A NEW HYBRID MODEL OF DENGUE INCIDENCE RATE USING NEGATIVE BINOMIAL GENERALISED ADDITIVE MODEL AND FUZZY C-MEANS MODEL: A CASE STUDY IN SELANGOR

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DEDICATION

To my beloved parents
Encik Mohamad bin Chokro and Puan Nur Sa'adah binti Md. Yatim
and
To my beloved siblings
Naily, Nadzreen and Nuratiqah
This humble work is a sign of my love to you!

Lots of love,
Nazeera Mohamad

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"In the name of Allah, Most Gracious, Most Merciful"

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ABSTRACT

Dengue is one of the top reason for illness and mortality in the world with beyond one-third of the world's population living in the risk areas of dengue infection. In this study, there are five stages to achieve the research objectives. Firstly, the verification of predetermined variables. Secondly, the identification of new datasets after clustered by district and Fuzzy C-Means Model (FCM). Thirdly, the development of models using the existing dataset and the new datasets which clustered by the two different clustering categories. Then, to assess the models developed by using three measurement methods which are deviance (*D*), Akaike Information Criteria (*AIC*) and Bayesian Information Criteria (*BIC*). Lastly, the validation of model developed by comparing the value of *D*, *AIC* and *BIC* between the existing model and the new models developed which used the new datasets. There are two different clustering techniques applied which are clustering the data by district and by FCM. This study proposed a new modelling hybrid framework by using two statistical models which are FCM and negative binomial Generalised Additive Model (GAM). This study successfully presents the significant difference in the climatic and non-climatic factors that influenced dengue incidence rate (DIR) in Selangor, Malaysia. Results show that the climatic factors such as rainfall with current month up to 3 months and number of rainy days with current month up to lag 3 months are significant to DIR. Besides, the interaction between rainfall and number of rainy days also shows strong positive relationship to DIR. Meanwhile, non-climatic variables such as population density, number of locality and lag DIR from 1 month until 3 months also show significant relationship towards DIR. For both clustering techniques, there are two clusters formed and there are four new models developed in this study. After comparing the values of *D*, *AIC* and *BIC* between the existing model and the new models, this study concluded that four new models recorded lower values compared to the existing model. Therefore, the four new models are selected to present the dengue incidence in Selangor.

ABSTRAK

Denggi adalah salah satu sebab utama penyakit dan kematian di dunia dengan lebih satu pertiga daripada populasi dunia yang hidup di kawasan risiko jangkitan denggi. Dalam kajian ini, terdapat lima peringkat untuk mencapai matlamat penyelidikan. Pertama, pengesahan pembolehubah yang telah ditetapkan. Kedua, pengenalpastian dataset baru selepas menggunakan teknik pengelompokan mengikut daerah dan *Fuzzy C-Means Model* (FCM). Ketiga, pembinaan model menggunakan dataset asal dan dataset baru yang dikelompokkan melalui dua kategori teknik pengelompokan yang berbeza. Kemudian, penilaian model yang dibina dengan menggunakan tiga kaedah pengukuran iaitu nilai penyimpangan terkecil (*D*), *Akaike Information Criteria* (*AIC*) dan *Bayesian Information Criteria* (*BIC*). Akhir sekali, pengesahan model yang dibina dengan membandingkan nilai *D*, *AIC* dan *BIC* antara model asal dan model baru yang dibina menggunakan dataset yang baru. Terdapat dua teknik pengelompokan yang berlainan iaitu mengikul daerah dan FCM. Kajian ini mencadangkan rangka kerja baru melalui pemodelan hibrid dengan dua model statistik iaitu FCM dan negatif binomial *Generalised Additive Model* (GAM). Kajian ini berjaya membuktikan faktor iklim dan bukan iklim yang signifikan mempengaruhi kadar kejadian denggi (DIR) di Selangor, Malaysia. Hasil daripada analisis untuk daerah dan FCM mendapati faktor iklim seperti hujan dengan bulan semasa sehingga 3 bulan sebelumnya dan jumlah hari hujan dengan bulan semasa sehingga 3 bulan seterusnya adalah penting kepada DIR. Selain itu, interaksi antara hujan dengan bilangan hari hujan juga menunjukkan hubungan positif yang kuat dengan DIR. embolehubah bukan iklim seperti kepadatan penduduk, bilangan lokaliti dan lag DIR dari 1 bulan hingga 3 bulan juga menunjukkan hubungan yang signifikan terhadap DIR. Kedua-dua teknik pengelompokan membentuk dua kelompok dan terdapat empat model baru yang dibina dalam kajian ini. Setelah membandingkan nilai *D*, *AIC* dan *BIC* antara model asal dan model-model baru, kajian ini mendapati bahawa empat model baru mencatatkan nilai yang lebih rendah

