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RELATIVE RISK ESTIMATION OF DENGUE DISEASE IN BANDUNG, INDONESIA, USING POISSON-GAMMA AND BYM MODELS CONSIDERING THE SEVERITY LEVEL

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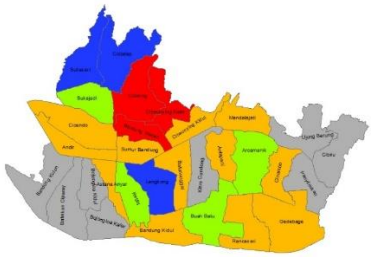
Graphical abstract



Abstract

Recently, dengue as one of the most dangerous diseases in the world has attracted more attention due to its soaring infection cases. One method to estimate the relative risks of dengue transmission commonly used is through the statistics approach. Dengue cases of all severity levels spread rapidly in every district in Bandung, Indonesia every month. There are two different severity levels of dengue disease: the early-stage known as Dengue Fever (DF) and the severe-stage manifested as Dengue Hemorrhagic Fever (DHF) and Dengue Shock Syndrome (DSS). This research investigates the early stage, the severe stage, and the combination of both stages. The non-spatial Poisson-gamma model and spatial Besag, York, and Mollie (BYM) model are applied to estimate the relative risks in each district in Bandung every month. These two models are chosen to analyze whether there is a spatial effect in dengue transmission in particular critical area. This research will use 2013's data from St. Borromeus hospital, one of the reputable hospitals in Bandung. The results show that the implementation of non-spatial Poisson-gamma and spatial BYM models does not depict a significant difference in the result of the relative risk estimation of dengue transmission in Bandung. The Deviance Information Criterion (DIC) diagnostic indicates that non-spatial model is better than the spatial model. Therefore, it can be concluded that there is no spatial effect in dengue transmission in Bandung. It means that dengue transmission in Bandung is not affected by neighboring areas. This analysis is also applicable to every stage estimated, both for the early-stage as well as the severe-stage.

Keywords: Dengue, Bandung, Poisson-gamma, BYM, relative risk

1.0 INTRODUCTION

Dengue is a mosquito-borne seasonal viral infection, transmitted by the bite of a female mosquito of the genus Aedes. Dengue is caused by four closely-related serotypes of dengue virus; those are DEN-1, DEN-2, DEN-3, and DEN-4. According to [1], there are two severity levels of dengue. The severity level itself is characterized by the symptoms of plasma leakage with or without haemorrhage. The early-stage of the severity is Dengue Fever (DF), and the severe-stage includes Dengue Haemorrhagic Fever (DHF) and Dengue Shock Syndrome (DSS).

The Health Department in Indonesia usually uses the total numbers of dengue occurrences across the regions for depicting the high-low risk areas. It is common to conclude that the level of dengue risks in particular areas is represented by the numbers of dengue cases of the areas without considering the population or the land size. It means the larger the number of cases, the higher the risks of the region are or vice versa; while in fact, such

generalization does not describe the actual condition related to population density and the area size. Some previous researchers have studied the transmission of dengue disease in some areas of Indonesia ([2], [3], [4], [5]).

However, they only analyse the deterministic model using the existed observed dengue data. In fact, in the real condition, there is also random effect which usually affects the process of particular disease transmission. Their studies indicated that stochastic models must also be considered since they are more realistic than the deterministic ones ([6], [7], [8], [9]).

Therefore, in this research, in order to obtain a better risk map approaching the real condition more closely, the high-low areas will be estimated and predicted using a better relative risk estimation method.

The relative risk should be considered to be mapped in term of disease mapping, because it is taken to measure the excess risk found in relation to the risk supported purely by the local population 'at risk' [10]. Relative risk is the ratio of the exposed group that will develop the disease to the unexposed group that will develop the same disease. In brief, relative risk is usually used to compare the risks of different groups. [11] explained the interpretation of relative risk as the probability of a person within a specified region contracted by the disease which is divided by the probability of a person in the population contracted by the disease.

