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# THE NEGATIVE BINOMIAL REGRESSION APPROACH IS MORE APPROPRIATE FOR IDENTIFYING TUBERCULOSIS RISK FACTORS (DATA ANALYSIS OF MADIUN AND PONOROGO DISTRICTS)

*Pendekatan Regresi Binomial Negatif Lebih Tepat untuk Mengidentifikasi Faktor Risiko Tuberkulosis (Analisis Data Kabupaten Madiun dan Ponorogo)*

**Aldi Wilaga Muktiwijaya[1*], Jaka Nugraha[1]**
[1]Program Studi Sarjana Statistika, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Islam Indonesia, Yogyakarta, Indonesia
[*]Email: 21611055@students.uii.ac.id

**_ABSTRAK_**

*Tuberkulosis merupakan penyakit menular yang disebabkan oleh bakteri Mycobacterium Tuberculosis, dan masih menjadi masalah kesehatan yang serius di Indonesia, termasuk di Kabupaten Madiun dan Kabupaten Ponorogo. Tren kasus tuberkulosis di kedua wilayah ini mengalami peningkatan yang signifikan sejak tahun 2021, meskipun sebelumnya sempat menunjukkan penurunan. Penelitian ini bertujuan untuk mengidentifikasi faktor-faktor yang memengaruhi jumlah kasus tuberkulosis di kedua kabupaten serta mengevaluasi metode analisis yang paling sesuai antara regresi Poisson dan regresi Binomial Negatif. Model regresi binomial negatif digunakan untuk mengatasi masalah overdispersi, yaitu kondisi ketika variansi data lebih besar daripada rata-rata, yang menyebabkan ketidaktepatan penggunaan regresi poisson. Hasil penelitian menunjukkan bahwa di Kabupaten Madiun, faktor signifikan yang memengaruhi jumlah kasus tuberkulosis meliputi tinggi wilayah, jumlah penduduk usia produktif, dan akses sanitasi yang baik. Sementara itu, di Kabupaten Ponorogo, faktor signifikan yang memengaruhi kasus tuberkulosis meliputi tinggi wilayah, jumlah penduduk usia produktif, dan jumlah tenaga kesehatan. Evaluasi model menunjukkan bahwa regresi binomial negatif lebih tepat digunakan dibandingkan regresi poisson, mengingat kemampuannya dalam menangani overdispersi.*

***Kata kunci****: epidemiologi, regresi binomial negatif, regresi poisson, tuberkulosis*

**ABSTRACT**

Tuberculosis is an infectious disease caused by the bacterium Mycobacterium Tuberculosis and remains a serious health problem in Indonesia, including in Madiun and Ponorogo Regencies. The trend of tuberculosis cases in these two regions has shown a significant increase since 2021, despite a previous decline. This study aimed to identify the factors affecting the number of tuberculosis cases in both regencies and evaluate the most suitable analysis method between Poisson regression and Negative Binomial regression. The Negative Binomial regression model is used to address the issue of overdispersion, which occurs when the data variance is greater than the mean, leading to inaccuracies in using Poisson regression. The results show that in Madiun Regency, significant factors influencing the number of tuberculosis cases include high altitude, the population of productive age, and good sanitation access. Meanwhile, in Ponorogo Regency, significant factors affecting tuberculosis cases include high altitude, the population of productive age, and the number of healthcare workers. Model evaluation indicates that Negative Binomial regression is more appropriate than Poisson regression due to its ability to handle overdispersion.

**Keywords:** epidemiology, negative binomial regression, poisson regression, tuberculosis



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## INTRODUCTION

Infectious diseases have long been a significant health problem in Indonesia and even in all parts of the world.[1] Some diseases such as Dengue Hemorrhagic Fever (DHF), malaria, influenza, and tuberculosis are often health threats to the community, especially in areas with high population density and lack of access to health facilities.[2] These diseases not only cause economic and social burdens, but also cause quite high mortality rates in various regions, especially in unhealthy environmental conditions.[3] In Indonesia, the tuberculosis situation is increasingly worrying. Based on a report issued by the *World Health Organization* (WHO), Indonesia is ranked second in the world after India in the number of tuberculosis cases.[4] The government issued Presidential Regulation No. 67 of 2021 on tuberculosis control as a serious effort to deal with this problem.[5] However, these efforts still face various challenges, including increased case detection to timely treatment.[6]

In recent years, innovations in the early detection and treatment of tuberculosis have developed rapidly.[7] One of them is the use of rapid diagnostic methods such as molecular rapid tests (TCM), which are able to detect the presence of *Mycobacterium Tuberculosis* bacteria more accurately and in a shorter time than traditional methods.[8] This innovation allows medical personnel to start treatment early, as it is essential to prevent further transmission. In addition, the development of new drugs with shorter treatment durations is also beginning to be implemented to improve patient adherence and reduce drug resistance rates.[9]

Research on tuberculosis has been going on for more than a century. On March 24, 1882, a German scientist named Robert Koch managed to reveal his discovery about the bacteria that cause tuberculosis.[10] The bacteria that cause tuberculosis, known as *Mycobacterium Tuberculosis*, are organisms that can survive in humid, cool, and dark environments for months.[11] Environmental factors also have an important role in the spread and transmission of tuberculosis. Research by Wulandari & Chamid (2022) in East Java showed that population density, access to proper sanitation, and the proportion of the productive-age population increase tuberculosis risk, while clean and healthy living behaviors (PHBS) reduce it.[12] An environment that does not meet health standards can increase the likelihood of the spread of tuberculosis bacteria, so handling environmental conditions is a crucial step in efforts to prevent and control tuberculosis.[13]

In Madiun Regency, cases decreased from 4968 in 2019 to 2515 in 2020, but increased to 6868 in 2023.[14] Meanwhile, in Ponorogo Regency, cases decreased from 6570 in 2019 to 3039 in 2021, then jumped to 9094 in 2023.[15] These trends highlight the need to identify influencing factors. Poisson and Negative Binomial regression are employed to address potential overdispersion and determine the most suitable model for tuberculosis case analysis.[16] The low public understanding of tuberculosis is also a challenge in efforts to handle and prevent transmission.[17]

This study aimed to identify factors influencing TB cases in Madiun and Ponorogo Regencies and to compare Poisson and Negative Binomial regression methods to determine the more appropriate model for analyzing tuberculosis data.

