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Bayesian Mapping of Human Immunodeficiency Virus Incidence in the National Capital Region

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Abstract: Human Immunodeficiency Virus (HIV) infection continues to exhibit public health threat in the Philippines and the number of cases is rapidly increasing. The National Capital Region (NCR) is reported to have the highest number of reported cases in the country. This study explores Bayesian hierarchical models in estimating relative risk of HIV infection in each city/municipality in NCR. It introduces the mixed effect Poisson-gamma model with covariate in obtaining HIV relative risk estimates in comparison with the Poisson-gamma model. The study also aims to provide Bayesian mapping of HIV infection which is essential in public health and epidemiology. Standardized Incidence Ratio (SIR) is the most common health index in disease mapping but is not always an appropriate measure especially when dealing with very small areas and small expected counts. Utilizing Bayesian models such as Poisson-gamma and mixed effect Poisson-gamma with covariate provide more stable relative risk estimate due to prior information, shrinkage, and spatial smoothing. Conditional plot maps show significant association between SIR of HIV infection and the covariate sexually active male population, that is, areas with higher proportions of sexually active male individuals are expected to experience higher HIV incidences. The mixed effect Poisson-gamma model with covariate resulted to six areas in NCR with high HIV relative risk estimates, namely Mandaluyong, Makati, Pasig, Pasay, Marikina, and Manila. The Poisson-gamma model resulted to seven NCR high relative risk areas of HIV infection with the inclusion of San Juan. The Bayesian maps revealed Mandaluyong, Makati, Pasig and Pasay to be the areas with highest relative risk of HIV infection in NCR.

Key Words: Bayesian mapping, Poisson-gamma, mixed effect Poisson-gamma with covariate, HIV relative risk, SIR

1. INTRODUCTION

Acquired Immune Deficiency Syndrome (AIDS) is a syndrome caused by Human Immunodeficiency Virus (HIV) and such illness alters the immune system, making people much more vulnerable to infections and diseases. The growth of HIV prevalence in the country is rapidly increasing. The Department of Health (DOH) has stated that HIV cases would likely reach to 133,000 by year 2022 if the infection is not addressed properly and immediately. There were 841 new HIV cases reported to HIV/AIDS & ART Registry of the Philippines (HARP) in June 2016. Compared to the previous year with 772 cases, this appeared to be 9% higher and considered to be the highest number of cases reported since 1984. From January 1984 to June 2016, the region with the most number of reported cases was National Capital Region (NCR) with 15,053 (43%) cases.

In line with studying the epidemiology and spatial patterns of HIV infection, this study aims to provide Bayesian mapping of estimated relative risks of HIV infection in each city/municipality of NCR obtained from Bayesian hierarchical models, namely Poisson-gamma model and mixed effect Poisson-gamma model with covariate. The study also introduces the mixed effect Poisson-gamma model with covariate in estimating the relative risk of HIV infection in NCR.

The scope of this study only includes the sexually active population (15-85 years old) and is only limited on the 2014 HIV count data in 16 cities and 1 municipality in NCR.

2. METHODOLOGY

1.1 Data

The data used for this study were given by the HIV Regional Epidemiology Surveillance Unit (HIV RESU) of DOH. The data include all HIV cases in each municipality/city of NCR for the year 2014. The sexually active population data (15 to 85 years old and over) in each NCR municipality/city was from the year 2010 since it is the most recent Census of the Population and Housing (CPH) from the Philippine Statistics Authority (PSA) available.

1.2 Theoretical Framework and Analysis

Standardized Incidence Ratio (SIR) is the most common statistic used to estimate the relative risk in disease mapping (Samat & Ma'arof, 2013). In disease mapping, suppose that the areas to be mapped is divided into *m* sub-areas *(i = 1,2,..., m)*. The common risk r is defined to be

$$r = \frac{y}{N}$$

where *y* is the total count of HIV cases and *N* is the total population exposed to risk in NCR. The estimator of relative risk θ_i for region *i* with respect to the common risk relative risk *r* is

$$\theta_i = \frac{y_i}{e_i};\ e_i = rN_i$$

where y_i is the count of cases in region i, N_i is the population exposed to risk in region i and e_i is the expected count which is computed with respect to the common risk *r*.