berbanding model asal. Oleh itu, empat model baru tersebut dipilih untuk mewakili kejadian denggi di Selangor.

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LIST OF SYMBOLS AND ABBREVIATIONS

AIC	-	Akaike Information Criterion
BIC	-	Bayesian Information Criterion
z	-	Climatic factors
r	-	Correlation coefficient
d	-	District
p	-	Estimation of the total population
e	-	Expected number of dengue cases
L	-	Likelihood
β	-	Linear predictor
μ	-	Mean
m	-	Month
x	-	Non-climatic factors
y	-	Number of new dengue cases
i	-	Number of observations
ϕ	-	Scale parameter
f	-	Smooth function
υ	-	Unknown relative dengue factor
t	-	Year
BI	-	Breteau Index
CI	-	Container Index
COMBI	-	Communication for Behavioral Impact
DENV-1	-	Dengue Type 1 Virus
DENV-2	-	Dengue Type 2 Virus
DENV-3	-	Dengue Type 3 Virus
DENV-4	-	Dengue Type 4 Virus

DHF	-	Dengue Hemorrhagic Fever
DIR	-	Dengue Incidence Rate
DoSM	-	Department of Statistics Malaysia
EWS	-	Early Warning System
FCM	-	Fuzzy C-Means Model
GAM	-	Generalised Additive Model
GLM	-	Generalised Linear Model
GLMM	-	Generalised Linear Mixed Model
GSV	-	Generalised Cross Validation
HI	-	House Index
MOH	-	Ministry of Health
ONI	-	Oceanic Niño Index
UBRE	-	Un-Biased Risked Estimator
WHO	-	World Health Organisation

CHAPTER 1

INTRODUCTION

This chapter introduces the main research objectives and the motivations of this study. Exploration of the relationship between climatic and non-climatic factors and the incidence rate of dengue is the major focus of the study and also for using the relationships which existed to provide prompt notification of dengue incidence. The chapter begins by outlining the factors associated with dengue disease generally and to be specific, in Selangor as well as Malaysia. It then moves to determine the research objectives and concludes by embarking the framework for the following chapters of the study.

1.1 Motivations

Infectious disease is a leading cause of death worldwide. Early exposure is important to control the emergence of disease, whether occurred naturally or deliberately introduced. Besides that, surveillance of infectious disease is conducted with the main intention to notify the epidemics in the early stage and necessary to control the epidemics of infectious disease. Around the world, every health agency is struggling to put an enormous effort in controlling the epidemics, unfortunately, the disease still continues to spread.

Meanwhile, the dengue incidence has grown severely in Malaysia and now significantly as a major public health concern (Mohd-Zaki *et al.*, 2014; Juni *et al.*, 2015). Public health agencies in Malaysia need to spend more attention and priority in reducing the number of dengue cases reported. Lin *et al.* (2016) proved the establishment of the integrated community-based control strategy as the new mechanism that could be applied to reduce the dengue activity.

