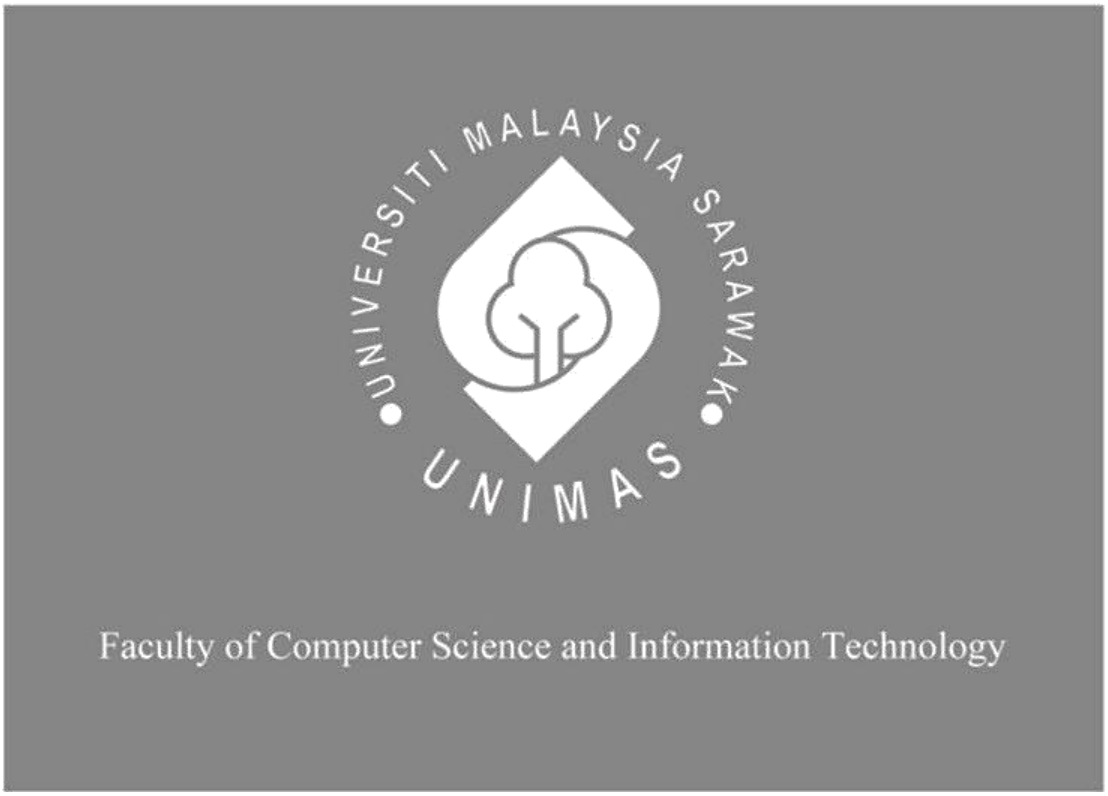


# Modelling the Dynamics and Control Efforts of Human Rabies Epidemic

**Nur'Ain Zuraida Binti Ishak**

Bachelor of Computer Science with Honours (Computational Science)

2019

# Modelling the Dynamics and Control Efforts of Human Rabies Epidemic

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This project is submitted in partial fulfilment of the requirements for the degree of Bachelor of Computer Science with Honours

Faculty of Computer Science and information Technology
UNIVERSITI MALAYSIA SARAWAK 2018

2019

**UNIVERSITI MALAYSIA SARAWAK**

**THESIS STATUS ENDORSEMENT FORM**

**TITLE** ~~HG~~ MODELLING THE DYNAMICS AND CONTROL EFFORTS OF HUMAN RABIES EPIDEMIC

**ACADEMIC SESSION:** 2018/2019

NUR 'AIN ZURAIDA BINTI ISHAK

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## ACKNOWLEDGEMENT

All praise to Allah for protection and ability to do this research project. First and foremost, I have to thank my research supervisors, Dr. Phang Piau. Without his assistance and dedicated involvement in every step throughout the process, this research project would have never been complete. I would like to thank you for his on-going support and willingness to guide me to complete this research project. I am also deeply thankful to my Final Year Project's examiner, Dr. Sarah Flora Samson Juan who encouraged and gives constructive comments that brought this research project towards completion.

Throughout the challenges dealing with feelings during the hardest time, my sincere friends that always give a shoulder to cry on for the past three years, Nor Afikah Binti Mazlan and Nureen Najjah Binti Zolkaifli. Through ups and downs, I am deeply thankful for their friendship. I am also would like to show my gratitude to my course mates from Computational Science programmes for their academic support throughout our final year.