## METHODS

This study covers all residents of Madiun and Ponorogo Regency who have been diagnosed with tuberculosis during 2023. The data used in this study was obtained from the book "Health Profile in 2023" published by the Health Offices of Madiun and Ponorogo Regencies. The sample of this study is in the form of the total number of tuberculosis patients in the two regions, with sampling techniques carried out in


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total sampling.[18] The inclusion criteria in this study include all tuberculosis cases officially recorded by the Health Office in 2023 and have complete and valid data. Meanwhile, the exclusion criteria include cases where the data is incomplete, invalid, or duplicate in the official report.

This study uses secondary data taken from the two districts in 2023, and data collection was carried out at the Madiun Regency Health Office and the Ponorogo Regency Health Office in October 2024. The research implementation time lasts from November 2024 to February 2025.

The variables used in this study consisted of one dependent variable, namely the number of tuberculosis (Y) cases, and six independent variables. These independent variables include area height (X1), number of productive age population (15-59 years) (X2), number of health workers (X3), number of health facilities (X4), number of households with access to good sanitation (X5), and percentage of household waste management (X6). These variables are measured based on data obtained from the two districts during 2023.

This study uses Microsoft Excel and RStudio software version 4.4.0 for data processing. The data obtained from the book "Health Profile in 2023" is then processed in an Excel worksheet for cleaning and recapitulation, so that it is ready for analysis.

The research method used is a quantitative method with a poisson regression approach and negative binomial regression. Poisson regression is used to model the number of tuberculosis cases, but if there is an overdispersion in the data (variance is greater than the average), then negative binomial regression is used as an alternative.[19] The analysis was carried out separately in Madiun and Ponorogo Regency to identify the factors influencing tuberculosis cases in both regions. After analysis, the results from the two regions were compared to determine whether there were differences or similarities in factors influencing the number of tuberculosis cases in the two regions.

## RESULT

### Descriptive Analysis

The descriptive analysis aims to provide an overview of the distribution of data on the study variables, including the number of tuberculosis cases and various factors suspected to affect them in Madiun and Ponorogo Regency.[20]

**Table 1. Descriptive Statistics of Madiun**

| | *Mean* | *Variance* | *Min* | *Max* |
|---|---|---|---|---|
| Y | 313 | 22132,92 | 72 | 553 |
| $X_1$ | 143,70 | 15899,35 | 57 | 543 |
| $X_2$ | 27952 | 55325530 | 15004 | 39284 |
| $X_3$ | 108 | 11221,26 | 20 | 376 |
| $X_4$ | 2 | 0,495 | 1 | 3 |
| $X_5$ | 15559 | 20184520 | 9685 | 23477 |
| $X_6$ | 71,35 | 314,53 | 30,17 | 90,94 |

Based on table 1, it can be seen that there is considerable variance in the tuberculosis variable (Y) as well as other variables such as the number of productive age population (X2) and the number of households with access to good sanitation (X5) among the sub-districts in Madiun Regency.

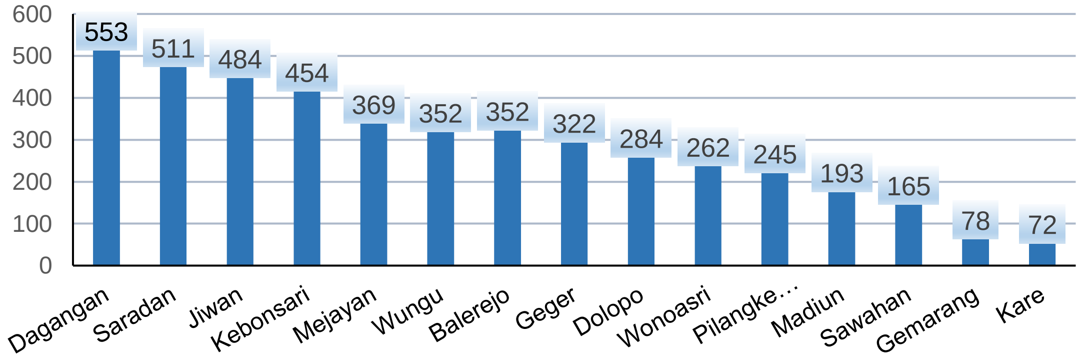


**Figure 1. Tuberculosis Cases in Madiun Regency in 2023**



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In figure 1, Dagangan District recorded the highest number of tuberculosis cases in Madiun Regency with 553 cases, followed by Saradan and Jiwan. Kare and Gemarang sub-districts recorded the lowest number of cases.

**Table 2. Correlation Between Data Variables of Madiun**

| | Y | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ |
|---|---|---|---|---|---|---|---|
| Y | 1 | -0,35 | 0,72 | 0,26 | 0,51 | 0,52 | 0,36 |
| $X_1$ | -0,35 | 1 | -0,27 | -0,20 | -0,31 | -0,22 | -0,04 |
| $X_2$ | 0,72 | -0,27 | 1 | 0,37 | 0,66 | 0,92 | 0,58 |
| $X_3$ | 0,26 | -0,20 | 0,37 | 1 | 0,84 | 0,32 | 0,32 |
| $X_4$ | 0,51 | -0,31 | 0,66 | 0,84 | 1 | 0,58 | 0,48 |
| $X_5$ | 0,52 | -0,22 | 0,92 | 0,32 | 0,58 | 1 | 0,52 |
| $X_6$ | 0,36 | -0,04 | 0,58 | 0,32 | 0,48 | 0,52 | 1 |

In table 2, the variable of the number of productive age population ($X_2$) has a strong positive correlation with the number of tuberculosis cases, with a correlation value of 0.72. The region height variable ($X_1$) showed a weak negative correlation of -0.35. In addition, there was a strong correlation between the variable number of health workers ($X_3$) and the number of health facilities ($X_4$) of 0.84.