Bandung is one of the most populous cities in West Java, Indonesia with a population that continues to increase from year to year. Bandung is located at 768 meters of mean sea level as well, which is according to [1], part of the habitats of the Aedes Aegypti. Because of the massive population and the mean sea level, Bandung, therefore, potentially becomes one of the most vulnerable places to this disease.

In this research, the relative risks of dengue cases in Bandung will be estimated using Poisson-gamma and BYM models. These two models has been applied in the same case in previous research, but without considering the severity of dengue disease [12]. Therefore, the investigation is continued by analysing the severity of dengue disease, i.e. the early-stage and the severe-stage separately and both-stages combined. For more convenient reading, in this paper, the both-stages combined is defined as the all-stages. In the previous research, [13] had applied the Standardized Morbidity Ratio (SMR) to estimate the relative risks in Bandung, Indonesia. However, this model has a drawback that it cannot estimate the relative risks in the areas with zero cases. Therefore, in order to overcome that drawback, the estimations of relative risk in the critical area in this paper apply the non-spatial model, Poisson-gamma and the spatial model, Besag, York and Mollie (BYM). These models are used in this paper in order to analysis whether there is a spatial effect in dengue transmission in Bandung. The BYM model as the spatial model usually provides a more accurate estimation if there is a spatial effect in the spread of the disease.

The results of both models will be compared based on the Deviance Information Criterion (DIC) as one of the goodness-of-fit method. The smoothness of the estimation models are analysed as well. The data have been taken from St. Borromeus hospital, one of the reputable hospitals in Bandung. From 5,749 cases of dengue disease in Bandung in 2013, there were 2,032 cases from this hospital.

2.0 METHODOLOGY

One of the problems frequently encountered in statistics is the uncertainty parameter. Naturally, by applying the Bayesian approach the uncertainty parameter can be set as a random variable and has a prior distribution as the primary idea about it. Another source provides additional information which is the likelihood as the data occurred. The multiplication of the prior and likelihood produces the posterior distribution for revising the understanding of the parameter set variation. This Bayesian framework is usually described as the proportionality:

$$p(\theta|y) \propto L(y|\theta)g(\theta), \tag{1}$$

where $g(\theta)$ is the joint distribution of the θ vector. To carry out the Bayesian approach which is applied in this case, the WinBUGS software is used. This software is useful to make the inference under Bayesian framework using Gibbs Sampling method.

The models used to estimate the relative risks in this research is a non-spatial Poisson-gamma model and spatial model, BYM. According to [14], these models are better compared to the SMR model which is implemented in the same case by [13]. The SMR model has some drawbacks since it is only based on ratio estimators which can result in large changes in estimating relative risk with relatively small changes in expected value.

2.1 Poisson-gamma Model

According to [15], Poisson-gamma model is one of the appropriate models from the Bayesian approaches. In this model, the relative risk estimation in certain area i, θ_i, is Gamma distributed with hyperparameters (α, β), with $\alpha, \beta \sim Exponential(0.1)$.

The data obtained as the Likelihood in this case are y_i, which are the number of dengue cases in area i and assumed mutually independent with,

$$y_i \sim Poisson(e_i\theta_i), \quad \forall i, \tag{2}$$

where e_i is the expected number of dengue cases in area i. The conjugate of posterior distribution from this proportionality is also Gamma distribution, that is,

$$\theta_i|y_i \sim Gamma(\alpha + y_i, \beta + e_i). \tag{3}$$

To find θ_i, the relative risk estimation of the *i-th region*, Equation (3) as the posterior distribution is determined using the proportionality in Equation (1). It can be solved numerically by applying the Gibbs Sampling method [5].

From the application in many previous researches, it is found out that Poisson-gamma model has a drawback i.e.: its inability to cope with the spatial correlation. The next model, BYM, offers a better approach in estimating the relative risks since it considers the neighboring areas.