Nobody has been more important to me in the pursuit of this project than the members of my family. I am thankful to my parents for the loves, support, and encouragement to accomplish this research project. Every time I insist to give up, both of you motivate me and I am forever grateful.

May the Almighty God bless all of you.

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## ABSTRACT

*Rabies has been known to occur in Malaysia since 1884. It was only since 1924 that records of human cases have been kept. Most of these cases occurred in Malaysian states bordering Thailand, which is highly endemic of rabies. Sarawak is the first state in Malaysia that recorded 12 rabies death where its outbreak started since July 2017. Mathematical approach can be an important tool in epidemiology study. For understanding disease dynamics, predicting outbreak severity, assessing effectiveness of control interventions, and strive to optimize the development of control measures, epidemiological model is the exact model. In this paper, a theoretical study on the dynamics and control efforts of human rabies epidemic is carried out. A mathematical compartmental susceptible-exposed-infectious-vaccinated (SEIV) model for the dog-human transmission of rabies, taking both domestic and stray dog into consideration is constructed. The control measures include vaccinating susceptible dogs and culling stray dogs. The governing equations are solved numerically using deSolve package in R programming. An interactive web application is built for helping public health practitioners to investigate the dynamics and control effort of human rabies epidemic theoretically.*

## ABSTRAK

Sejak 1884, penyakit rabies telah merebak di Malaysia. Hanya sehingga tahun 1924 rekod kes manusia telah disimpan. Kebanyakan kes ini berlaku di negara-negara yang bersempadan dengan Malaysia, Thailand merupakan negara yang sangat tinggi rekod penyakit rabies. Sarawak merupakan negeri pertama penyakit rabies berlaku di Malaysia yang mencatatkan 12 kematian di mana wabaknya telah bermula sejak bulan Julai 2017. Pendekatan matematik relevan untuk dijadikan medium bagi kajian epidemiologi. Untuk memahami penularan wabak penyakit, meramalkan keadaan wabak, menilai keberkesanan kawalan, dan usaha untuk mengoptimumkan langkah kawalan, model epidemiology merupakan model yang tepat. Dalam makalah ini, satu kajian secara teori mengenai usaha dinamik dan kawalan wabak penyakit rabies dalam kalangan manusia telah dijalankan. Model sebatian matematik, model berpotensi dijangkiti-terdedah-berjangkit-vaksinasi (SEIV) penularan penyakit rabies antara anjing dan manusia yang melibatkan anjing belaan dan terbiar telah dibina. Langkah kawalan melibatkan vaksinasi kepada anjing yang berpotensi untuk dijangkiti dan pembunuhan anjing-anjing liar. Persamaan pentadbir diselesaikan secara berangka menggunakan pakej deSolve dalam pengaturcaraan R. Aplikasi interaktif laman web dibina bagi membantu pengamal kesihatan awam untuk mengkaji penularan dan usaha untuk mengawal penyakit rabies dalam kalangan manusia dilakukan secara teori.

# CHAPTER 1: INTRODUCTION

## 1.1 Project Title

Modelling the dynamics and control efforts of human rabies epidemic.

## 1.2 Introduction

Illness and death from infectious diseases are particularly devastating because they are preventable and treatable. Infectious diseases can spread by many aspects such environment, contact and lack of awareness also contributing to the transmission of infectious diseases. Managing infectious diseases is one of the most challenging problems human face (King et al., 2006), from both human health, agricultural, and conservation perspectives. Rabies, for instance, known as zoonotic viral disease maintained in domestic and wild carnivores and bats all over the world. Within close contact with saliva from infected animals, rabies can be transmitted to other animals and human. Mortality rate nearly 100% proved that this major public health disease is keep increasing.

Rabies has been known to occur in Malaysia since 1884. It was only since 1924 that records of human cases have been kept. Most of these cases occurred in Malaysian states bordering Thailand, which is highly endemic of rabies. Sarawak is the first state in Malaysia that recorded 12 rabies death where its outbreak started since July 2017. There are several modes contributing to the transmission of rabies epidemic. For example, from stray dog infected with rabies virus (under incubation period) that hanging around from the border town along the highway. Other than that, the construction on Pan Borneo Highway and opening more land for palm oil plantations that have possibility for foreign labourers brought with them animals from Kalimantan Barat. Other than that, adoptions of stray dogs which cause translocation of stray

dogs, and irresponsible manner which some owner left their pets at other towns when they noticed their pets were ill. From all of this spread mode mentioned, this study considers the transmission of human rabies epidemic in which the dog population is further divided into stray dogs and domestic dogs.