**Table 3. Descriptive Statistics of Ponorogo**

| | *Mean* | *Variance* | *Min* | *Max* |
|---|---|---|---|---|
| Y | 441 | 45433,09 | 124 | 879 |
| $X_1$ | 267,40 | 52906,55 | 119 | 959 |
| $X_2$ | 25282 | 93350300 | 5762 | 48413 |
| $X_3$ | 141 | 49001,36 | 15 | 874 |
| $X_4$ | 4 | 0,60 | 3 | 5 |
| $X_5$ | 13464 | 30608890 | 3425 | 24400 |
| $X_6$ | 59,33 | 165,68 | 30 | 86 |

Based on table 3, there is considerable variance between sub-districts in Ponorogo Regency. The number of productive age residents varies in each sub-district, and significant differences are also seen in access to sanitation and the percentage of household waste management. Compared to Madiun Regency, Ponorogo Regency shows a lower percentage of household waste management, which can affect the quality of the environment.

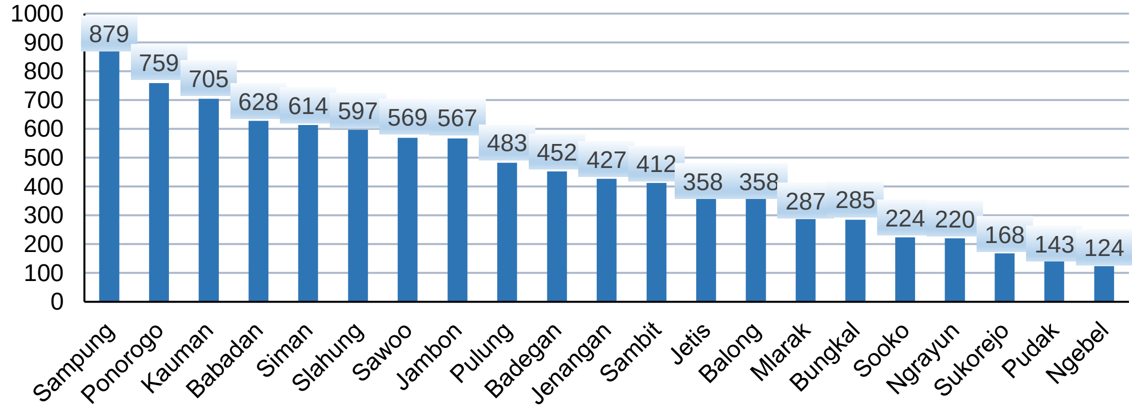


**Figure 2. Tuberculosis Cases in Ponorogo Regency in 2023**

Based on figure 2, Sampung District recorded the highest number of tuberculosis cases in Ponorogo Regency with 879 cases. Ngebel and Pudak districts have the lowest number of cases. Overall, there is significant variance in the distribution of the number of tuberculosis cases between sub-districts. In table 4, the variable of the number of productive age population ($X_2$) has a strong positive correlation with the number of tuberculosis cases, with a correlation value of 0.51. The region height variable ($X_1$) showed a weak negative correlation of -0.54. In addition, there was a strong correlation between the variable number of productive age population ($X_2$) and the number of households with access to good sanitation ($X_5$) of 0.89.

**Table 4. Correlation Between Data Variables of Ponorogo**

| | Y | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ |
|---|---|---|---|---|---|---|---|
| Y | 1 | -0,54 | 0,51 | -0,01 | 0,36 | 0,33 | -0,12 |
| $X_1$ | -0,54 | 1 | -0,50 | -0,08 | -0,22 | -0,44 | -0,06 |
| $X_2$ | 0,51 | -0,50 | 1 | 0,54 | 0,73 | 0,89 | 0,21 |
| $X_3$ | -0,01 | -0,08 | 0,54 | 1 | 0,30 | 0,49 | 0,30 |
| $X_4$ | 0,36 | -0,22 | 0,73 | 0,30 | 1 | 0,62 | 0,18 |
| $X_5$ | 0,33 | -0,44 | 0,89 | 0,49 | 0,62 | 1 | 0,22 |


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| | Y | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ |
|---|---|---|---|---|---|---|---|
| $X_6$ | -0,12 | -0,06 | 0,21 | 0,30 | 0,18 | 0,22 | 1 |

## Analysis of Madiun Regency

After a descriptive analysis, the next stage is to conduct a follow-up analysis to understand more deeply the relationship between variables that are suspected to affect the number of tuberculosis cases in Madiun Regency.

**Table 5. Variable VIF Value of Madiun**

| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ |
|---|---|---|---|---|---|---|
| VIF | 1,06 | 9,46 | 4,04 | 5,14 | 6,72 | 2,21 |

Based on table 5, it shows that there is no multicollinearity between independent variables, because the VIF value of each variable is not more than 10.

**Table 6. Estimation of Poisson Regression Parameter in Madiun**

| | *Estimate* | *Std. Error* | Pr(>\|Z\|) |
|---|---|---|---|
| $\beta_0$ | 4,42 | $9,05\times10^{-2}$ | $< 2\times10^{-16}$ *** |
| $\beta_1$ | $-8,04\times10^{-4}$ | $1,79\times10^{-4}$ | $7,49\times10^{-6}$ *** |
| $\beta_2$ | $1,17\times10^{-4}$ | $7,14\times10^{-6}$ | $< 2\times10^{-16}$ *** |
| $\beta_3$ | $-9,33\times10^{-4}$ | $2,93\times10^{-4}$ | 0,00146 ** |
| $\beta_4$ | $2,18\times10^{-1}$ | $5,60\times10^{-2}$ | $9,92\times10^{-5}$ *** |
| $\beta_5$ | $-1,13\times10^{-4}$ | $9,21\times10^{-6}$ | $< 2\times10^{-16}$ *** |
| $\beta_6$ | $-6,91\times10^{-3}$ | $1,40\times10^{-3}$ | $8,32\times10^{-7}$ *** |

Ket : * (significant at level 0.05)
** (significant at level 0.01)
*** (significant at the level of 0.001)

Based on table 6, all independent variables in the poisson regression model have a significant influence on the number of tuberculosis cases in Madiun Regency.