2.2 Besag, York and Mollie (BYM) Model

In [14], it is elaborated that by using the same model of likelihood in Equation (1), as mentioned above, the BYM model considers the spatial correlation between neighbouring areas. This model is developed by [16]. In this model, there are two factors which affect the relative risks estimation. The first factor is the effects of clustering or correlated heterogeneity and the second factor is the effects of uncorrelated heterogeneity.

θ_i as the relative risks estimated in area *i* is assumed as follows,

$$\log \theta_i = \alpha + u_i + v_i,$$

$$\theta_i = \exp(\alpha + u_i + v_i), \quad (4)$$

where α is an overall level of the relative risk, u_i is the correlated heterogeneity and v_i is the uncorrelated heterogeneity. The details about the correlated and uncorrelated heterogeneity factors are beyond the scope of this paper, the interested readers may read [14] and [17] to have a deeper understanding about this topic.

v_i as the uncorrelated heterogeneity factor in Equation (4) is assumed has Normal distribution with parameter $(0, \tau_v^2)$. Moreover, the correlated heterogeneity parameter u_i is assumed to apply the spatial correlation, since the relative risk estimations in each area should depend on the neighbouring areas. Therefore, the conditional autoregressive (CAR) is proposed to be applied in u_i, as $[u_i|u_j, i \neq j, \tau_u^2] \sim N(\bar{u}_i, \tau_i^2)$, where $\bar{u}_i = \frac{1}{\sum_j \omega_{ij}} \sum_j u_j \omega_{ij}$, $\tau_i^2 = \frac{\tau_u^2}{\sum_j \omega_{ij}}$, and $\omega_{ij} = 1$ if i, j are adjacent (or 0 if they are not).

Using the same method in Poisson-gamma model, the relative risks in area-*i* using BYM model as stated in Equation (4), are numerically estimated by Gibbs Sampling.

3.0 RESULTS AND DISCUSSION

As mentioned before, the data are taken from St. Borromeus hospital in Bandung. The data are considered to be applied for the analysis although they are only from one hospital. It is found out that there are 2,032 cases elicited from this hospital out of total 5,749 cases of dengue disease in Bandung in 2013.

The data collected are those cases that occurred in 30 districts in Bandung. Out of the total, there were only 357 cases of Dengue Fever. It is smaller compared to the number of the severe stage, which is 1675 cases. The relative risks of two stages, i.e. the early-stage, the severe stage and also the aggregate data of all stages are estimated using both models described before. Those relative risks are analyzed within monthly interval of each conditions. The results obtained from each model are compared based on the DIC to suggest the best model which suits the data.

All of those implementations are run on WinBUGS software with 10,000 iterations. This software is useful because it can run the Gibbs Sampling method to result the Bayesian inference. The obtained posterior expectations of Equations (2) and (4) are displayed in Table 1, which have been grouped according to the different stages, i.e., early, severe and all stages.

Table 1 Result of relative risk estimations using Poisson-gamma and BYM models for Early (DF), Severe Stage (DHF&DSS) and All Stages

No.	District	Early (DF)		Severe (DHF & DSS)		All Stages	
		PG	BYM	PG	BYM	PG	BYM
1.	ANDIR	0.8686	0.8431	0.3229	0.3235	0.4131	0.413
2.	ANTAPANI	0.9469	0.9124	0.82	0.8115	0.8335	0.8394
3.	ARCAMANIK	1.429	1.408	0.8804	0.8706	0.98	0.9895
4.	ASTANAANYAR	0.5807	0.5562	0.8249	0.8175	0.7657	0.7703
5.	BABAKAN CIPARAY	0.2519	0.2697	0.4037	0.4032	0.3663	0.3669
6.	BANDUNG KIDUL	0.6576	0.6304	1.029	1.019	0.9459	0.9555
7.	BANDUNG KULON	0.4391	0.4363	0.4784	0.4752	0.4618	0.463
8.	BANDUNG WETAN	3.349	3.721	3.734	3.833	3.901	3.807
9.	BATUNUNGGAL	0.5619	0.5488	0.4884	0.4862	0.493	0.4955
10.	BOJONGLOA KALER	0.2504	0.2691	0.2384	0.2437	0.2327	0.2268
11.	BOJONGLOA KIDUL	0.3376	0.3468	0.5505	0.5466	0.4946	0.4974
12.	BUAH BATU	1.021	0.9932	0.8616	0.8547	0.8832	0.892
13.	CIBEUYING KALER	2.244	2.287	1.95	1.957	2.044	2.038
14.	CIBEUYING KIDUL	0.912	0.8898	0.5055	0.5044	0.571	0.5757
15.	CIBIRU	0.3107	0.3276	0.2332	0.2425	0.2369	0.2271
16.	CICENDO	0.7341	0.7046	1.244	1.237	1.141	1.148
17.	CIDADAP	1.644	1.637	1.691	1.687	1.706	1.705
18.	CINAMBO	0.5119	0.4957	0.1441	0.1883	0.2037	0.1689