Mathematical approach can be an important tool in epidemiology study. For understanding disease dynamics, predicting outbreak severity, assessing effectiveness of control interventions, and strive to optimize the development of control measures, epidemiological model is the exact model. One of the mathematical models, such as SEIV which defined as susceptible-exposed-infectious-vaccinated compartment models, can be used to explore disease dynamics and control programmes in a qualitative manner even though, the complexity of real epidemics is frequently limiting to get the precise data. Despite that, the type of model which sensible to real world problem is determine how far the model is useful for planning and assessing control measures for the epidemic.

In this project, a theoretical study on the dynamics and control efforts of human rabies is carried out. A mathematical compartmental susceptible-exposed-infectious-vaccinated (SEIV) model for the dog-human transmission of rabies, taking both domestic and stray dog into consideration is constructed. The control measures include vaccinating susceptible dogs and culling stray dogs. The governing equations are solved numerically using deSolve package in R. An interactive web application is built for helping public health practitioners to investigate the dynamics and control efforts of human rabies epidemic theoretically without having to deal with R programming.

## 1.3 Problem Statement

Rabies can cause inflammation of the brain and spinal cord, and is almost always fatal once contracted, according to the World Health Organisation. Sarawak was the first state in Malaysia that recorded rabies fatality cases in almost two decades. Since July 2017, the public health authorities have been working hard to fight this rare outbreak of the rabies disease. However, it is still being a serious public-health problem in Sarawak. For instance, from 1$^{st}$ April until 27$^{th}$ July 2017, 1016 numbers of dog bite cases were identified in Sarawak. It has been reportedly that these dog bite cases were not only resulting from bites of stray dogs but also domestic dogs. As the data on these stray and domestic dogs are typically not available, mathematical modelling can be used as the medium to enhance the public health practitioners' investigations on the human rabies epidemic. Hence, this project focuses on modelling the dynamics and control efforts of human rabies epidemic, in which both the stray and domestic dog populations are take into considerations. In addition, an interactive web application will be developed to ease the public health practitioners in order to perform numerical simulation for the dynamics of rabies disease spreading and to measure the control efforts of human rabies epidemic theoretically.

## 1.4 Scope

Ordinary differential equations (ODEs) has been used to model the dynamic populations that contain the rabies virus. This project classified each of the stray dog, domestic dog and human populations in four compartmental model: susceptible, exposed, infective and vaccinated. SEIV model is proposed for the dog-human transmission of rabies in which both domestics and stray dogs are considered. Consists of 12 ordinary differential equations and counts for susceptible, exposed, infectious and recovered domestic dog, stray dog and

human. Translating mathematical model by solving numerically and determine the control effort using sensitivity analysis. R programming will be used to resolve the numerical simulation.

### 1.5 Aim and Objective

The main objectives of this project are:

- To study the dynamics and control efforts of human rabies, in which the populations of dogs are subdivided into stray and domestic dogs, mathematically in ordinary differential equation.
- To investigate the dynamics and control efforts of human rabies model through numerical simulation and sensitivity analysis.
- To build an interactive web application for visualizing the dynamics of human rabies model.

### 1.6 Brief Methodology

The methodology of this project is the modelling process in which every mathematical model applied the same method to complete the system. By justifying the assumptions, the model will be constructed in system of non-linear differential equations, in specific, the SEIV (susceptible-exposed-infectious-vaccinated) compartmental model is used. The governing equations will then be solved by numerical simulation using R programming since the number of equations and the parameters involved are large. Figure 1 shows the common methodology of the modelling process.