**Table 7. Poisson Regression Overall Test Madiun**

| $G^2$ | $\chi^2_{(0,05;6)}$ | Pr(>\|Z\|) | α |
|---|---|---|---|
| 758,73 | 12,59 | $< 2,2\times10^{-16}$ *** | 0,05 |

Based on table 7, it is found that the value of G2 > $\chi2_{(0.05;\ 6)}$ and *p-value* < α which means minus H0. These results show that these variables simultaneously affect the number of tuberculosis cases in Madiun Regency.

**Tabel 8. Parsial Regresi Poisson Test Madiun**

| | *Estimate* | W value | $\chi^2_{(0,05;1)}$ | Decision |
|---|---|---|---|---|
| $X_1$ | $-8,04\times10^{-4}$ | 20,07 | 3,84 | Reject ($H_0$) |
| $X_2$ | $1,17\times10^{-4}$ | 269,75 | 3,84 | Reject ($H_0$) |
| $X_3$ | $-9,33\times10^{-4}$ | 10,12 | 3,84 | Reject ($H_0$) |
| $X_4$ | $2,18\times10^{-1}$ | 15,15 | 3,84 | Reject ($H_0$) |
| $X_5$ | $-1,13\times10^{-4}$ | 150,73 | 3,84 | Reject ($H_0$) |
| $X_6$ | $-6,91\times10^{-3}$ | 24,28 | 3,84 | Reject ($H_0$) |

**Tabel 9. Overdispersion Testing in Madiun**

| Nilai *Deviance* | degrees of freedom |
|---|---|
| 339,64 | 8 |

In table 9, the *ratio degrees of freedom* (df) is obtained as 42.46, which is much greater than the value of 1. This indicates an overdispersion in the model, when the variance of the data is much greater than expected by the poisson model.

**Tabel 10. Negative Binomial Regression Parameter Estimation for Madiun**

| | *Estimate* | *Std. Error* | Pr(>\|Z\|) |
|---|---|---|---|
| $\beta_0$ | 4,33 | $3,92\times10^{-1}$ | $< 2\times10^{-16}$ *** |
| $\beta_1$ | $-1,53\times10^{-3}$ | $6,65\times10^{-4}$ | 0,02121 * |
| $\beta_2$ | $1,09\times10^{-4}$ | $3,14\times10^{-5}$ | 0,00053 *** |
| $\beta_3$ | $-1,29\times10^{-3}$ | $1,51\times10^{-3}$ | 0,39082 |
| $\beta_4$ | $2,99\times10^{-1}$ | $2,87\times10^{-1}$ | 0,29553 |
| $\beta_5$ | $-1,15\times10^{-4}$ | $4,44\times10^{-5}$ | 0,00954 ** |
| $\beta_6$ | $-2,22\times10^{-3}$ | $5,44\times10^{-3}$ | 0,68352 |

In table 10, it can be seen that there are three independent variables that have a significant effect at the level of 5% on the number of tuberculosis cases in Madiun Regency. The three variables are the height of the area ($X_1$), the number of productive age population ($X_2$) and the number of households with access to good sanitation ($X_5$).

**Table 11. Negative Binomial Regression Overall Test of Madiun**

| $G^2$ | $\chi^2_{(0,05;6)}$ | Pr(>\|Z\|) | α |
|---|---|---|---|
| 19,90 | 12,59 | 0,00289 ** | 0,05 |

Based on table 11, it is found that the value of$G^2$ > $\chi^2_{(0,05;6)}$ and *p-value* < α which means subtract H0. These results show that these variables simultaneously affect the number of tuberculosis cases in Madiun Regency.

**Table 12. Partial Test of Negative Binomial Regression in Madiun**

| | *Estimate* | W value | $\chi^2_{(0,05;1)}$ | Decision |
|---|---|---|---|---|
| $X_1$ | $-1,53\times10^{-3}$ | 5,31 | 3,84 | Reject ($H_0$) |
| $X_2$ | $1,09\times10^{-4}$ | 11,99 | 3,84 | Reject ($H_0$) |
| $X_3$ | $-1,29\times10^{-3}$ | 0,74 | 3,84 | Fail to reject ($H_0$) |
| $X_4$ | $2,99\times10^{-1}$ | 1,10 | 3,84 | Fail to reject ($H_0$) |
| $X_5$ | $-1,15\times10^{-4}$ | 6,72 | 3,84 | Reject ($H_0$) |
| $X_6$ | $-2,22\times10^{-3}$ | 0,17 | 3,84 | Fail to reject ($H_0$) |

Based on table 12, it was found that the variables of area height ($X_1$), the number of productive age population ($X_2$) and the



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number of households with access to good sanitation ($X_5$) had a *greater Wald* value than the value $\chi^2_{(0,05;1)}$ which shows that these three variables have a significant effect on the number of tuberculosis cases in Madiun Regency.

**Table 13. Estimation of Negative Binomial Regression Parameters of Madiun (After Iteration)**

| | *Estimate* | W value | $\chi^2_{(0,05;1)}$ | Decision |
|---|---|---|---|---|
| $\beta_0$ | 4,38 | 152,48 | 3,84 | Reject ($H_0$) |
| $\beta_1$ | $-1{,}59\times10^{-3}$ | 5,72 | 3,84 | Reject ($H_0$) |
| $\beta_2$ | $1{,}21\times10^{-4}$ | 18,37 | 3,84 | Reject ($H_0$) |
| $\beta_5$ | $-1{,}21\times10^{-4}$ | 6,99 | 3,84 | Reject ($H_0$) |

Based on the results in table 13, the negative binomial regression model for Madiun Regency is obtained as follows:

$\mu_i$ = $\exp(4{,}38 – 1{,}59\times10^{-3}X_1 + 1{,}21\times10^{-4}X_2 – 1{,}21\times10^{-4}X_5)$.

