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Dengue Disease Mapping with Standardized Morbidity Ratio and Poisson-gamma Model: An Analysis of Dengue Disease in Perak, Malaysia

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***Abstract*—**Dengue disease is an infectious vector-borne viral disease that is commonly found in tropical and sub-tropical regions, especially in urban and semi-urban areas, around the world and including Malaysia. There is no currently available vaccine or chemotherapy for the prevention or treatment of dengue disease. Therefore prevention and treatment of the disease depend on vector surveillance and control measures. Disease risk mapping has been recognized as an important tool in the prevention and control strategies for diseases. The choice of statistical model used for relative risk estimation is important as a good model will subsequently produce a good disease risk map. Therefore, the aim of this study is to estimate the relative risk for dengue disease based initially on the most common statistic used in disease mapping called Standardized Morbidity Ratio (SMR) and one of the earliest applications of Bayesian methodology called Poisson-gamma model. This paper begins by providing a review of the SMR method, which we then apply to dengue data of Perak, Malaysia. We then fit an extension of the SMR method, which is the Poisson-gamma model. Both results are displayed and compared using graph, tables and maps. Results of the analysis shows that the latter method gives a better relative risk estimates compared with using the SMR. The Poisson-gamma model has been demonstrated can overcome the problem of SMR when there is no observed dengue cases in certain regions. However, covariate adjustment in this model is difficult and there is no possibility for allowing spatial correlation between risks in adjacent areas. The drawbacks of this model have motivated many researchers to propose other alternative methods for estimating the risk.

***Keywords*—**Dengue disease, Disease mapping, Standardized Morbidity Ratio, Poisson-gamma model, Relative risk.

I. Introduction

THIS paper discusses and demonstrates the most common methods used in the study of disease mapping which are Standardized Morbidity Ratio and Poisson-gamma model and its application to dengue data of Perak, Malaysia. First, we describe the classical method in estimating relative risk using SMR method. This includes the definition of SMR and its drawbacks.

This is followed by an overview of the earliest application of Bayesian methodology called Poisson-gamma model which is based on model suggested by [1]. Finally, these two methods are applied to observed dengue data of Perak in Malaysia in order to demonstrate and identify a better method of estimating dengue risk.

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II. Standardized Morbidity Ratio (SMR)

SMR is the commonest statistic used in disease mapping to estimate the relative risk of a disease in a map. In this research, SMR basically compares the observed incidence with the expected incidence, which has been used traditionally for the analysis of counts within tracts as explained in [2]. It is used to estimate the relative risk, which may be interpreted as the probability that a person within a specified region contracts the disease divided by the probability that a person in the population contracts the disease.

In disease mapping, suppose that the study area to be mapped is divided into M mutually exclusive regions (i=1, 2, …, M). Each region has its own observed number of cases o_i and expected number of cases e_i based on an assumption of homogeneity in its simplest form. Using o_i and e_i as obtained from the available data, we can calculate the relative risk θ_i for state i, which is the SMR defined as

$$\hat{\theta}_i = \frac{o_i}{e_i} \tag{1}$$

Equation (1) is used and discussed by [3] in their study on standardized morbidity ratio and its application to dengue disease mapping in Malaysia.

Although the SMR has been used commonly as an index to measure relative risk, it has several disadvantages. According to [1], since it is based on a ratio estimator, the mean and variance of SMR are highly dependent upon e_i. The SMR is very large in areas where the expected numbers of cases are small, and small for areas where the expected numbers of cases are large. Furthermore, in areas where there are no observed count data or cases, the SMR is necessarily zero. This makes the interpretation of SMR difficult and it should be done with caution. This view is supported by [4], who points out that the SMR is a reliable measure of relative risk for large geographical regions such as countries or states, but is unreliable for small areas such as counties.

III. Poisson-Gamma Model

The drawbacks of the SMR have led many researchers to investigate a variety of methods for estimating the relative risk

of a disease, including the use of Bayesian methods. One of the earliest examples of Bayesian mapping is the Poisson-gamma model as discussed and demonstrated by [1].

In this model, for i=1,2,…,M study regions and j=1,2,…,T time periods, the numbers of new infectives y_{ij} are assumed to follow a Poisson distribution within a given period of time, with mean and variance $e_{ij}\theta_{ij}$ where e_{ij} is the expected number of new infectives and θ_{ij} is the relative risk:

$$y_{ij}\left|e_{ij},\theta_{ij}\right. \sim Poisson(e_{ij}\theta_{ij}) \quad (2)$$

The relative risk parameter has a gamma prior distribution with parameters α and β:

$$\theta_{ij} \sim Gamma(\alpha,\beta) \quad (3)$$

The output of the analysis includes the posterior expected relative risks for all regions and for all time periods, based on this Poisson-gamma model.