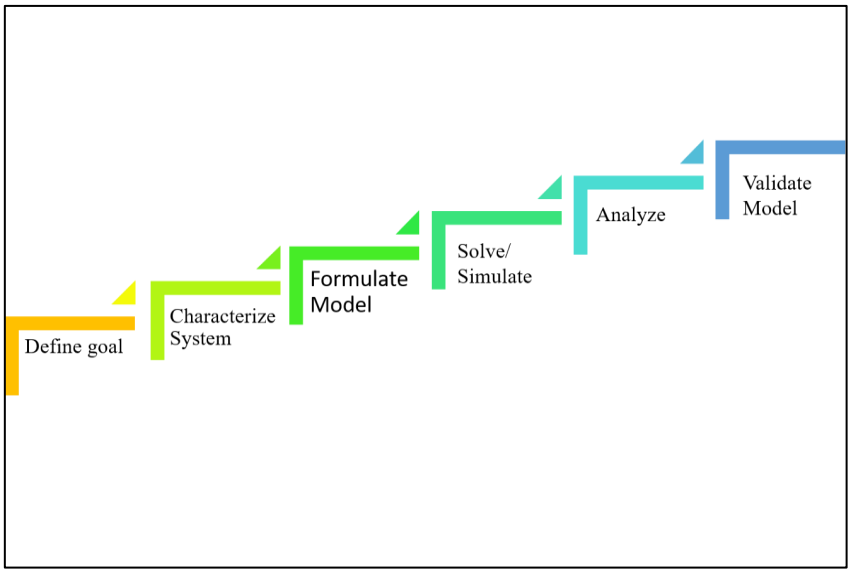


*Figure 1. 1* The Methodology of Modelling Process

## 1.7 Significance of Project

This project will contribute to the already existing research knowledge of rabies. The findings of this project will give to the benefit of society considering that mathematics plays an important role in science and technologies today. The significance of this project is the study will create awareness of the risk of rabies epidemic and decision makers in recognising how to reduce the rabies infectious among dog and human. For community, the finding of the data of human rabies epidemics infected by stray and domestic dog will aware people the importance of prevention and improving the care for the animals. Meanwhile, by carrying out some sensitivity analysis and numerical simulation, this study will help public health practitioners determine the exact solution to overcome this disease. Hence, an interactive website application can be useful for visualizing the dynamics of human rabies epidemic.

## 1.8 Project Schedule

As project schedule is important for ensuring project success, Gantt chart is selected medium to determine the milestone of each step of the project. The project began on 29th September 2018 and expected to end on 20th May 2019 with the estimation durations of 169 days. The detailed of project schedule is shown on Appendix A.

## 1.9 Expected Outcome

At the end of this final year project, we can provide:

- A mathematical model that formulates the dynamics and control efforts of human rabies.
- Numerical simulations and sensitivity analysis of the dynamics and control effort of human rabies.
- An interactive web application for visualizing the dynamics of human rabies model.

## 1.10 Thesis Outline

### 1.10.1 Chapter 1: Introduction

In chapter 1, the overview will be described and briefly introduce the proposed research project. Chapter 1 contains introduction, problem statement, objectives, methodology, project scope, significance of project, project schedule, expected outcome and summary. In introduction section describes the background and some useful information about the proposed research project. In problem statement, it describes the current cases in Sarawak and proposed solution to overcome the problem. Methodology section describes briefly on the process will be used in order to achieve the objectives. The scope illustrates the limitation of the proposed research project to be developed. Besides, significance of project consists of importance of the project and benefit to community. The planned timeline to carried out this project shown in project

schedule section. Expected outcome is the final steps explained the achievement and final result of proposed research project.

### 1.10.2 Chapter 2: Literature Review

Chapter 2 discusses about the literature review done by other researchers based on articles, research paper, book, and other reliable sources. This chapter contains a review of related techniques and methods and a brief explanation to the related works. Background study is carried out to do the comparison between existing projects and the proposed project. At the end of this chapter, a brief description of mathematical model used is given.

### 1.10.3 Chapter 3: Research Methodology

Chapter 3 discusses and explain about the methodology to be used in this project. Mathematical modelling is being used as a guideline to complete the project. Justifying assumptions, model formulation and identifying parameters involved will be discussed in this chapter. Since this project is using complex differential equations, numerical simulation will be used instead of analytical solution to get the approximate data.

### 1.10.4 Chapter 4: Result and Discussion

In chapter 4, the numerical simulation, sensitivity analysis and discussion of results will be presented. It will be discussed further in this chapter.

### 1.10.5 Chapter 5: Conclusion and Future Work

In chapter 5, conclusion is comprising of awareness and improvement throughout this research project. On the other hand, future enhancement on the developed purposed model is being outlined.

## 1.11 Summary

In this project, a mathematical model will formulate the dynamics and control effort of human rabies epidemic. Since the number of parameters are large, numerical simulations will be used also to predict the human rabies infectious cases in Sarawak. Further investigations using sensitivity analysis to control human rabies epidemic that are subdivided into stray dogs and domestic dogs will be conducted. In order to complete the goals, this project is expected to give better understanding on rabies outbreak by visualizing the dynamics of human rabies model in a web application.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Overview

In this chapter, we will discuss about the literature review done by other researchers based on articles, research paper, book, and other reliable sources. This chapter contains a review of related techniques and methods and a brief explanation to the related works. At the end of this chapter, a brief description of mathematical model used is given.

