Modeling the Number of Pneumonia in Toddlers in East Java Province in 2021 with Generalized Poisson Regression

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ABSTRAK – **Pneumonia saat ini masih menjadi salah satu penyebab tertinggi kematian balita di Indonesia. Pada tahun 2021, penemuan kasus Pneumonia di Jawa Timur balita sebesar 50%. Penelitian ini bertujuan untuk mendapatkan faktor-faktor yang memperngaruhi jumlah kasus pneumonia sebagai upaya penanggulangan. Metode yang digunakan adalah *Genralized Poisson Regression* (GPR), dengan menggunakan dan tanpa variabel eksposur. GPR adalah metode regresi yang digunakan ketika terjadi overdispersi. Data yang digunakan dalam penelitian ini adalah data dari Dinas Kesehatan Provinsi Jawa Timur yang meliputi jumlah balita penderita Penumonia di Provinsi Jawa Timur menurut kabupaten/kota beserta faktor-faktor yang diduga mempengaruhinya. Berdasarkan hasil analisis, model GPR dengan menggunakan variabel eksposur adalah model yang lebih baik dibandingkan model GPR tanpa variabel eksposur. Model GPR dengan variabel eksposur yang memiliki AICc terkecil adalah model yang memuat variabel persentase bayi berat lahir rendah, persentase balita batuk/sulit bernapas yang diberikan tatalaksana standar, dan persentase balita yang mendapat vitamin A. Semua variabel dalam model berpengaruh signifikan terhadap jumlah pneumonia pada balita.**

Kata kunci – **Jawa Timur, Generalized Poisson Regression, Overdispersion, Pneumonia.**

ABSTRACT – **Pneumonia is one of the highest causes of toddler's mortality, including Indonesia. In East Java 2021, the discovery of pneumonia is 50%. It is relatively high, especially among children under five. This study aimed to obtain the factors that influence the number of pneumonias in toddlers in East Java by using Generalized Poisson Regression (GPR) model with and without exposure variable. GPR is used when the assumption of Poisson regression is not met due to the overdispersion. Data was obtained from the East Java province health office containing the number of Pneumonia patients in East Java by districts/cities and the factors that allegedly affect them. Based on the analysis, GPR with exposure variable is better than GPR without exposure variable. The possible GPR models with exposure that has the smallest AICc is model that included the percentage of low-birth-weight babies, percentage of coughing/difficulty breathing toddlers given standard management, and percentage of toddlers getting vitamin A. All independent variables included in the model has significance effect to the number of pneumonias in toddlers.**

Keywords – **East Java, Generalized Poisson Regression, Overdispersion, Pneumonia.**

I. INTRODUCTION

Pneumonia is an infection that causes the lungs to become inflamed and the sacs less able to absorb oxygen. Lack of oxygen makes body cells unable to work. In addition to the spread of infection throughout the body, people with pneumonia can die [1]. Pneumonia cases in East Java are relatively high until August 2022. Most of the pneumonia sufferers are toddlers. According to the Head of the Surabaya City Health Service "Age 1 to 5 years is a vulnerable age, where the body's immunity has not been formed optimally". Many cases of pneumonia in toddlers are caused by frequent interactions with many people and visiting various places. So that the risk of exposure to viruses/germs that cause respiratory tract infections is higher than the age of infants 0-1 years [2]. Pneumonia is one of the main causes of under-five deaths in the world. WHO states that the proportion of under-five deaths due to ARI in the world is 19-26% [3]. In 2007 it was estimated that there were 1.8 million deaths due to pneumonia or about 20% of the total 9 million deaths in children [4]. In Indonesia based on Basic Health Research (Riskesdas) in 2007, Pneumonia is the second cause of death in toddlers after diarrhea. Based on these facts, proper modeling is needed to determine the pattern of spread and the factors that influence the number of pneumonia cases for reference in taking preventive measures or making policies to reduce the number of pneumonia cases in East Java.

Based on the 2021 Health Profile, 278,261 toddlers in Indonesia suffer from pneumonia [5]. East Java has the highest number of pneumonia sufferers in under-fives in Indonesia with a total of 74,071 cases of pneumonia in under-fives in 2021. East Java ranks seventh for the number of deaths due to pneumonia in under-fives in Indonesia with a total of 25 people death in 2021. Seeing the high cases of pneumonia in toddlers, it is necessary to make efforts to overcome this problem. One of the efforts that can be made to reduce the high cases of pneumonia in toddlers is to find out the causes of pneumonia. The statistical method used to model the incidence of pneumonia in East Java toddlers was previously developed by Santoso [6] with Geographically Weighted Regression (GWR) analysis. According to Santoso, external factors that affect pneumonia in toddlers are giving vitamin A twice, and toddlers getting immunizations. Noviana [7] researched the modeling of pneumonia in toddlers in East Java using binary logistic regression stratification and found that the significant influencing factors were measles immunization, duration of breastfeeding and the classification of children's residence. One of the statistical methods used to model the incidence of pneumonia is the development of Poisson regression.