IV. Application of Standardized Morbidity Ratio and Poisson-Gamma Model to Dengue Disease Mapping

This section demonstrates and displays the results of the applications of existing relative risk estimation methods, corresponding to the classical model based on the standardized morbidity ratio and the earliest example of Bayesian mapping methods based on the Poisson-gamma model using observed dengue data of Perak, Malaysia. The data set are analysed using Win BUGS software, which is a package designed to carry out wide variety Bayesian Models. All of these results are then compared and presented in table, graphs and maps, and the best fitted model for relative risk estimation for dengue disease mapping in Perak, Malaysia is revealed.

A. The Data Set

Data used in this analysis were provided by the Perak State Department of Health and the Department of Statistics, both in Malaysia. Both methods presented here are applied to dengue data in the form of counts of cases within ten administrative districts of Perak, Malaysia. These administrative districts are Batang Padang, Manjung, Kinta, Kerian, Kuala Kangsar, Larut Matang & Selama, Hilir Perak, Hulu Perak, Perak Tengah and Kampar.

In this analysis, dengue data refer to observed new infective dengue cases of humans, which were observed every week from epidemiology week 1 to epidemiology week 52 of the year 2011.

B. The Results

The outcomes of relative risk estimation for both models in all districts of Perak, Malaysia are displayed in Figs. 1 and 2, respectively.

Both graphs show that most districts have relative risk below one for all epidemiology weeks. This is a necessary consequence of the positive skew inherent in the distribution of the positive valued relative risk.

Based on the definition of relative risk explained in [5], a relative risk less than one means that susceptible people within this district is generally less likely to contract dengue compared with people in the overall population. Otherwise, it can be seen clearly from both graphs that the districts of Kuala Kangsar, Manjung and Hilir Perak have relative risks greater than one for most epidemiology weeks, which indicates that susceptible people within these three districts are more likely to catch dengue compared with people in the overall population of Perak, Malaysia.

Table I presents numerical values for the relative risk based on the SMR method and Poisson-gamma model, specifically for epidemiology week 1 of the year 2011. This time period is chosen as an example for comparison purposes only. For the Poisson-gamma models, the prior parameters value, α and β are unknown but assumed to have exponential prior distributions with hyperparameter values of 0.1 as suggested by [1]. Furthermore, the prior expected relative risks based on this model are equal to 1.

From Table I, it can be seen that by using SMR model, susceptible people within the district of Manjung have the highest risk of contracting dengue, while susceptible people within the districts of Kerian and Kampar have the lowest risk of contracting dengue, when compared with people in the overall population. The corresponding values of relative risk are approximately 3.63 and 0, respectively. Estimation based on Poisson-gamma also shows that susceptible people within the district of Manjung have the highest risk of about 2.53, while susceptible people within the districts of Kerian have the lowest risk of about 0.44. It can be seen that when using the SMR method, the estimated relative risk becomes zero when there are no observed cases, as in the districts of Kerian and Kampar, which can be problematic disadvantage of this SMR approach. However, the Poisson-gamma model does not suffer from this drawback and generates positive estimates of relative risk in districts that have no observed cases.

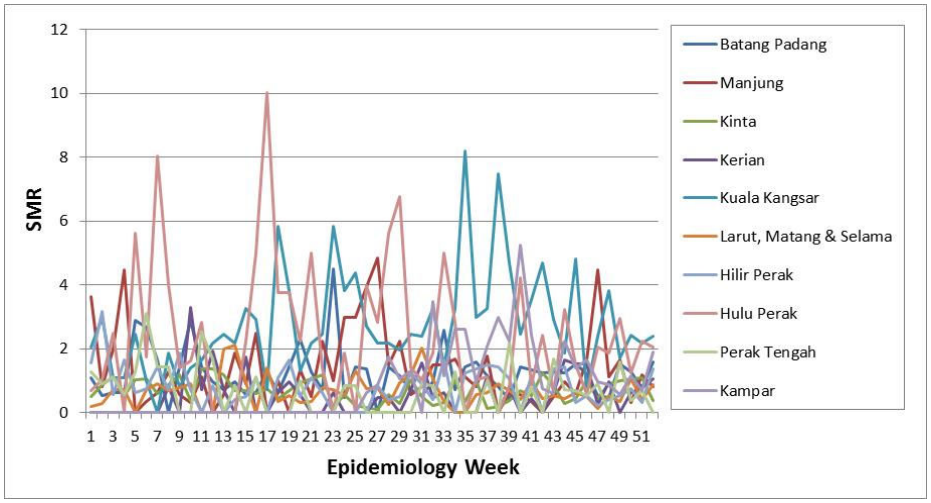

Fig. 1 Time series plots of the estimated relative risk based on the SMR method for different districts in Perak, Malaysia