SIR is greatly affected when the expected count is small and very small spatial units are involved. There are more variations of SIR in small cities compared to large cities (Tango, 2010). Hence, SIR does not always provide an appropriate measure for disease mapping. This happens when the difference in population exposed to risk among areas are large, and hence, causing a misleading estimation of the relative risk

.Utilizing Bayesian hierarchical models provide more stable relative risk estimate due to prior information, shrinkage, and spatial smoothing. Bayesian mapping is appropriate when very small spatial units are involved. The prior information allows a Bayesian model to provide "good enough" estimates despite the small sample size.

In Bayesian mapping, an assumed prior distribution for θ in a Poisson likelihood model is the gamma distribution, thus the resulting Bayesian conjugacy model named Poisson-gamma model. The Poisson-gamma model aims to cope with the drawback of the SIRs.

For the Poisson-gamma model, y_i is the observed count of HIV cases in the i^{th} area, and has a Poisson distribution. The parameter of interest is θ_i where in it is the relative risk that quantifies whether area *i* has a higher or lower occurrence of HIV cases. The parameter of interest θ_i has an exponential distribution which is a special case of the conjugate prior gamma distribution, and hence, the parameters b_i and β_0 have the prior gamma distribution. Uniform or flat hyperprior distribution is assigned to the parameter α providing equal probabilities and little effect on the results. The Poisson-gamma model is shown below.

$$y_i \sim Poisson(e_i\theta_i)$$
$$\theta_i = \exp(\beta_0 + b_i)$$
$$b_i \sim Gamma(\alpha, \alpha)$$
$$\alpha \sim Uniform\ (\,)$$
$$\beta_0 \sim Gamma\ (1,1)$$

The mixed effect Poisson-gamma model with covariate resembles the Poisson-gamma model but with the addition x_1 that serves as the covariate which is the percentage of sexually active male individuals with associated regression coefficient, β_1. The mixed effect Poisson-gamma model with covariate is shown below.

$$y_i \sim Poisson(e_i\theta_i)$$
$$\theta_i = \exp(\beta_0 + \beta_1 X_1 + b_i)$$
$$b_i \sim Gamma(\alpha, \alpha)$$
$$\alpha \sim Uniform(\,)$$
$$\beta_0 \sim Gamma\ (1,1)$$

Bayesian hierarchical models were generated by OpenBUGS. This software enables the user to specify a statistical model and includes a system which determines an appropriate MCMC scheme for the specified model. GeoBUGS, was used to map the models. R was used to convert the shapefile to S-PLUS format needed in GeoBUGS.

ArcGIS was used for the conversion of latitude and longitude into meters. Results were generated based on MCMC simulation of 30,000 iterations after discarding initial 3,000 burn-ins.

3. RESULTS AND DISCUSSION

Standardized Incidence Ratio (SIR) of HIV infection for each municipality/city in NCR for the year 2014 was computed. Seven cities have SIR greater than 1 which implies that more HIV incidence occurred than expected in these areas. Areas with SIR greater than 1 are described as areas with high relative risk of HIV infection. Table 1 shows the SIR of HIV infection for each municipality/city in NCR for the year 2014 with Mandaluyong city having the highest relative risk of HIV infection.

Table 1. SIR of HIV Infection in NCR

NCR Cities/ Municipality	Number of HIV Cases (y_i)	Population Exposed to Risk (N_i)	SIR
Caloocan	159	1,017,262	0.5721
Las Piñas	68	390,644	0.6371
Makati	206	398,383	1.8925
Malabon	49	246,188	0.7285
Mandaluyong	149	237,586	2.2953
Manila	348	1,173,946	1.0849
Marikina	97	306,470	1.1584
Muntinlupa	64	312,838	0.7488
Navotas	16	167,691	0.3492
Parañaque	85	422,804	0.7358
Pasay	109	282,651	1.4114
Pasig	188	476,765	1.4432
Pateros	12	45,149	0.9728
Quezon City	526	1,948,715	0.9879
San Juan	26	92,993	1.0233
Taguig	113	443,167	0.9332
Valenzuela	70	399,792	0.6408
Total	$y=$ *2,285*	$N=$ *8,363,044*	

Conditional maps showing the significant association between the SIR of HIV cases and the spatial units in condition to the covariate, sexually active male population, are shown in Figure 1. These maps show that spatial units with higher proportions of sexually active male individuals are expected to experience higher HIV incidences. Specifically, the cities of Mandaluyong and Makati are observed to have high reported incidences of HIV infection while exhibiting high percentages of sexually active male individuals as well.