However, the symptoms were slightly identical with other infectious disease and the situation made the disease difficult to confirm. In general, the dengue cases reported keep on increasing because the geographical distribution of dengue expands year by year. This leads to the detection of new dengue risk area in rural and also in urban areas (Aloka *et al.*, 2013; Juni *et al.*, 2015). Figure 1.1 presents the increasing number of dengue cases which peak point was in 2015 compared lower cases recorded in 2011.

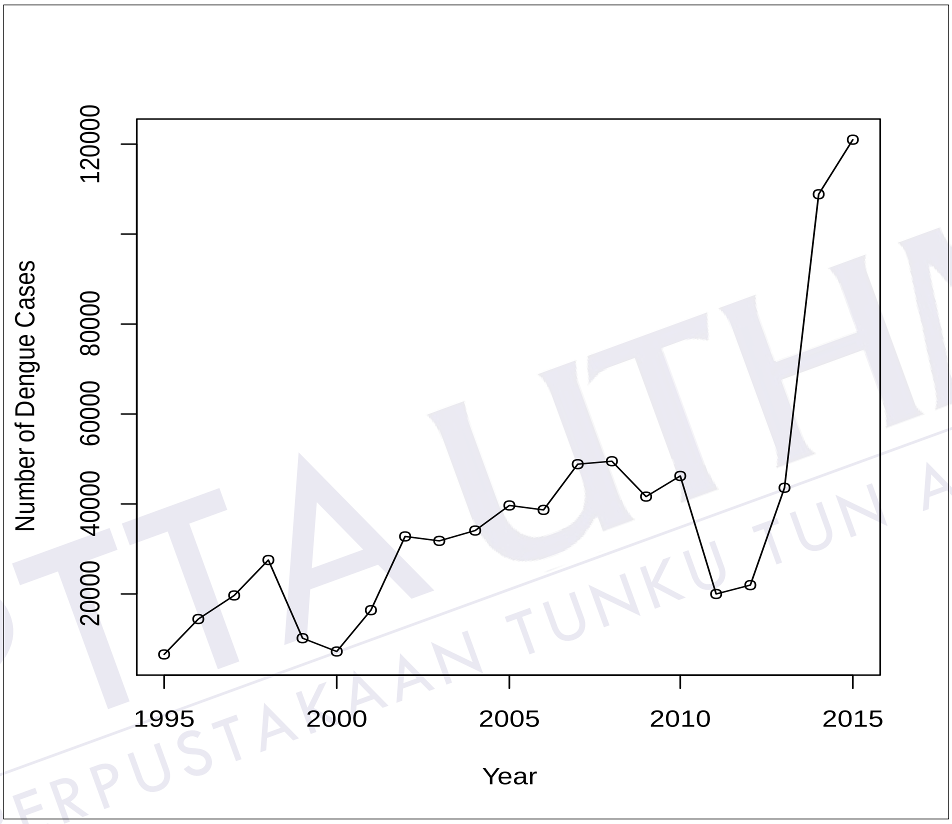

Figure 1.1: Dengue cases reported in Malaysia 1995-2015
(Ministry of Health Malaysia, 2015)

Dengue is the main health problem in Malaysia where Ministry of Health (MOH) Malaysia reported dengue is endemic since 1971. Since then, Malaysia was known as one of the worst affected countries and the dengue incidence rate (DIR) has fluctuated from 5.4 cases per 100,000 population in 1974 and the cases reported double to 10.4 cases per 100,000 population in 1987 (Shehkar & Huat, 1992). Meanwhile, the rate continues to increase four times higher between the year 1999 to the next eight years (MOH Malaysia, 2010). The frequency of dengue outbreaks has occurred relatively every 2 years (Guzman & Kouri, 2008). The number of dengue reported keep increasing and numerous programs have been introduced involving community and health authorities since the 1970s (Che Him *et al.*, 2012). However, there has been slightly little research on modelling dengue by using climate and other covariates across the state that is recorded as the hotspot area in Malaysia.