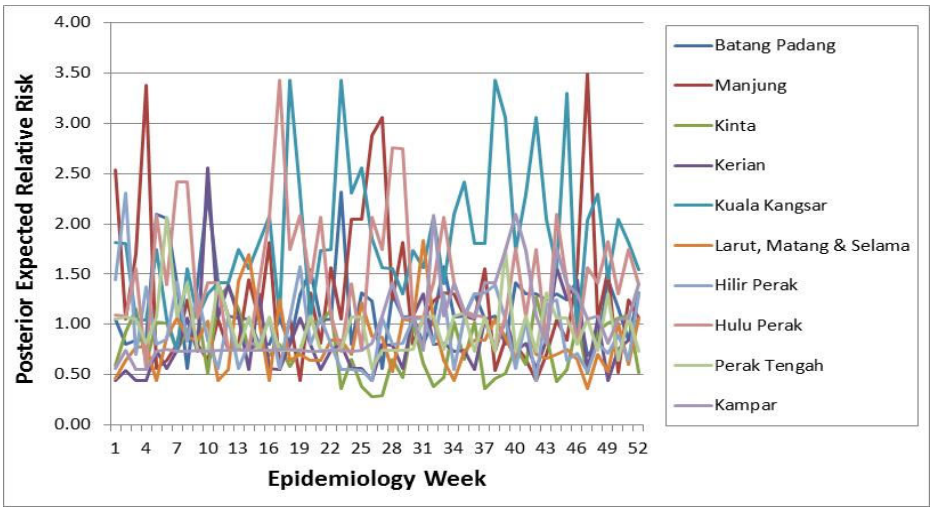

Fig. 2 Time series plots of the estimated relative risk based on the Poisson-gamma model for different districts in Perak, Malaysia

In this analysis, a gamma prior distribution is used as this distribution is the conjugate prior for the Poisson distribution, and the use of it is common. A sensitivity analysis using less and more informative priors and hyperpriors revealed very similar results in all districts.

Moreover, the results of relative risk estimation based on both methods presented in Table I for week 1 only give similar conclusions to those results presented in Figs. 1 and 2 for the whole year, whereby susceptible people within the districts of Manjung, Kuala Kangsar and Hilir Perak are more likely to contract dengue compared to people within the overall population of Perak, Malaysia, whilst susceptible people within the other districts are less likely to contract dengue compared to people within the overall population.

TABLE I
COMPARISON OF THE RELATIVE RISK ESTIMATION BASED ON SMR METHOD AND POISSON-GAMMA MODEL FOR EPIDEMIOLOGY WEEK 1 OF THE YEAR 2011

Districts	Relative Risk based on SMR Method	Relative Risk based on Poisson-gamma Model
Batang Padang	1.08	1.05
Manjung	3.63	2.53
Kinta	0.51	0.59
Kerian	0	0.44
Kuala Kangsar	2.05	1.82
Larut, Matang & Selama	0.20	0.46
Hilir Perak	1.55	1.45
Hulu Perak	0.70	1.09
Perak Tengah	1.26	1.06
Kampar	0	0.56

C. Win BUGS Code for Relative Risk Estimation Based On the SMR Method and the Poisson-gamma Model

The Win BUGS code in Fig. 3 demonstrates one of many types of software used to estimate the relative risk of dengue occurrences for the SMR method described above. Similarly, Fig. 4 depicts the Win BUGS code used in the estimation of relative risk based on the Poisson-gamma model.

```
model{

for (i in 1:M){
for (j in 1:T){

        #Relative Risk-SMR
        theta[i,j]<-y[i,j]/e[i,j]
}}}
```

Fig. 3 Standardized Morbidity Ratio in WinBUGS

This code for the Poisson-gamma model was written by [1], who applied to an analysis of influenza data from South Carolina.

```
model{

for (i in 1:M){
for (j in 1:T){

      #Poisson likelihood for observed counts
      y[i,j]~dpois(mu[i,j])
      mu[i,j]<-e[i,j]*theta[i,j]
      #Relative Risk
      theta[i,j]~dgamma(a,b)
}
}
#Prior distribution for "population" parameters
a~dexp(0.1)
b~dexp(0.1)

#Population Mean and Population variance
mean<-a/b
var<-a/pow(b,2)

}
```

Fig. 4 Poisson-gamma Model in WinBUGS

D. Maps of the Relative Risk Estimates for Dengue Disease Mapping in the Ten Districts of Perak, Malaysia

In this section, disease maps are used as a means of graphical presentation of the statistical results for relative risk estimation discussed in previous section. For the purposes of interpretation in our application, choropleth maps with single-hue progression colours are used in this analysis in order to display and differentiate between the high and low risk areas of dengue occurrences for each district in Perak, Malaysia.