Based on table 14, the negative binomial regression model shows better performance than poisson regression in analyzing factors that affect tuberculosis cases in Madiun Regency.

**Tabel 14. Selecting the Best Model for Madiun Analysis**

| Model | AIC value | *Deviance* / db |
|---|---|---|
| Poisson | 465,20 | 42,46 |
| Negative Binomial | 184,19 | 1,38 |

**Table 15. Individual Insignificant Variable Test in Madiun**

| | *Estimate* | W value | *p-value* | Decision |
|---|---|---|---|---|
| $X_3$ | 0,001 | 0,921 | 0,337 | Fail to reject ($H_0$) |
| $X_4$ | 0,477 | 7,515 | 0,006 | Reject ($H_0$) |
| $X_6$ | 0,012 | 2,521 | 0,112 | Fail to reject ($H_0$) |

Based on table 15, testing of insignificant variables is performed individually by modeling each variable without interaction with other variables. From the test results, only the variable number of health facilities ($X_4$) showed a significant influence on tuberculosis cases, while the number of health workers ($X_3$) and the percentage of household waste management ($X_6$) remained insignificant.

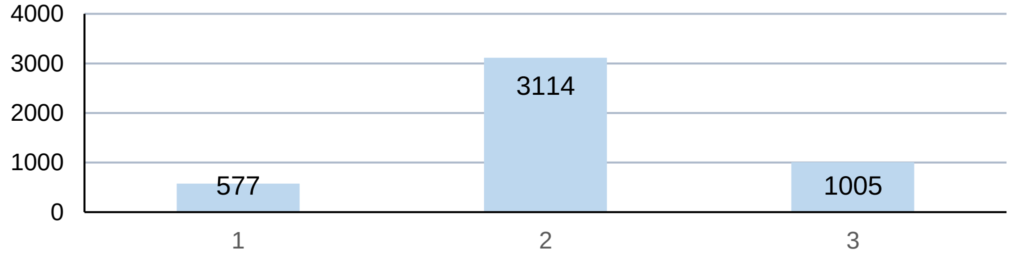


**Figure 3. Tuberculosis Cases for Every Number of Health Facilities in Madiun Regency**

Based on Figure 3, the results of negative binomial regression analysis show that the variable number of health facilities (X4) is significant for the number of tuberculosis cases. However, descriptive analysis shows that the variance of these variables is relatively small, ranging from 1 to 3 facilities per sub-district. Based on figure 3, the number of tuberculosis cases appears to increase when the number of facilities increases from 1 to 2, but actually decreases when it increases to 3.

**Analysis of Ponorogo Regency**

After the analysis for Madiun Regency, the next step is to conduct an analysis to understand more deeply the relationship between variables that are suspected to affect the number of tuberculosis cases in Ponorogo Regency.

**Table 16. Variable VIF Value of Ponorogo**

| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ |
|---|---|---|---|---|---|---|
| VIF | 1,23 | 8,36 | 1,94 | 2,64 | 4,33 | 1,11 |

Table 16 shows that there is no multicollinearity between independent variables, since the VIF value of each variable is no more than 10.

**Table 17. Estimation of Poisson Regression Parameters in Ponorogo**

| | *Estimate* | *Std. Error* | Pr(>\|Z\|) |
|---|---|---|---|
| $\beta_0$ | 6,13 | $7{,}99\times10^{-2}$ | $< 2\times10^{-16}$ *** |
| $\beta_1$ | $-9{,}68\times10^{-4}$ | $7{,}33\times10^{-5}$ | $< 2\times10^{-16}$ *** |
| $\beta_2$ | $5{,}89\times10^{-5}$ | $3{,}41\times10^{-6}$ | $< 2\times10^{-16}$ *** |
| $\beta_3$ | $-7{,}18\times10^{-4}$ | $6{,}39\times10^{-5}$ | $< 2\times10^{-16}$ *** |
| $\beta_4$ | $-5{,}34\times10^{-2}$ | $2{,}30\times10^{-2}$ | 0,02040 * |
| $\beta_5$ | $-4{,}70\times10^{-5}$ | $4{,}22\times10^{-6}$ | $< 2\times10^{-16}$ *** |
| $\beta_6$ | $-6{,}86\times10^{-3}$ | $9{,}20\times10^{-4}$ | $8{,}76\times10^{-14}$ *** |


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Based on table 17, all independent variables in the poisson regression model have a significant influence on the number of tuberculosis cases in Ponorogo Regency.

**Table 18. *Overall* Regression Test of Poisson in Ponorogo**

| $G^2$ | $\chi^2_{(0,05;6)}$ | Pr(>\|Z\|) | α |
|---|---|---|---|
| 1258,60 | 12,59 | < $2{,}2\times10^{-16}$ *** | 0,05 |

Based on table 18, it is found that the value of G2 > $\chi2_{(0.05;\ 6)}$ and *p-value* < α which means minus $H_0$. These results show that these variables simultaneously affect the number of tuberculosis cases in Ponorogo Regency.

**Table 19. Partial Regression Test of Poisson**

| | *Estimate* | W value | $\chi^2_{(0,05;1)}$ | Decision |
|---|---|---|---|---|
| $X_1$ | $-9{,}68\times10^{-4}$ | 174,21 | 3,84 | Reject ($H_0$) |
| $X_2$ | $5{,}89\times10^{-5}$ | 298,08 | 3,84 | Reject ($H_0$) |
| $X_3$ | $-7{,}18\times10^{-4}$ | 126,46 | 3,84 | Reject ($H_0$) |
| $X_4$ | $-5{,}34\times10^{-2}$ | 5,38 | 3,84 | Reject ($H_0$) |
| $X_5$ | $-4{,}70\times10^{-5}$ | 123,68 | 3,84 | Reject ($H_0$) |
| $X_6$ | $-6{,}86\times10^{-3}$ | 55,63 | 3,84 | Reject ($H_0$) |

Based on table 19, the *Wald* values obtained for each variable, show that all independent variables show a significant influence on the number of tuberculosis cases.