No.	District	Early (DF)		Severe (DHF & DSS)		All Stages	
		PG	BYM	PG	BYM	PG	BYM
19.	COBLONG	4.009	4.134	3.711	3.738	3.832	3.811
20.	GEDEBAGE	0.6715	0.6376	0.4393	0.4342	0.4565	0.4592
21.	KIARACONDONG	0.2787	0.2927	0.9	0.8966	0.7783	0.7817
22.	LENGKONG	1.902	1.912	1.685	1.685	1.743	1.745
23.	MANDALAJATI	0.5307	0.5144	0.3533	0.3562	0.37	0.3665
24.	PANYILEUKAN	0.3642	0.3786	0.2668	0.2794	0.2647	0.2535
25.	RANCASARI	0.8468	0.8135	0.7949	0.7905	0.7955	0.801
26.	REGOL	1.245	1.213	1.303	1.296	1.291	1.297
27.	SUKAJADI	1.028	0.9969	1.093	1.088	1.076	1.083
28.	SUKASARI	1.685	1.683	2.137	2.142	2.082	2.078
29.	SUMUR BANDUNG	0.8247	0.778	1.283	1.264	1.177	1.193
30.	UJUNG BERUNG	0.4461	0.4449	0.3889	0.3859	0.3827	0.3831
	RANGE	3.7586	3.8649	3.5899	3.6447	3.6973	3.6421

From the relative risk estimations displayed in Table 1, it can be analyzed that relative risk estimations at the early-stage is greater than those at the severe stage, which is contrary to the fact whereas the number of cases at the early-stage is actually smaller than the number of cases at the severe stage. It happens because the y_i is small, the case of e_i is small as well; which eventually will result in a greater relative risks estimations. This condition is applicable to both models. On the other hand, the relative risk estimations of all stages show that there are no significant differences between the results produced by both models.

The data displayed on the same table above, provide a picture that the application of both of non-spatial model, which is Poisson-gamma model, and the spatial model, which is BYM model, to approach the case provides the relatively same result. Therefore, it can be concluded that there is no spatial effect in the transmission of this disease by implementing the two models. Using both models, it is found out that there are eleven districts at severe stage and ten districts at all stages, respectively, with the relative risk estimations more than 1. These numbers do not reflect positive pictures, since it means that susceptible people in those districts in Bandung are more likely to be infected by dengue compared to the overall population in Bandung. There are two districts coming at the first and second place of the highest relative risk estimations, i.e.: Coblong dan Bandung Wetan.

Conversely, different results are obtained by Poisson-gamma and BYM model for Dengue Fever stage. The number of districts which has relative risk estimations more than 1, estimated by BYM is smaller than that of Poisson-gamma, i.e.: eight districts for BYM and ten districts for Poisson-gamma. The two models show the same condition for Coblong and Bandung Wetan districts; they become the two districts having the greatest relative risk estimations.

