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Article

Spatial Analysis and Risk Factor Association of Pneumonia Cases Among Under-Five Children in Surakarta City

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Abstract: The increasing number of pneumonia cases among under-five children in Surakarta City over the past three years indicates the need for preventive measures to curb the rise. Spatial analysis and risk factor assessment are essential tools for understanding the geographical distribution and contributing determinants of pneumonia in young children.; (1) Background: To analyze the spatial distribution and associations between risk factors and pneumonia cases among under-five children in Surakarta City.; (2) Methods: This research is a quantitative study with a cross-sectional design; (3) Results: Multivariate regression showed that poor nutrition, population density, rainfall, and humidity significantly influenced pneumonia prevalence.; (4) Conclusions: The prevalence of pneumonia in toddlers shows a high level of vulnerability in Sangkrah subdistrict. The Health Office of Surakarta City can intervene with priority level 1 area.

Keywords: GIS, Multivariate Analysis, Pneumonia in Toddlers, Spatial Analysis

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1. Introduction

According to the Ministry of Health in Indonesia, pneumonia is an inflammation of the lungs in the alveolar tissue. This inflammation leads to the accumulation of fluid or pus, which disrupts the breathing process and limits oxygen intake. Pneumonia is a disease that can infect children aged 0-5 years. According to WHO, pneumonia is the pneumonia is the single leading infectious cause of death among children worldwide. In 2019, 740.180 under-five children died from pneumonia, with 14% being children under the age of five and 22% being children aged one to five years reported that globally[1]. UNICEF report that there are 1,400 pneumonia cases per 100,000 children—equivalent to 1 in every 71 children per year [2].

According to Health ministry of Indonesia, cases of pneumonia in toddlers become the largest cause of death under five of children in Indonesia [3]. In 2018 alone, more than 19,000 children died from pneumonia—equivalent to over two deaths every hour [4]. Indonesian government has shown its commitment to combating pneumonia by launching the National Action Plan for the Prevention of Pneumonia and Diarrhea (2023–2030). This plan aligns with the Sustainable Development Goals (SDGs), particularly Goal 3, Target 3.2, which aims to reduce maternal and child mortality by 2030 [5].

Many risk factors can increase pneumonia cases in among five children. This disease can be influenced by factors from the sufferer or host, agent, social environmental, as well as natural environmental factors [6]. Several studies have identified an association between pneumonia in children and factors such as poor nutritional status [7]; exclusive breastfeeding [8]; population density [9]; rainfall, and humidity [10].

According to the 2023 Health Profile by the Ministry of Health, the provinces reporting the highest pneumonia cases among under-five children are West Java, East Java, and Central Java. Central Java ranked third with 55,232 reported cases. Surakarta City, located in Central Java, reported 452 cases in 2023—ranking 25th among 35 regencies/municipalities. Although Surakarta does not have the highest case burden, the

trend of pneumonia cases in the city has continued to increase, especially during 2022–2024.

According to Surakarta City Health Office reports, there were 169 cases of pneumonia among under-five children in 2022. This figure increased to 473 cases in 2023—a 179% increase, with 304 additional cases. Preliminary studies from the Disease Prevention and Control (P2P) division of the Surakarta City Health Office indicated that the number rose again in 2024, reaching 520 cases—a 10% increase from the previous year

Spatial analysis plays a crucial role in transforming spatial data into meaningful insights. It helps to understand patterns in disease distribution and associated risk factors, enabling the identification of areas with high vulnerability [11]. Explicit spacial analysis of infectious diseases contributes to the design of an appropriate management and control for the disease prevention [12]Click or tap here to enter text..

The significant rise in pneumonia cases in Surakarta demands immediate attention and strategic prevention efforts. A comprehensive approach is needed to understand and address the contributing risk factors to effectively mitigate disease spread. At the local level, spatial analysis aids in planning and implementing targeted interventions. However, limited research has focused on the spatial distribution and risk factors of pneumonia in under-five children in Surakarta. As the most densely populated city in Central Java, Surakarta requires localized interventions, particularly at the sub-district (kelurahan) level.

Based on the above considerations, the researcher is interested in conducting spatial analysis of pneumonia case distribution among under-five children in Surakarta and its association with malnutrition, exclusive breastfeeding, population density, rainfall, and humidity.

Pneumonia is an inflammation of the alveolar tissue in the lungs that leads to fluid or pus accumulation, disrupting the breathing process and limiting oxygen intake. According to the World Health Organization (WHO), pneumonia is the single leading infectious cause of death among children worldwide. In 2019, approximately 740,180 under-five children died from pneumonia, with 14% being children under one year and 22% aged one to five years [1]. UNICEF further reported that there are about 1,400 pneumonia cases per 100,000 children annually, equivalent to 1 in every 71 children [2].

In Indonesia, pneumonia remains a major public health problem. The Ministry of Health identifies pneumonia as the largest cause of death among children under five [3]. In 2018 alone, more than 19,000 Indonesian children died of pneumonia, equal to over two deaths every hour [4]. To address this, the government launched the National Action Plan for the Prevention of Pneumonia and Diarrhea (2023–2030). This program aligns with the Sustainable Development Goals (SDGs), particularly Goal 3, Target 3.2, which seeks to reduce maternal and child mortality by 2030 [5].