A major problem arises in pursuing this study is the availability of information regarding non-climatic factors in Malaysia. This problem also occurred in many different countries, for example, in Vietnam, Schmidt *et al.* (2011) used population density and water supply as the main variables in their study. However, they justified that population density measure is imprecise because of the insufficient information such as information for death, migration and travel are not account in their study. But, there are some researchers found the relationship between non-climatic factors and dengue fever. For example, Stewart-Ibarra & Lowe (2013) investigated the importance of climatic and non-climatic factors in dengue fever in Ecuador and found that climatic and non-climatic factors gave important role in dengue transmission. Therefore, the results from the previous research could be the benchmark for further study to plan the exploration in finding the relationship between climatic and non-climatic factors and dengue incidence in Malaysia.

The application of statistical analysis in modelling dengue cases has been applied worldwide. Che Him *et al.* (2012) used Negative Binomial Generalised Additive Models (GAM) to explore the potential for using climatic covariates in modelling dengue in Malaysia. They found that both numbers of rainy days and rainfall with zero and three months, temperature lagged zero month and sea surface temperature lagged six months as the best predictor in a dengue prediction model in Malaysia. Even clustering technique is quite new in modelling dengue fever. Shaukat *et al.* (2015) able to apply clustering technique to different areas of the district in Jhelum, Pakistan. They strongly suggested to adopt clustering technique in future research since this study has proved better visualization in determining the highest potential dengue risk area.

Therefore, there has been only a few research on modelling dengue by using climatic and non-climatic covariates across the state that is recorded as the “hotspot” area in Malaysia. There are a few questions that need to be explored throughout this study; to what extent can relationships established, to what extent are there hotspot area affected and to what extent do any of potential factors incorporate in order to develop sensible models for dengue disease in Malaysia. The next section focuses on more specific research aims.

1.2 Problem statement

The distribution of dengue epidemics is growing exponentially while the distribution in terms of number and severity cases and the new areas of localities infected by dengue virus infection are found. One of the major problem endured in dengue epidemiology is the poor knowledge of the dengue risk factors including both climatic and non-climatic factors and the relationship among them. This problem usually occurs in rural areas as many dengue cases were not reported. Besides, there are existing studies reported on the relationship between dengue incidence and climatic factors, such as a number of rainy days and amount of rainfall. However, in Malaysia, there has been a limited amount of research on the relationship between those climatic factors and DIR. Besides, there are some limitations to the non-climatic confounding factors such as number of localities and population density due to unavailability of data which lead to misleading the climate-disease relationship.

Next, dengue fever is contagious in Malaysia since the early 1970s. Therefore, it is necessary to identify the high-risk areas of dengue fever. So far, in Malaysia, there is no author used clustering areas of localities in their study. Therefore, by applying clustering technique in this study, the health authorities and professionals can determine and focus on the source of dengue attack in any area especially the high-risk areas. Lastly, in modelling DIR, there are non-linear relationships with independent variables potentially to occur (Che Him *et al.*, 2012). For this reason, GAM is the most appropriate statistical model to identify the non-linear relationships. In addition, in Malaysia, due to data limitations, there is a lack of modelling dengue studies has been conducted on large enough data sets to predict the incorporation of climatic and non-climatic factors to provide an early alarm of future dengue outbreak. Therefore, this study comprises of monthly dengue data from the year 2010 until 2015 and hopefully, the outcome can help health workers and stakeholders to speed up the development of dengue program in future dengue outbreaks.

1.3 Research objectives

This study embarks on the following objectives:

1. To verify pre-determined factors to be adopted in the new modelling framework.

2. To identify datasets by clustering based on district and Fuzzy C-Means Model (FCM) categories.
3. To propose the new modelling framework by using a combination of the Negative Binomial Generalised Additive Model (GAM) and Fuzzy C-Mean Model (FCM) for dengue fever in Malaysia.
4. To assess the performance of new models which is a combination of Negative Binomial Generalised Additive Model (GAM) and Fuzzy C-Mean Model (FCM) by comparing value of Deviance (D), Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC).
5. To validate models by comparing the proposed model with existing model.