Figs. 3 and Fig. 4 show the thematic dengue risk maps for relative risk estimation based on the SMR method and the Poisson-gamma model in the ten administrative districts of Perak, Malaysia on one representative epidemiology week during the year 2011. Similar maps can be generated to represent the relative risks for each epidemiology week from 1st January 2011 until 31st December 2011. Each district is assigned one of five different levels of relative risk which are very low, low, medium, high and very high risks, with respective intervals of [0.0,0.5), [0.5,1), [1,1.5), [1.5,2) and [2,∞) respectively. The darkest hue represents the very high risk and the lightest shade representing the very low risk for different levels of relative risk for all choropleth maps.

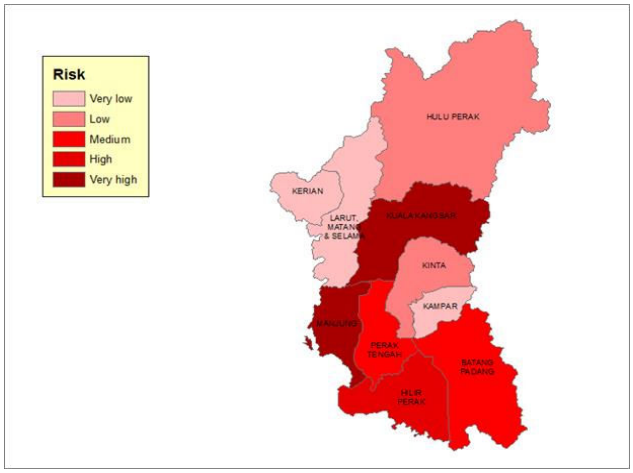

Fig. 5 Disease map of estimated relative risks based on the SMR method

The SMR map in Fig. 5 depicts that the districts with very high risk are Manjung and Kuala Kangsar. This is followed by the district of Hilir Perak with high risk and the districts of Batang Padang and Perak Tengah with medium risk. Districts with low risk include the districts of Hulu Perak and Kinta. The other districts with very low risk are Kerian, Larut, Matang & Selama, and Kampar.

The Poisson-gamma model map in Fig. 6 shows that the district of Manjung has very high risk of dengue occurrences, while the district of Kuala Kangsar has high risk. The districts with medium risk are Hulu Perak, Hilir Perak, Batang Padang and Perak Tengah. The districts of Kinta and Kampar have low risk, while districts with very low risk include the districts of Kerian and Larut, Matang & Selama.

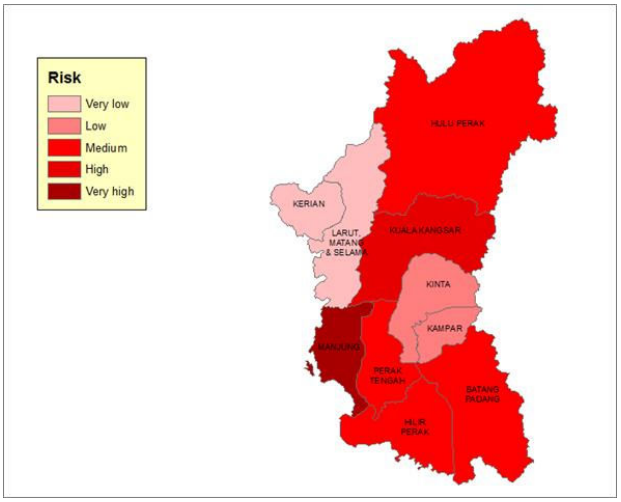

Fig. 6 Disease map of posterior relative risks based on the Poisson-gamma model

Comparisons among the SMR map and Poisson-gamma map, specifically for epidemiology week 1, demonstrate no obvious differences in terms of the estimated risks generated by both methods considered. These maps are primarily intended to be a good presentation tool for identifying regions with high risk, so that further attention could be given to these priority districts.

V. Conclusion

Relative risk estimation based on Poisson-gamma model has been demonstrated as a better model compared to the most common model in disease mapping which is standardized morbidity ratio (SMR). This Poisson-gamma model can overcome the problem of SMR especially when there is no observed dengue case in certain regions. However, covariate adjustment in this model is difficult and there is no possibility for allowing spatial correlation between risks in adjacent areas as discussed in [1]. The disadvantages of this model have motivated many researchers to propose other alternative methods for estimating the risk.

Therefore, extensions to this work include the estimation of relative risk based on the dengue disease transmission model as suggested by [6].

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