**Tabel 20. Overdispersion Testing in Ponorogo**

| *Deviance value* | degrees of freedom |
|---|---|
| 892,78 | 14 |

Based on table 20, the *ratio of deviance* to df is obtained as 63.77, which is much greater than the value of 1. This indicates an overdispersion in the model.

Based on table 21, it can be seen that there are three independent variables that have a significant effect at the level of 5% on the number of tuberculosis cases in Ponorogo Regency. The three variables are the height of the area (X1), the number of productive age population (X2) and the number of health workers (X3).

**Table 21. Estimation of Negative Binomial Regression Parameters of Ponorogo**

| | *Estimate* | *Std. Error* | Pr(>\|Z\|) |
|---|---|---|---|
| $\beta_0$ | 6,18 | $5{,}11\times10^{-1}$ | < $2\times10^{-16}$ *** |
| $\beta_1$ | $-8{,}61\times10^{-4}$ | $3{,}92\times10^{-4}$ | 0,02789 * |
| $\beta_2$ | $6{,}75\times10^{-5}$ | $2{,}24\times10^{-5}$ | 0,00259 ** |
| $\beta_3$ | $-9{,}65\times10^{-4}$ | $4{,}21\times10^{-4}$ | 0,02179 * |
| $\beta_4$ | $-1{,}33\times10^{-1}$ | $1{,}47\times10^{-1}$ | 0,36505 |
| $\beta_5$ | $-4{,}81\times10^{-5}$ | $2{,}91\times10^{-5}$ | 0,09760 |
| $\beta_6$ | $-5{,}56\times10^{-3}$ | $5{,}86\times10^{-3}$ | 0,34274 |

**Table 22. Negative Binomial Regression Overall Test of Ponorogo**

| $G^2$ | $\chi^2_{(0,05;6)}$ | Pr(>\|Z\|) | α |
|---|---|---|---|
| 20,48 | 12,59 | 0,00227 ** | 0,05 |

Based on table 22, it is found that the value of $G^2 > \chi^2_{(0,05;6)}$ and *p-value* < α which means subtract $H_0$. These results show that these variables simultaneously affect the number of tuberculosis cases in Ponorogo Regency.

**Table 23. Partial Test of Negative Binomial Regression in Ponorogo**

| | *Estimate* | W value | $\chi^2_{(0,05;1)}$ | Decision |
|---|---|---|---|---|
| $X_1$ | $-8{,}61\times10^{-4}$ | 4,84 | 3,84 | Reject ($H_0$) |
| $X_2$ | $6{,}75\times10^{-5}$ | 9,07 | 3,84 | Reject ($H_0$) |
| $X_3$ | $-9{,}65\times10^{-4}$ | 5,26 | 3,84 | Reject ($H_0$) |
| $X_4$ | $-1{,}33\times10^{-1}$ | 0,82 | 3,84 | Fail to reject ($H_0$) |
| $X_5$ | $-4{,}81\times10^{-5}$ | 2,74 | 3,84 | Fail to reject ($H_0$) |
| $X_6$ | $-5{,}56\times10^{-3}$ | 0,91 | 3,84 | Fail to reject ($H_0$) |

Based on table 23, it was found that the variables of regional height ($X_1$), the number of productive age ($X_2$) and the number of health workers ($X_3$) had *a greater Wald* value than nilai $\chi^2_{(0,05;1)}$ value which shows that these three variables have a significant effect on the number of tuberculosis cases in Ponorogo.

**Table 24. Estimation of Negative Binomial Regression Parameters of Ponorogo (After Iteration)**

| | *Estimate* | W value | $\chi^2_{(0,05;1)}$ | Decision |
|---|---|---|---|---|
| $\beta_0$ | 5,66 | 283,57 | 3,84 | Reject ($H_0$) |
| $\beta_1$ | $-1{,}07\times10^{-3}$ | 6,98 | 3,84 | Reject ($H_0$) |
| $\beta_2$ | $3{,}01\times10^{-5}$ | 7,02 | 3,84 | Reject ($H_0$) |
| $B_3$ | $-8{,}58\times10^{-4}$ | 3,97 | 3,84 | Reject ($H_0$) |

Based on the results in table 24, the negative binomial regression model for Ponorogo Regency is obtained as follows:

$\mu_i = \exp(5{,}66 - 1{,}07\times10^{-3}X_1 + 3{,}01\times10^{-5}X_2 - 8{,}58\times10^{-4}X_3)$.

Based on table 25, the negative binomial regression model shows better performance than poisson regression in analyzing the factors that affect tuberculosis cases in Ponorogo Regency.



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**Table 25. Selection of the Best Model for Analysis of Ponorogo**

| Model | AIC value | *Deviance* / df |
|---|---|---|
| Poisson | 1070,40 | 63,77 |
| Negative Binomial | 276,17 | 1,26 |

Based on table 26, the results of individual testing of previously insignificant variables in the negative binomial regression model found that there were no individually significant variables in the model.