1.4 Significance of study

This study has diversified unique features that can contribute to minimise the identified dengue risk problem in Malaysia. Firstly, this study aimed to develop modelling dengue cases which focused on monthly data of dengue cases in Selangor and related confounding factors from January 2010 to August 2015 (68 months). This study is different from the other research because this study considered a long amount of time on a monthly basis of dengue data in Selangor. Secondly, in the modelling, this study undergo two different clustering processes in which the data set clustered by district and the application of FCM. After the clustering process, the clustered data set then adopted by Negative Binomial GAM to develop model represent dengue incidence in Selangor. So far, this is the first study that has considered the clustering approach especially the application of FCM with the combination of Negative Binomial GAM.

Next, another major contribution of this study is the application of GAM in modelling dengue cases in Selangor. Due to the small scale of year data, this study used the smooth function for month to narrow down the impact of analysis for GAM. Therefore, one of the most important findings in this study is the ability to deal with the next dengue outbreak by made several months ahead of preparation by referring to the potential model developed in this study.

1.5 Scope of study

The data that has been used in this study is dengue data. The dengue data was obtained from Vector Unit of Operational Dengue, Public Health Division at Ministry of Health Malaysia. This data was collected from nine administrative districts in Selangor which included Gombak, Hulu Langat, Hulu Selangor, Klang, Kuala Langat, Kuala Selangor, Petaling, Sabak Bernam and Sepang were used in this study. The collated data consists of monthly confirmed dengue cases in nine districts in Selangor. This data was recorded from January 1st, 2010 until August 31st, 2015, which consists of 68 months. In addition, a number of locality in each district of Selangor that has been affected by dengue virus also provided in the datasets besides the dengue data. This study choose Selangor as a case study because it has recorded the highest number of dengue cases, which accounted for 50% (50,000 cases) of total dengue cases (100,028 cases) reported in Malaysia during 2016. Besides that, Selangor was one of the highest population density of all states in Malaysia, which estimated 674 people per square kilometre (Department of Statistics Malaysia, 2011).

The second variable that used in this study is rainfall. The rainfall data was obtained from Department of Irrigation and Drainage Malaysia. This study collated rainfall data from 22 rainfall stations in Selangor. All the rainfall stations that used in this study have to represent each district in Selangor. From the data that has been provided, the average amount of rainfall (in millimetre) and the average number of rainy days (in days) were used to modelling dengue cases in Selangor.

1.6 Summary

This chapter has outlined the motivation for the research considered in the next chapters of this study. Therefore, the outline of next chapters is as follows. Chapter 2 include a literature review of confounding factors related to the DIR including climatic and non-climatic factors. Dengue fever and its transmission both global and specific in Malaysia and Selangor, together with an extra review of related studies using statistical techniques to develop dengue model is included. A brief introduction to Malaysia and its climate as well as dengue surveillance practiced are also discussed. Then, Chapter 3 is an introduction of GLM and GAM to explain monthly dengue cases in Selangor from January 2010-August 2015. FCM also introduced to discuss the clustering process of the datasets. Subsequently, Chapter 4 explores datasets particularly to dengue in Selangor and potential climatic and non-climatic covariates relevant to DIR. Selection of factors is used to identify climatic and non-climatic factors that have a relationship with DIR in Selangor. The used of clustering approach in the datasets is also explained. In Chapter 5, the application of FCM and GAM to develop model represent dengue incidence in Selangor. The potential models for Selangor are then tested by comparing the values of Akaike Information Criteria (*AIC*), Bayesian Information Criteria (*BIC*) and deviance, in order to choose the best models, represent DIR in Selangor. The final chapter of this study summarises the conclusions, results and recommendations for future modelling dengue research.

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