Poisson regression is the most frequently used method for calculating data types as predictor variables [8]. Based on research that has been done before, it is often found that the equidispersion assumption is not fulfilled in Poisson regression because the variance is much larger than the average response variable used, it is necessary to develop Poisson regression methods, one of which is GPR which is an extension of Poisson regression.

The application of the use of GPR in modeling pneumonia cases in toddlers in East Java is something new in this study. In addition, the novelty of this study is the use of the exposure variable in the form of the number of children under five. Based on the description that has been explained, the problem that leads to this research is to get the best model of pneumonia cases in toddlers in East Java Province along with identifying the factors that influence it with the GPR approach that considers exposure.

II. MATERIAL AND METHODS

The data used in this study is secondary data taken from the 2021 East Java Province Health Profile. The research units used were districts/cities in East Java, a total of 38 districts/cities. The dependent variable used is the number of pneumonias in toddlers, while the independent variable used was shown in Table 1. All independent variables used are ratios. In addition, the number of toddlers is used as an exposure variable.

Table 1 Independent Variables

Independent Variables
Percentage of low-birth-weight babies (X_1)
Percentage of coughing/difficulty breathing toddlers given standard management (X_2)
Percentage of DPT-HB3/DPT-HB-Hib3 immunization coverage (X_3)
Percentage of BCG immunization coverage in infants (X_4)
Population density per-km² (in hundreds) (X_5)
Percentage of villages with UCI (Universal Child Immunization) (X_6)
Percentage of babies given exclusive breastfeeding (X_7)
Percentage of toddlers getting vitamin A (X_8)

A. Variance Inflation Factor (VIF)

VIF (Variance Inflation Factor) is a way to detect multicollinearity in the independent variable in the form of continuous data [8]. VIF can be calculated through the following formula.

$$VIF_j = \frac{1}{\left(1-R_j^{\,2}\right)} \tag{1}$$

where R_j^2 is the coefficient of regression determination with the j-th independent variable as a response and other independent variables as predictors. The coefficient of determination can be calculated by the following formula.

$$R_j^{\,2} = \frac{\sum_{i=1}^{n}\left(\hat{x}_{ij}-\bar{x}_j\right)^2}{\sum_{i=1}^{n}\left(x_{ij}-\bar{x}_j\right)^2} \tag{2}$$

where x_{ij} is the i-th data on the j-th independent variable, is the estimated value of $\hat{x}_{ij}$ based on the regression equation formed, and $\bar{x}_j$ is the average of the j-th independent variable. VIF which values more than 10 indicates the presence of multicollinearity between independent variables.

B. Poisson Regression

The Poisson regression model is generally used in may field including public health to model the relationship between independent variables and dependent variable. The dependent variable (y) is usually the number of events where the data is discrete, and the number of events is Poisson distributed. The Poisson probability distribution of y is given as follows [8].

$$P(y,\mu) = \frac{e^{-\mu}\mu^{y}}{y!};\ y = 0,1,2,\ldots \tag{3}$$

where y is the number of counts data, which is a non-negative integer, and μ is the mean of count data.

One of the characteristics of the Poisson distribution is that the variance equals the mean, that is.

$$\text{var}(Y) = E(Y) = \mu$$

If the variance is larger than mean, we would have overdispersion. However, if the variance is less than the mean, we would have underdispersion, and it is relatively sparse. If the overdispersion happened and the parameters are estimated by using Poisson regression, then the results will be inefficient because the standard error becomes an underestimate [9].

There are several link functions that are commonly used with the Poisson distribution, one of which is the log link. The log link is particularly attractive for Poisson regression because it ensures that all the predicted values of the response variable will be nonnegative. The fitted Poisson regression model using the log link can be written as follows [8].

$$\mu = \exp\left(\mathbf{x}^T \boldsymbol{\beta}\right) \tag{4}$$

C. Over/Underdispersion

The strict assumptions contained in Poisson regression are the mean and variance of the response variables must be the same (equidispersion). However, this assumption is often not fulfilled since overdispersion cases are more frequently found. When the dispersion of the data is greater than the expected value in the Poisson model, it can be said that the data is experiencing overdispersion [9]. Overdispersion is caused by several things, including a positive correlation between response variables or excess variation between response opportunities, there is a violation of the distribution assumptions of the data, when previous events affect subsequent events, the model eliminates important predictor variables, there are outliers in the data, the model fails to include interactions between variables, the predictor must be transformed to another measurement scale (log, root), and the error in the assumption of a linear relationship between the response variable and the link function and the predictor variable [10], [11].