**Table 26. Individual Insignificant Variable Test in Ponorogo**

| | *Estimate* | W value | *p-value* | Decision |
|---|---|---|---|---|
| $X_4$ | 0,228 | 2,727 | 0,099 | Fail to reject ($H_0$) |
| $X_5$ | $3{,}181\times10^{-5}$ | 2,681 | 0,102 | Fail to reject ($H_0$) |
| $X_6$ | -0,005 | 0,307 | 0,579 | Fail to reject ($H_0$) |

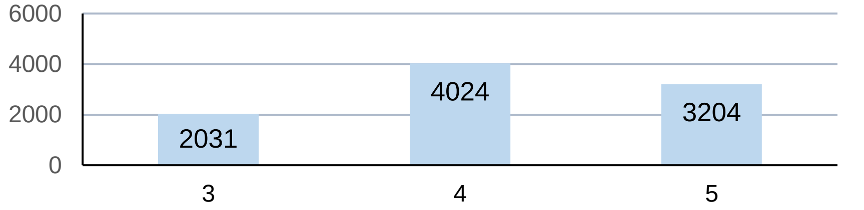

**Figure 4. Tuberculosis Cases for Every Number of Health Facilities in Ponorogo Regency**

Based on Figure 4, the results of negative binomial regression analysis show that the variable number of health facilities (X4) is not significant to the number of tuberculosis cases. However, descriptive analysis shows that the variance of these variables is relatively small, ranging from 3 to 5 facilities per sub-district. Based on figure 4, the number of tuberculosis cases appears to increase when the number of facilities increases from 3 to 4, but decreases when it increases to 5.

## DISCUSSION

### Descriptive Analysis

Descriptive analysis shows notable variation in tuberculosis (TB) cases across sub-districts in Madiun and Ponorogo Regencies, influenced by environmental and health infrastructure factors. In Madiun Regency, differences in elevation and the number of health workers ($X_3$) significantly affect TB distribution. Higher areas tend to have limited access to health services, while sub-districts with fewer health workers face greater challenges in TB prevention and treatment. The highest number of cases in Dagang District may relate to health service accessibility and worker availability, emphasizing the importance of health infrastructure ($X_4$) in controlling TB spread.

A positive relationship between the productive age population ($X_2$) and TB cases indicates that larger populations in this age group increase the risk of transmission, while elevation shows a negative correlation possibly due to reduced access and underreporting in higher areas.

In Ponorogo Regency, the variation in TB cases is strongly associated with differences in the productive age population ($X_2$), sanitation access ($X_5$), and waste management conditions. Sampung District, with the highest TB cases, may be influenced by socioeconomic factors and population activity levels. Poor sanitation and limited waste management contribute to higher transmission risks, as unhealthy environments facilitate TB spread.

Furthermore, the strong relationship between the productive age population ($X_2$) and access to sanitation ($X_5$) suggests that sub districts with larger populations generally have better sanitation infrastructure, which can help reduce TB transmission in Ponorogo Regency.

### Analysis of Madiun Regency

The multicollinearity test was performed to determine whether there are similarities between independent variables in the model used. The results of the multicollinearity test found no indication of significant multicollinearity problems in the regression model used. The highest VIF value obtained, which was 9.46 in the variable of the number of


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productive age population ($X_2$), was still below the commonly used threshold, which was 10. Thus, it can be said that no significant symptoms of multicollinearity occur in this model. These findings are in line with the results of research by Syafiqoh et al. (2024), which also show that all independent variables in TB analysis have VIF values below 10, so multicollinearity is not a significant issue in regression modeling.[21]

The Poisson regression model is a non-linear *regression model* used to model the relationship between dependent variables in the form of *count* data and one or more independent variables.[22] The *overall test* was carried out by comparing the values *Likelihood Ratio Test* ($G^2$) with *Chi-Square* or *p-value* with α.[23] The results showed that the Poisson regression model constructed had independent variables that simultaneously had a significant effect on the number of TB cases. The much larger $G^2$ value compared to the *Chi-Square table value*, as well as the *much smaller p-value* than the α, gives confidence that this regression model is worth using.

Based on the results of the Poisson regression estimation, several variables have a positive influence, such as the number of productive age population ($X_2$) and the number of health facilities ($X_4$), which means that the increase in these variables tends to increase the number of TB cases. On the other hand, other variables have a negative influence, which suggests that increases in these variables tend to decrease the number of cases

Overdispersion in poisson regression occurs when the variance of the data is greater than its mean value, which means that the poisson model's basic assumptions about equidispersion are not met.[21] This condition can affect the results of parameter estimation, produce inefficient estimates, and affect the results of statistical tests that become biased.[24]

Based on a *deviance value* much greater than 1, it can be concluded that the poisson regression model is not suitable for the data in Madiun Regency because the data shows significant overdispersion. To solve this problem, one commonly used approach is to replace the poisson distribution with a negative binomial distribution. Negative binomial distributions are able to handle overdispersion by introducing additional parameters that can accommodate larger variances.[24]

The use of the negative binomial regression model to overcome the problem of overdispersion in TB data in Madiun Regency provides more accurate results than the poisson model.[19] The negative binomial model is able to cope with conditions when the variance is greater than the mean, which is characteristic of overdispersion.[25]

The negative binomial regression results show that all independent variables significantly affect the number of TB cases. The large $G^2$ value and very small p-value confirm the model's suitability. Area elevation and household access to sanitation negatively influence TB cases, while the productive age population has a positive effect, indicating that higher elevation and better sanitation reduce cases, whereas an increase in the productive age population raises them.

Other variables, such as the number of health workers, health facilities, and household waste management, did not show a significant influence on this model. This may be due to other factors that are more dominant or the presence of more complex variances in the relationship between these variables and the number of TB cases.[25]

To ensure that the model used only includes significant independent variables, repeated partial testing is performed by removing the insignificant variables one by one. Any variable with a significance value above α = 0.05 is removed from the model.


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Based on the results of the estimated negative binomial regression model that has been iterated, it can be interpreted that every increase in the height of the area by 1 meter above sea level (masl), assuming that the other variables are fixed, the average number of TB cases tends to decrease by $\exp(-1{,}59\times10^{-3}) \approx 0{,}99841$, which means there is a reduction of about 0.159% in the number of cases. For every 1 addition of the productive age population, the average number of cases tends to increase by $\exp(1{,}21\times10^{-4}) \approx 1{,}00012$, This means that there is an increase of around 0.012%. In addition, every addition of 1 household with good sanitation access will reduce the average number of cases by $\exp(-1{,}21\times10^{-4}) \approx 0{,}99988$, or reduction around 0,012%.