Since there is no spatial effect in this transmission, it is necessary to identify a model which suits the data better. In this paper, the Deviance Information Criterion (DIC) is applied as a consideration tool. This method is usually applied to compare the Bayesian models [18]. Basically, DIC measures the goodness of fit and the complexity of the data. It can be written as follows,

$$DIC = 2.E_{\theta|y}[D(\theta)] - D\left[E_{\theta|y}[\theta]\right], \qquad (5)$$

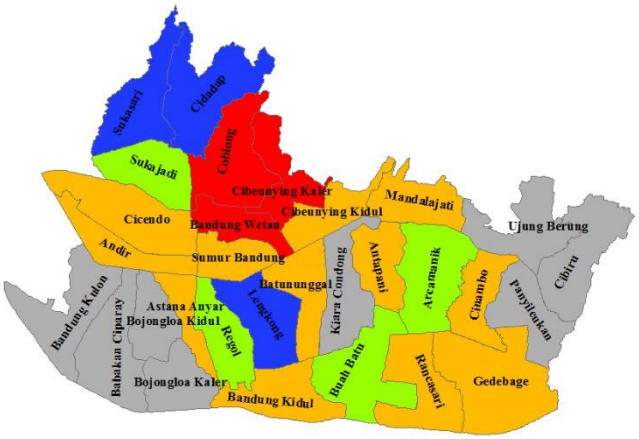
where $E_{\theta|y}[D(\theta)]$ is the posterior mean of the deviance and $D\left[E_{\theta|y}[\theta]\right]$ is the deviance evaluated at the posterior mean of the parameters. The DICs of both models applied to the yearly data of all stages are displayed in Table 2.

Table 2. Comparison of the Deviance Information Criterion (DIC) from Poisson-gamma and BYM Model

Model	DIC
Poisson-gamma	227.894
BYM	228.795

From the DICs displayed, it can be concluded that Poisson-gamma model fits the data, better than BYM model since the DIC of Poisson-gamma is smaller than the DIC of BYM model. Furthermore, from the range data in Table 1, it can be verified that Poisson-gamma model is also smoother than BYM model for early stage and severe stage considering the facts that the range of Poisson-gamma is smaller than the BYM. Conversely, BYM model is smoother than Poisson-gamma model if it is applied to all stages since the range is smaller. These conditions are depicted in the maps below. The risk levels in the maps are divided into 5 levels, which are very low, low, medium, high and very high.

For more details, the monthly relative risk estimations are analyzed as well. However, since the monthly results are abundant, therefore the results are displayed in time series.



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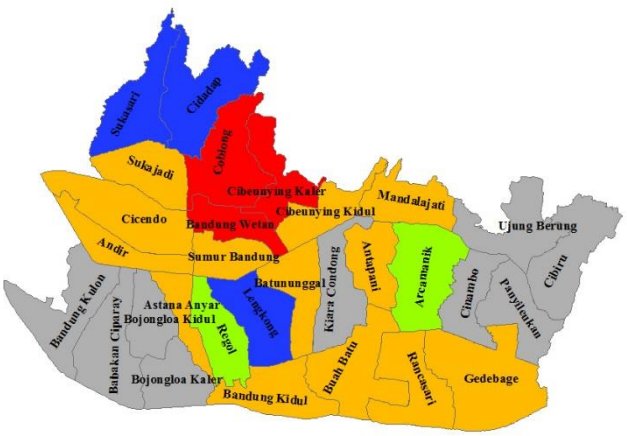

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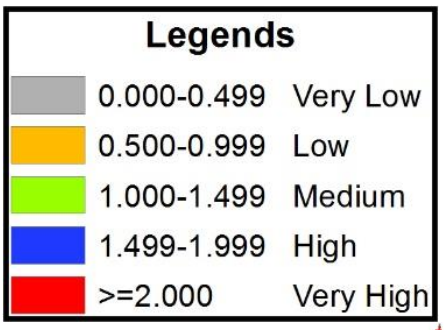