D. Generalized Poisson Regression (GPR)

Generalized Poisson Regression (GPR) models are a suitable model for the count data. When a Poisson regression analysis is carried out it is found discrepancy between the mean and variance of the response variable or under/over dispersion. In GPR, besides μ paramater, there is also θ parameter as a dispersion parameter. The GPR models are similar to Poisson regression models however, the GPR models assumes that the random component is a General Poisson (GP) distribution. For example, $y = 0,1,2,...$ is a responses variable, then the GP distribution is stated as follows [10].

$$P(y,\mu,\theta) = \left(\frac{\mu}{1+\theta\mu}\right)^y \frac{(1-\theta y)^{y-1}}{y!} \exp\left(\frac{-\mu(1+\theta y)}{1+\theta\mu}\right) \tag{5}$$

With $y = 0,1,2,...$. Means and variance of GPR models is successively $E(y) = \mu$ and $\text{var}(y) = \mu(1+\theta\mu)^2$. If θ together with 0 so GPR models to be normal Poisson regression. If θ more than 0 so GPR models represent count data containing phenomena overdispersion and if θ less than 0 so GPR models represent count data containing phenomena underdispersion. GPR models can be written as (6),

$$\mu = \exp\left(\mathbf{x}^T \boldsymbol{\beta}\right) \tag{6}$$

and GPR models with exposure stated as (7),

$$\mu = q \; \exp\left(\mathbf{x}^T \boldsymbol{\beta}\right) \tag{7}$$

where q is exposure variable, $\mathbf{x}$ is independent variables, and $\boldsymbol{\beta}$ is coefficient of regression as follows.

$$\mathbf{x}^T = \begin{bmatrix} 1 & x_1 & x_2 & \cdots & x_p \end{bmatrix}$$

$$\boldsymbol{\beta} = \begin{bmatrix} \beta_0 & \beta_1 & \beta_2 & \cdots & \beta_p \end{bmatrix}$$

Parameter estimation for the Generalized Poisson model using Maximum Likelihood Estimation (MLE) is not in close form, so Newton-Raphson numerical iterations are used to estimate the parameters. Hypothesis testing GPR models use Maximum Likelihood Ratio Test (MLRT) that find two likelihoods for get statistics hypothesis testing simultaneously as follows. The hypothesis testing is as follows.

$H_0 : \beta_1 = \beta_2 = ... = \beta_p = 0$

H_1 : at least one of $\beta_j \neq 0$

and the test statistics is below.

$$D(\hat{\boldsymbol{\beta}}) = 2\left(\ln L(\hat{\Omega}) - \ln L(\hat{\omega})\right)$$

where $L(\hat{\Omega})$ is score likelihood with variable independent, $L(\hat{\omega})$ is without variable independent, and $D(\hat{\boldsymbol{\beta}})$ is score devians Poisson regression models or likelihood ratio. Test statistics follow chi-square distribution with degrees of freedom k. Null hypothesis rejection area is if $D(\hat{\boldsymbol{\beta}}) > \chi^2_{(\alpha;p)}$.

E. Comparing Models

The goodness-of-fit of the models was compared using the AICc [12]. The advantage of using AICc, compared to AIC, is AICc calculates sample size by increasing relative penalty for complex model with small data set. The better model fit is determined by the smallest value of AICc. The formula of AICc is given as follows.

$$AICc = -2\ln L(\hat{\boldsymbol{\beta}};\hat{\theta}) + 2p + \frac{2p(p+1)}{n-p-1} \tag{8}$$

where L represents the log-likelihood, and p is the number of model parameters that is the number of variables and the intercept in the model.