The comparison between Poisson and Negative Binomial regression shows that the Negative Binomial model is more appropriate for analyzing TB cases in Madiun Regency. This is supported by its ability to handle overdispersion, reflected in lower AIC and deviance values compared to the Poisson model. A smaller deviance per degree of freedom indicates that the Negative Binomial regression provides a more accurate and efficient representation of data variation.

Individual significance testing was conducted to determine whether variables became significant when modeled separately. The results show that variable $X_4$ (number of health facilities) significantly affects TB cases when tested individually. However, due to high correlations between $X_4$ and other variables specifically the number of health workers ($r = 0.84$) and the productive age population ($r = 0.66$) its significance decreases when analyzed together, as these variables share explanatory power.

Differences between the individual regression results and the visualization in Figure 3 may be influenced by other factors, such as differences in facility capacity and service quality, public accessibility to health services, or the presence of stronger prevention programs in areas with more health facilities.

**Analysis of Ponorogo Regency**

The results of the multicollinearity test found no indication of significant multicollinearity problems in the regression model used. The highest VIF value obtained, which was 8.36 in the variable of the number of productive age population ($X_2$), was still below the commonly used threshold, which was 10.[21] Thus, it can be said that the relationships between independent variables in the model are not very strong.

The Poisson regression analysis for Ponorogo Regency demonstrates that all independent variables collectively have a significant effect on the number of tuberculosis (TB) cases. The large $G^2$ value compared to the Chi-Square table value and the very small p-value confirm that the model fits well. The estimation results show that the productive-age population ($X_2$) has a positive effect, meaning that an increase in this population is associated with a higher number of TB cases. In contrast, the other variables exhibit negative effects, indicating that their increases tend to reduce TB incidence.

However, the overdispersion test produced a deviance value much greater than 1, indicating that the Poisson model is unsuitable for the data due to significant overdispersion. To address this, the model was replaced with a Negative Binomial regression. The overall test of this model shows that all independent variables again have a simultaneous and significant effect on TB cases, supported by a large $G^2$ value and a p-value smaller than $\alpha$, confirming the model's reliability.

Parameter estimation from the Negative Binomial regression indicates that elevation and the number of health workers ($X_3$) negatively affect TB cases, meaning increases in these variables reduce incidence, whereas the productive age population ($X_2$) positively


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influences TB cases, showing that larger productive populations are associated with higher TB risk.

Other variables, such as the number of health facilities, the number of households with good sanitation access and household waste management, did not show a significant influence on this model. This may be due to other factors that are more dominant or the presence of more complex variances in the relationship between these variables and the number of TB cases.[25]

To ensure that the model used only includes significant independent variables, repeated partial testing is performed by removing the insignificant variables one by one. Any variable with a significance value above α = 0.05 is removed from the model.

Based on the results of the estimated negative binomial regression model that has been iterated, it can be interpreted that every increase in the height of the area by 1 meter above sea level (masl), assuming that other variables are fixed, the average number of TB cases tends to decrease by exp(-1.07×10-3) ≈ 0.99893, which means there is a reduction of about 0.107% in the number of cases. For every 1 addition of the productive age population, the average number of cases tends to increase by exp(3.01×10-5) ≈ 1.00003, which means an increase of about 0.003%. In addition, every addition of 1 health worker will reduce the average number of cases by exp(-8.58×10-4) ≈ 0.99914, or a reduction of about 0.086%.

The comparison between Poisson and Negative Binomial regression models shows that the Negative Binomial regression is more appropriate for analyzing TB cases in Ponorogo Regency. This suitability is supported by smaller AIC and deviance values, indicating its effectiveness in addressing overdispersion in the data.

Individual significance testing revealed that none of the independent variables had a significant effect on TB cases when analyzed separately. The low correlation between these variables and TB incidence suggests that, although theoretically relevant, they do not have a strong direct impact on the number of cases when assessed independently.

Visualization results indicate a slight increase in TB cases when the number of health facilities rises from 3 to 4, followed by a decrease at 5 facilities. This inconsistency supports the regression results showing that the number of health facilities has no significant effect. The absence of a clear pattern implies that other aspects such as accessibility and service quality may play a more dominant role in influencing TB cases in Ponorogo Regency.

These findings are consistent with Banapon et al. (2020) in West Java, who also applied Negative Binomial regression to address overdispersion, with model selection based on lower AIC values compared to Poisson regression. However, the significant variables differ; this study identifies altitude, the productive age population, and sanitation access as the main determinants, underscoring that TB risk factors vary across regions depending on social, economic, and environmental conditions.[26]

Overall, this study demonstrates the strength of the Negative Binomial regression model in producing a more accurate analysis of factors affecting TB cases in Madiun and Ponorogo Regencies. Nonetheless, its limitation lies in using only secondary data from 2023, which restricts the exploration of other influential variables. The findings emphasize the need to enhance sanitation access and focus on the productive age population in TB prevention and control programs.

## CONCLUSION

The application of Poisson and Negative Binomial regression models to tuberculosis cases in Madiun and Ponorogo Regencies produced differing results. In Madiun Regency, all independent variables in the Poisson model were significant, while in the


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Negative Binomial model, only $X_1$ (Area Height), $X_2$ (Number of Productive Age Population), and $X_5$ (Number of Households with Good Sanitation Access) remained significant. In Ponorogo Regency, all variables in the Poisson model were also significant; however, in the Negative Binomial model, the significant variables were $X_1$ (Area Height), $X_2$ (Number of Productive Age Population), and $X_3$ (Number of Health Workers). Model evaluation results indicate that the Negative Binomial regression model is more appropriate for both regions, as it better addresses overdispersion and provides a more reliable representation of TB case variations.

This study recommends strengthening region-based intervention programs by focusing on key factors improving sanitation access in Madiun Regency and increasing health workers in Ponorogo Regency. The government and health agencies should also enhance counseling on TB related factors, while future research is encouraged to explore additional social and environmental variables such as climate and population density.

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