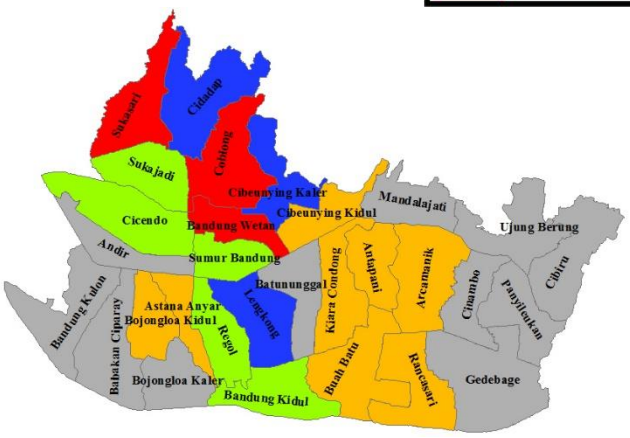

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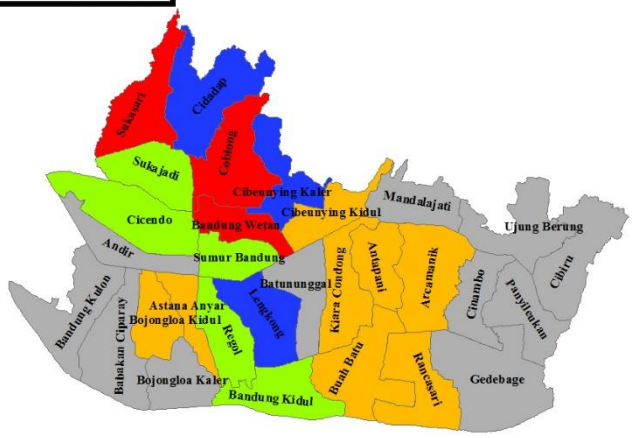

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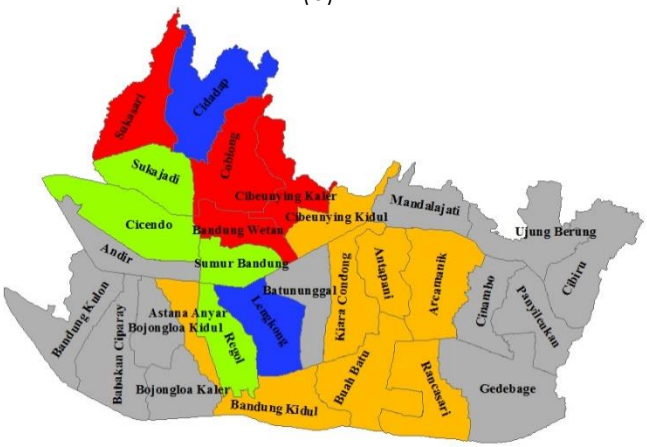
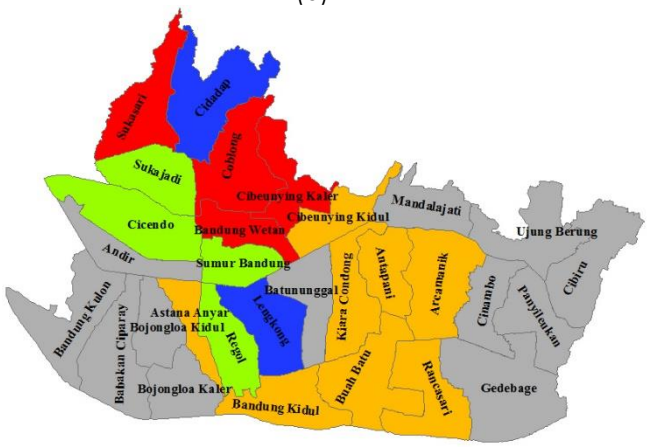


(c)

Figure 1 Dengue Disease Maps using Poisson-gamma Model in Bandung, 2013 for (a) DF, (b) Severe (DHF & DSS), (c) All stages



(c)