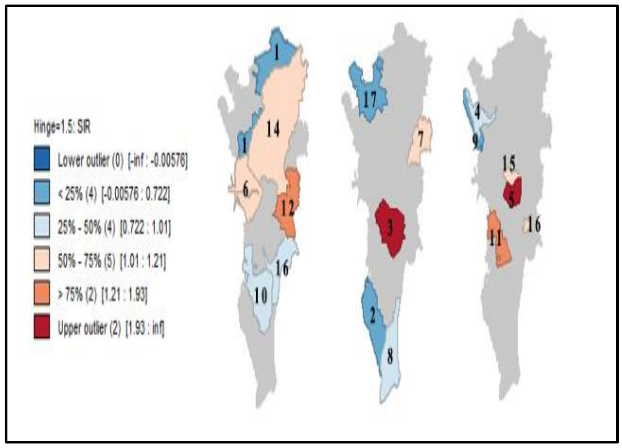

Fig.1. Conditional plot maps for the SIR of HIV based on sexually active male population

Posterior relative risk estimates of HIV infection for each NCR city/municipality based on the Poisson-gamma model and mixed effect Poisson-gamma model with covariate percentage of sexually active male individuals are shown in Table 2.

Table 2. Bayesian HIV Relative Risk (RR) Estimates

NCR Cities/ Muncipality	SIR	Poisson-gamma RR	Mixed Effect Poisson-gamma with covariate RR
Caloocan	0.5721	0.5778	0.5685
Las Piñas	0.6371	0.6489	0.6279
Makati	1.8925	1.866	1.884
Malabon	0.7285	0.7436	0.7121
Mandaluyong	2.2953	2.232	2.281
Manila	1.0849	1.085	1.082
Marikina	1.1584	1.154	1.147
Muntinlupa	0.7488	0.7596	0.7378
Navotas	0.3492	0.3974	0.6651
Parañaque	0.7358	0.7442	0.7282
Pasay	1.4114	1.396	1.399
Pasig	1.4432	1.433	1.436
Pateros	0.9728	0.986	0.8948
Quezon City	0.9879	0.9884	0.9861
San Juan	1.0233	1.026	0.9883
Taguig	0.9332	0.9357	0.9248
Valenzuela	0.6408	0.6526	0.633

Majority of relative risk estimates of HIV infection under these Bayesian hierarchical models in Table 2 have shrunk towards the SIR indicating shrinkage and spatial smoothing of the estimates.

Results show that under the Poisson-gamma model, seven NCR cities have high relative risk estimates of HIV infection. Mandaluyong has the highest relative risk estimate of HIV infection, followed by Makati, Pasig, Pasay, Marikina, Manila, and San Juan. These are also the seven NCR cities with SIR greater than 1.

With the addition of the covariate, proportion of sexually active male individuals, in the mixed effect Poisson-gamma model, results show that six NCR cities have high relative risk estimates of HIV infection. Mandaluyong is still the area with the highest relative risk estimate of HIV infection followed by Makati, Pasig, Pasay, Marikina and Manila.

Bayesian mapping of relative risk estimates of HIV infection under the Poisson-Gamma model and mixed effect Poisson-gamma model with covariate are shown in Figures 2 and 3, respectively. The colors of the Bayesian maps indicate the level of occurrences of the HIV relative risk. Areas with the darkest blue represent the lowest relative risk while areas with darkest red illustrate the highest relative risk.

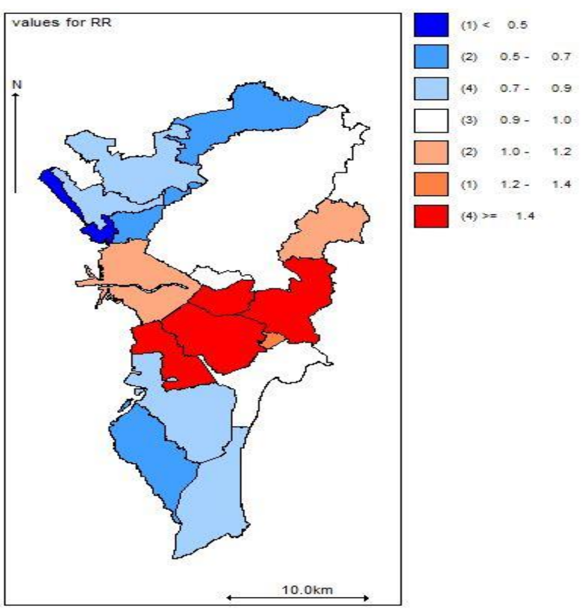

Fig. 2. Poisson-gamma Map of HIV Infection in NCR

The Poisson-gamma map of HIV infection in NCR shown in Figure 2 reveals that Mandaluyong, Makati, Pasig, and Pasay are the areas in darkest red indicating that these cities have the highest relative risk of HIV infection in NCR. The areas in Poisson-gamma map shown in Figure 2 do not exhibit spatial patterns indicating overdispersion which need further smoothing.