F. Pneumonia

Based on the results of the 2001 Susenas it is known that 80-90% of all cases of ARI deaths (Infection Tract Upper Respiratory) are caused by pneumonia. ARI cases which continue to pneumonia generally occur in toddlers especially when there is malnutrition with the condition unhealthy environment (cigarette smoke, pollution). According to WHO, pneumonia can spread in several ways. Viruses and bacteria are usually found on the walls of the nose or a child's throat which can infect the lungs if inhaled. Viruses and bacteria can also be spread by airborne droplets through coughing or sneezing, but it can also be spread through blood. Pneumonia is a form of acute respiratory infection that affects the lungs. When an individual has pneumonia, the alveoli are filled with pus and fluid, which makes breathing painful and limits oxygen intake [3]. One of Indonesia government’s efforts to control pneumonia is increasing pneumonia discovery in toddlers. According to Kementerian Kesehatan Indonesia 2021, East Java has the largest pneumonia discovery (50%) in Indonesia [5].

Several previous studies regarding Pneumonia among others Rudan, et al [13] reported that risk factors the occurrence of pneumonia is always there (definite) including malnutrition, low birth weight, not getting breast milk, air pollution in space, and dense settlements. According to the Department RI Health (2002), one source of disease transmission media pneumonia is the physical condition of the house as well as the environment is a place to live in and directly interact with its inhabitants. According to Santoso [6] with the approach Geographically Weighted Regression (GWR) results were obtained that external factors influence pneumonia toddlers in East Java is the provision of vitamin A and toddlers get immunized. According to research by Kusumawati [14] with factor analysis obtained that the grouping of factors supporting the occurrence of toddler pneumonia is a need toddlers, environmental sanitation, and health services. According to Thesis research by Yuwono [15] that floors, conditions house walls, house ventilation area, occupancy density level, humidity level, the use of wood fuel types and the smoking habits of family members are related with pneumonia.

G. Data Analysis

Descriptive statistics were used to summarize all the variables of this study. In the presence of under/over-dispersion, Generalized Poisson regression model were used to analyze the data. The Generalized Poisson regression without exposure and Generalized Poisson regression with exposure were compared between models that contain all independent variables. Then, models with all possible combinations of independent variables compared between the better model.

III. RESULTS AND DISCUSSION

Based on Table 2, it shows that the number of pneumonias in toddlers has a mean of 1,614 and variance of 3,139,659. It means that the average number of pneumonias in toddlers of each district/city is 1,614. The high variance indicates that the distribution of the number of pneumonias in toddlers in East Java is very high. It is possible that there are districts/cities with very high or very low numbers of pneumonia in toddlers compared to other districts/cities. Since the variance of dependent variable is higher than the mean, overdispersion existed. Hence, Poisson regression cannot be used, so Generalized Poisson regression is used to overcome overdispersion.

Table 2 Descriptive Statistics

Variables	Mean	Variance	Min.	Max.	VIF
Y	1,614	3,139,659	63	9,308	-
X_1	6.38	108.89	0.60	66.40	1.26
X_2	89.62	153.39	53.10	103.80	1.01
X_3	77.96	349.42	29.80	141.10	1.53
X_4	94.00	182.93	43.10	128.40	1.13
X_5	19.22	506.66	2.81	87.74	1.13
X_6	76.15	525.62	26.00	100.00	2.00
X_7	72.81	205.09	42.10	92.20	1.26
X_8	89.14	88.17	56.40	101.00	1.70

Table 3 Correlation Between Independent Variables

	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1	0.023	0.067	0.000	0.143	0.150	0.203	0.218
X_2		-0.007	0.028	-0.058	-0.028	-0.084	0.005
X_3			0.293*	0.056	0.522**	0.054	0.338**
X_4				-0.045	0.238	0.013	0.243
X_5					0.052	0.081	-0.222
X_6						0.281*	0.498**
X_7							0.303*

* : significant at α=0.1
** : significant at α=0.05

The average of percentage of coughing/difficulty breathing toddlers given standard management, percentage of DPT-HB3/DPT-HB-Hib3 immunization coverage, percentage of BCG immunization coverage in infants, percentage of villages with UCI, percentage of babies given exclusive breastfeeding, and percentage of toddlers getting vitamin A (X_2, X_3, X_4, X_6, X_7, X_8) is quite high, around above 70%. Even so, this number needs to be improved again to be able to reduce the number of pneumonias in toddlers in East Java. In addition, VIF for all predictor variables is less than 10, so it can be concluded that there is no multicollinearity between predictor variables.

Table 3 shows that there are several variables that have significant correlations. The percentage of DPT-HB3/DPT-HB-Hib3 immunization coverage (X_3) has a positive correlation with the percentage of BCG immunization coverage in infants (X_4), the percentage of villages with UCI (X_6), and the percentage of toddlers getting vitamin A (X_8). There is also positive correlation between the percentage of villages with UCI (X_6), the percentage of babies given exclusive breastfeeding (X_7), and the percentage of toddlers getting vitamin A (X_8). Apart from these variables, the correlation between other independent variables is not significant.