## 2.2 Epidemiological Modelling

Epidemiology refers to the study of the distribution and determinants of health-related states or events (including disease), and the application of this study to control of diseases and other health problems. Various methods can be used to carry out epidemiological investigations: surveillance and descriptive studies can be used to study distribution; analytical studies are used to study determinants. (WHO). Epidemiology study of distribution of disease can lead to answer the causes, effect, time, and place of the disease outbreak. To recognize the risk factors for the infectious or causes, in order to find out the reason of different infection, epidemiology can enhance the finding. To construct and test theories, formulate, and estimate the causes of infection occurred, as well as find the best way to cure, epidemiology modelling is used by developing control and prevention programs. In this research project, only focus on the modelling of human rabies epidemics, in which both the stray and domestic dog populations are take into consideration while do not considering on models of chronic diseases, such as cancer and heart diseases. In most cases, epidemiological modelling is divided into compartments per their epidemiological status. We consider a four-dimensional model, which consists of the susceptible individuals ($S$), exposed individuals but not yet infectious ($E$), infectious individuals ($I$) and vaccinated-treated individuals ($V$). There is movement between

the individual compartments which known as dynamic deterministic modelling. As susceptible individuals get exposed to the infection and then move to the infectious stage and then to the vaccinated stage.

Differential or difference mathematical equations indicates the movement between compartments. There are vaccines for many infectious diseases such as rabies, however the vaccination sold are least. In particular, some infected domestics dogs are not treated properly and abandoned by their hosts or run away from their host. This lead to the mortality and this disease still suffering in the world, especially in developing countries. There availability of mass vaccination and other effective tools for the control rabies in the domestic dog populations is increase, but the disease has been neglected in Asia and Africa where rabies incidence has been largely attributed to the population growth of domestic dogs (*Knobel et al., 2005).*

Assumptions, variables, and parameters are clarified by model formulation mechanism. Mathematical model brings to represent the real problem situations. Models acts as communicators to others by providing information and impact in changing conditions because it is a powerful tool for analysing and predicting the dynamics of phenomena. Mathematical models also get the conceptual results such as, basic reproduction number '$R_0$', thresholds '$\Theta$, $H_1$', contact rate number '' and effective reproductive number '$E_{R0}$'. Mathematical models and numerical simulations also have become useful experimental tools for develop and testing theories, assessing quantitative assumptions, noticing specific request, deciding sensitivities to changes in parameter values, and estimating key parameters from data. The transmission of epidemic disease can be reduced as having a good knowledge of the transmission dynamics of infectious disease in which can give awareness and lead to come out with a better approach of prevention. Mathematical model can be used in comparing, actualizing, planning, measuring and optimizing various observation, prevention cure and control programs.

## 2.3 Review of Related Research Work

### 2.3.1 Analysis Rabies in China: Transmission Dynamics and Control

There are many researchers have been done the investigation of rabies epidemiology and the study of the infection. However most of the studies are about modelling wildlife rabies, and some have been studies on modelling canine and human rabies. The research done by Zhang et al. (2011) on rabies transmission in China, purpose deterministic model consists of susceptible, exposed, infectious, and recovered subpopulations of both dogs and humans. The spread of rabies among dog and from infectious dog to human is described.

The research come out with a basic reproduction number $R_0 = 2$ for rabies transmission in China. Sensitivity analysis of $R_0$ in terms of model parameters was performed by Zhang et al. (2011) and compare the effect of culling and immunization of dogs that demonstrates (i) reducing dog birth rate and increasing the dog immunization coverage rate are the most effective methods in controlling human rabies infection in China; and (ii) culling of dogs can be replaced by immunizations of dogs. In China, the annual crop of new-born puppies can exceed 5 million and the proportion of immunized dogs is only 10%, which is too low. When the per capita cost of vaccination is less than 20% of the per capita cost of culling, both approach that demonstrate by Zhang et al. (2011) will be cheaper. However, in this research they did not consider pre-exposure vaccination of the human population and the same vaccination parameter for both exposed and susceptible class of the dog compartment is same.

This research proposed a susceptible, exposed, infectious, and recovered model to determine the transmission dynamics of rabies in China. This model does not include culling of dogs. By conduct some sensitivity analysis, Zhang (2011) found that human rabies can be controlled with two strategies. The first strategy is the annual crop of new-born puppies should