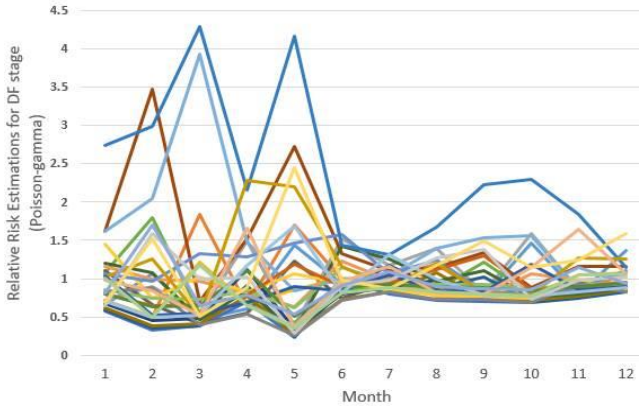
Figure 2 Dengue Disease Maps using BYM Model in Bandung, 2013 for (a) DF, (b) Severe (DHF & DSS), (c) All stages

From the time series plots depicted in Figures 3 and 4, it can be figured out that monthly relative risks estimated by BYM produce a higher magnitude, even though the critical areas from both results do not show significant differences. It can be noted that in this case, the BYM model supports the relative risk estimations resulted by Poisson-gamma model.

The early-stage in this case, has higher risks in particular periods of the year. In Figure 3(a) and 4(a), it can be observed that there are 3 until 7 districts in high and very high levels of risk in January until May and October. This condition is different from relative risk estimations for the severe stage. As depicted in Figure 3(b) and 4(b), there are 4 until 7 districts that have high and very high level almost every month in 2013, except in September. This condition will absolutely influence the relative risk mapping applied on all stages. Considering the fact that there are a lot of areas at the high risk level up to the very high risk level, i.e.: three until seven districts, the relative risk mapping on both levels respectively provides an average result for every month of the whole year. These conditions are depicted in Figure 3(c) and 4(c).

The estimation results can be used as a reference to anticipate the spread of dengue in Bandung. Strategic decision and action are required to be implemented in critical months and have to be carried out by the government and the society at the same time to achieve a more optimal prevention.

A concrete action the government can take is by giving useful information to the public about the possibility of dengue disease infection in particular areas. It is expected that after people know the information, they can anticipate the situation better by improving the environmental hygiene to reduce or eliminate mosquito population and at the same time they increase their stamina to prevent them from being easily infected by the dangerous disease.



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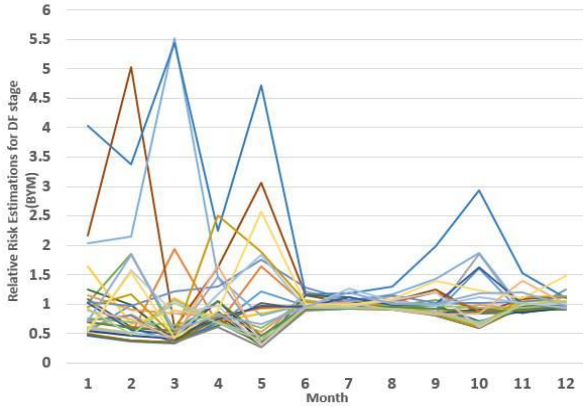

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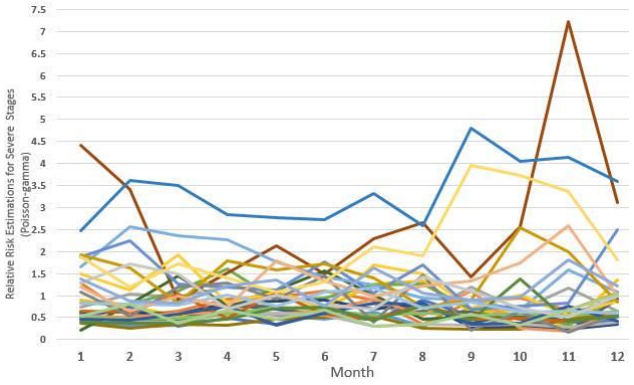