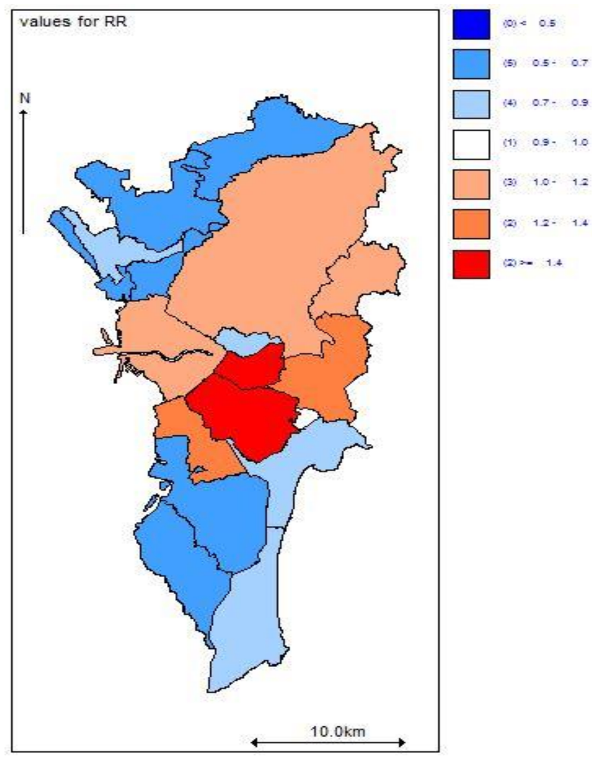

Fig. 3. Mixed Effect Poisson-gamma with Covariate Map of HIV Infection in NCR

The Bayesian map generated from the mixed effect Poisson-gamma with covariate shown in Figure 3 reveals that Mandaluyong and Makati appear to be the areas in darkest red, and so, these areas have highest relative risk of HIV infection in NCR. These are followed by Pasig and Manila in dark red orange areas indicating high relative risk of HIV infection. It can be seen in Figure 3 that areas in mixed effect Poisson-gamma with covariate map now exhibit spatial patterns and smoothing.

4. CONCLUSIONS

SIR is the most common health index in disease mapping but is not always an appropriate measure especially when dealing with very small areas and small expected counts. The use of Bayesian models such as Poisson-gamma and mixed effect Poisson-gamma with covariate provide more stable relative risk estimate due to prior information, shrinkage, and spatial smoothing. A significant covariate of HIV infection is the proportion of sexually active male individuals. Conditional plot maps show that areas with higher proportions of sexually active male individuals are expected to experience higher HIV incidences. The Poisson-gamma model resulted to seven NCR cities with high relative risk estimates of HIV infection such as Mandaluyong, Makati, Pasig, Pasay, Marikina, Manila, and San Juan. These are also the seven cities in NCR with SIR greater than 1. The mixed effect Poisson-gamma model with covariate resulted to six areas in NCR with high HIV relative risk estimates, namely Mandaluyong, Makati, Pasig, Pasay, Marikina, and Manila. The Bayesian maps revealed Mandaluyong, Makati, Pasig and Pasay to be the areas with highest relative risk of HIV infection. The Poisson-gamma map of HIV infection showed these four NCR cities to have the highest relative risk of HIV infection. However, areas in Poisson-gamma map do not exhibit spatial patterns indicating overdispersion which needs further smoothing. The Bayesian map under the mixed effect Poisson-gamma model with covariate sexually active male population revealed that Mandaluyong and Makati have the highest relative risk of HIV infection in NCR followed by Pasig and Pasay. The areas under the mixed-effect Poisson-gamma with covariate map exhibit spatial patterns and smoothing. It is recommended that further smoothing can be done by taking into account spatial autocorrelation and other significant covariates of HIV infection.

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Note: Full paper can be included in the conference proceedings.