A. Generalized Poisson Regression Model

First, models that contain all independent variables compared based on AICc. Table 4 shows that GPR model with exposure has smaller AICc than GPR model without exposure variable. Hence, GPR model with exposure is the better model. Then, we compare all possible combinations of independent variables using GPR model with exposure. The AICc value of some possible GPR model using exposure given in Table 5.

Table 4 GPR Model with All Independent Variables

Model	AICc
Without exposure	654.4
With exposure	635.4

Table 5 Several Possible GPR Model with Exposure

Model	AICc
X_1, X_2, X_8	623.1
X_1, X_2, X_5, X_8	623.8
X_1, X_2, X_3, X_8	624.7
X_1, X_2, X_6, X_8	625.0
X_1, X_2, X_4, X_8	625.3

GPR model with exposure using the percentage of low-birth-weight babies, percentage of coughing/difficulty breathing toddlers given standard management, and percentage of toddlers getting vitamin A (X1, X2, X8) has the smallest AICc among all the possible GPR model with exposure, so that the model is selected as the best model. Table 6 show that all parameters have p-value of <0.05, it means that all parameters included in the GPR model with exposure is statistically significance.

Table 6 Partial Significance Test

Parameters	Estimate	SE	Z	p-value
θ	0.02201	0.002788	7.90	<0.0001
β_0	-11.1794	1.9671	-5.68	<0.0001
β_1	-0.04714	0.006452	-7.31	<0.0001
β_2	0.05191	0.01346	3.86	0.0004
β_8	0.03481	0.01259	2.77	0.0087

Based on Table 6, the percentage of low-birth-weight babies, percentage of coughing/difficulty breathing toddlers given standard management, and percentage of toddlers getting vitamin A (X1, X2, X8) take effect significance to the number of pneumonias in toddlers. The chosen GPR model with exposure is given as (9).

$$\hat{\mu} = q \ \exp\left(-11.1794 - 0.04714x_1 + 0.05191x_2 + 0.03481x_8\right) \quad (9)$$

Assuming other variables are constant, an increase in the percentage of low-birth-weight babies by 1 unit will reduce the number of pneumonia in toddlers by exp(-0.04714)=0.95 unit. Increasing the percentage of coughing/difficulty breathing toddlers given standard management by 1 unit will increase the number of pneumonia in toddlers by exp(0.05191)=1.05 unit, assuming other variables are constant. While increasing the percentage of toddlers getting vitamin A by 1 unit will increase the number of pneumonia in toddlers by exp(0.03481)=1.03 unit, assuming other variables are constant. The coefficient of determination of the model formed is 85.25%, meaning that the model formed is able to describe 85.25% of the variation in the response variable, while 14.75% of the other variations are described by other variables outside the model.

The regression model formed contradicts existing theory, where the percentage of coughing/difficulty breathing toddlers given standard management and the percentage of toddlers getting vitamin A can reduce the number of toddlers' pneumonia, while the percentage of low-birth-weight babies can increase the number of toddlers' pneumonia. This can happen because there are many other factors outside of the health aspect that can also affect the number of pneumonias in toddlers. Therefore, more in-depth research is needed regarding the factors from other aspenes that can affect the number of pneumonias in toddlers in East Java Province.

IV. CONCLUSION

GPR model with exposure (the number of toddlers) is better than GPR model without exposure for modeling the number of pneumonias in toddlers in East Java Province in 2020. The possible GPR models with exposure that has the smallest AICc (623.1) is GPR model with exposure using the percentage of low-birth-weight babies, percentage of coughing/difficulty breathing toddlers given standard management, and percentage of toddlers getting vitamin A (X1, X2, X8). All independent variables included in the model has significance effect to the number of pneumonias in toddlers. This model can describe 85.25% of the variation in the response variable.

Based on this study, the regression model obtained is not in accordance with the theory of each variable. This can happen because there are still many aspects and other factors that can also influence pneumonia rates in toddlers, so more in-depth research is needed on other aspects and factors that affect the number of pneumonias in toddlers in East Java. Even so, we recommend the East Java Province Government to provide easier and more widespread access to standard management for coughing/difficulty breathing toddlers given and vitamin A to toddlers in East Java to reduce the number of toddler pneumonia. For the future works, we recommend considering the development of GPR to fit data with its probability such as mixed-Poisson regression.

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