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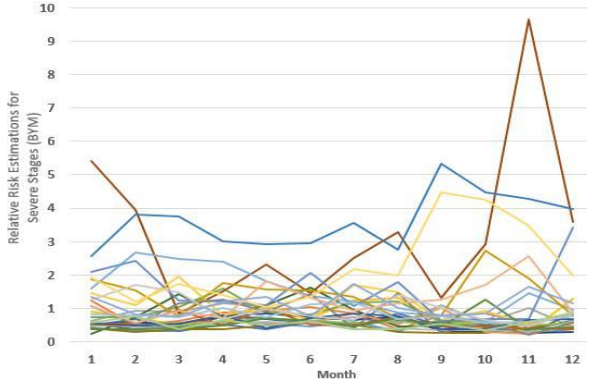

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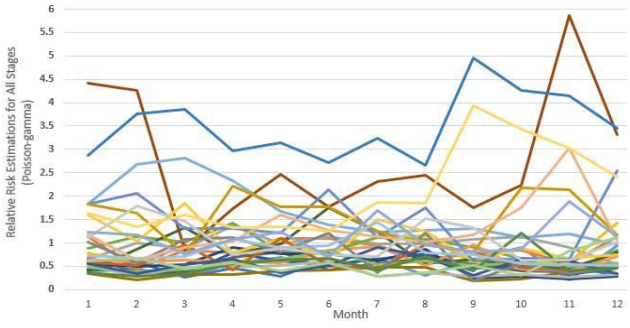
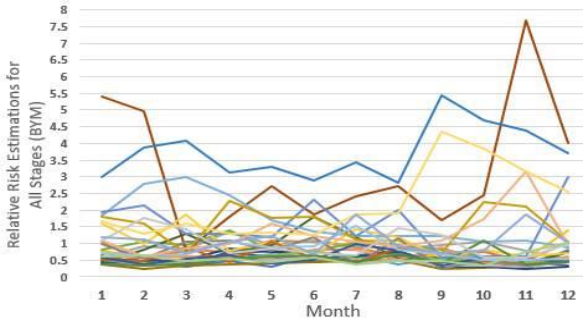


(c)

Figure 3 Time Series Plots for the Estimated Relative Risks using Poisson-gamma model, applied to (a) DF, (b) Severe (DHF & DSS), and (c) All Stages



(c)

Figure 4 Time Series Plots for the Estimated Relative Risks using BYM model, applied to (a) DF, (b) Severe (DHF & DSS), and (c) All Stages

4.0 CONCLUSION

The severity of the stage in dengue disease is one factor that must be considered in dengue prevention. It is expected that once the outbreak of the early-stage is detected, the right treatment to handle this disease at this level and the necessary action to prevent the level from developing into the severe stage can be implemented in the right time and location.

From the frequency of dengue occurrences shown on the data obtained so far, the expected actions have not yet been implemented effectively in Bandung. It was proved by the condition that the cases of early and severe stages are frequently found every month spreading in some districts in Bandung. Therefore, the maps of the relative risk estimations of this research can be considered as a tool to decide more effective and efficient strategic actions of dengue prevention in Bandung. The effective strategic actions decided to be implemented definitely need to be carried out by both the government as well as the society at the same time.

The implementation of non-spatial Poisson-gamma and spatial BYM in estimating the relative risks apparently does not result in significant difference of dengue transmission in Bandung. This analysis also applies to every stage estimated, both to the early-stage as well as the severe stage. Therefore, it can be concluded that there is no spatial effect in dengue transmission in Bandung. However, further investigation considering the spatial effect in Bandung can be continued by taking data from not only St. Borromeus hospital but also other hospitals.

Further research can be conducted by choosing the prior distribution with other parameter values. Other than that, for a better mapping result, it would be beneficial to take data from wider areas considering other hospitals in other areas than St. Borromeus. Finally, the period of data collection needs to be longer, not only one year.

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