According to the 2023 Health Profile, West Java, East Java, and Central Java reported the highest pneumonia cases in under-five children, with Central Java ranking third at 55,232 cases. Within Central Java, Surakarta City reported 452 cases in 2023, ranking 25th among 35 regencies/municipalities. Although not the highest, the city has shown a concerning upward trend in pneumonia cases. Reports from the Surakarta City Health Office revealed 169 cases in 2022, increasing to 473 cases in 2023 (a 179% rise), and further reaching 520 cases in 2024 (a 10% increase).

The significant rise in pneumonia cases in Surakarta highlights the urgent need for effective prevention strategies. While previous studies have examined risk factors such as malnutrition, lack of exclusive breastfeeding, high population density, rainfall, and humidity, few have focused on their combined influence in the local context. Moreover, research on pneumonia in Surakarta has rarely incorporated spatial analysis, especially at the sub-district (kelurahan) level, where variations in environmental and social conditions are more pronounced. This study addresses these gaps by analyzing the spatial distribution of pneumonia cases among under-five children in Surakarta and examining

their association with key risk factors, providing evidence to support targeted and area-specific interventions.

2. Materials and Methods

This study employed a descriptive quantitative approach with a cross-sectional design. Geographic Information Systems (GIS) were utilized to map the spatial distribution of pneumonia cases among under-five children, along with the independent variables. The researcher used statistical analysis multivariate regression to analyze its relationship with pneumonia cases in under-five children.

Table 1. Research Variables Summary

Variable	Symbol	Variable Description	Operational Definition	Unit	Scale	Data Source	Measurement Results
Response	y	Prevalence of pneumonia in toddlers	Proportion of toddlers aged 0–59 months diagnosed with pneumonia in a given year in a subdistrict	per 100 under-five children	54 subdistricts in Surakarta city	Health Office, BPS Surakarta City	Prevalence rate per 100 toddlers in each subdistrict
Predictor	x_1	Poor nutritional status	The proportion of toddlers aged 0–59 months with poor nutritional status (BB/TB Z-score –3 elementary to <–2 elementary school) in a subdistrict	%	54 subdistricts in Surakarta city	Public Health Centers	Percentage of undernourished toddlers per subdistrict
	x_2	Exclusive breastfeeding	The percentage of <6-month-old babies who were only breastfed without additional food/drink for 6 months	%	54 subdistricts in Surakarta city	Public Health Centers	Percentage of exclusively breastfed babies per subdistrict
	x_3	Population density	Number of people per square kilometer in a subdistrict	people/km²	54 subdistricts in Surakarta city	BPS Surakarta City	Number of people/km² per subdistrict
	x_4	Rainfall	Average rainfall (mm) in subdistrict based on satellite imagery	mm	54 subdistricts in Surakarta city	NASA POWER (satellite)	Average rainfall per subdistrict
	x_5	humidity	Average relative humidity (%) in subdistrict based on satellite imagery	%	54 subdistricts in Surakarta city	NASA POWER (satellite)	Average humidity per subdistrict

The population in this study consists of pneumonia cases among under-five children recorded by the Surakarta City Health Office between 2023 and 2024, as well as Central Statistics Agency (BPS) in 2022. This study used total sampling as the number of cases was manageable, ensuring complete data representation and accuracy in spatial analysis. Data collection was conducted through a documentation study, using secondary data obtained from the Surakarta City Health Office, the Central Statistics Agency, and the Surakarta City Public Health Centers (Puskesmas). Ethical approval was waived as the study utilized secondary, anonymized data without involving direct interaction with human participants.

Spatial analysis was conducted using QGIS software to determine the distribution patterns of pneumonia cases among under-five children in relation to several risk factors. This study also uses Overlay analysis techniques. Overlay analysis is done by combining or by overlapping between basemaps to produce new information. Overlay analysis techniques were applied by combining or superimposing multiple base maps to generate new spatial information. In addition, a scoring method was used to identify subdistricts with high levels of vulnerability, facilitating the development of a priority intervention map. To test the hypothesis regarding the association between pneumonia prevalence and the risk factors, a multivariate regression analysis was employed.

3. Results and Discussion

3.1. Spatial Distribution of Pneumonia Cases in Surakarta City in 2022 – 2024

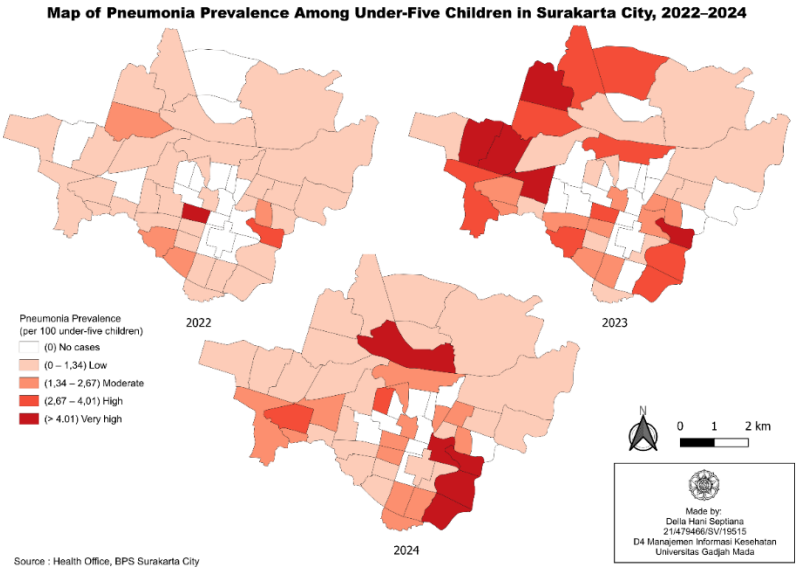
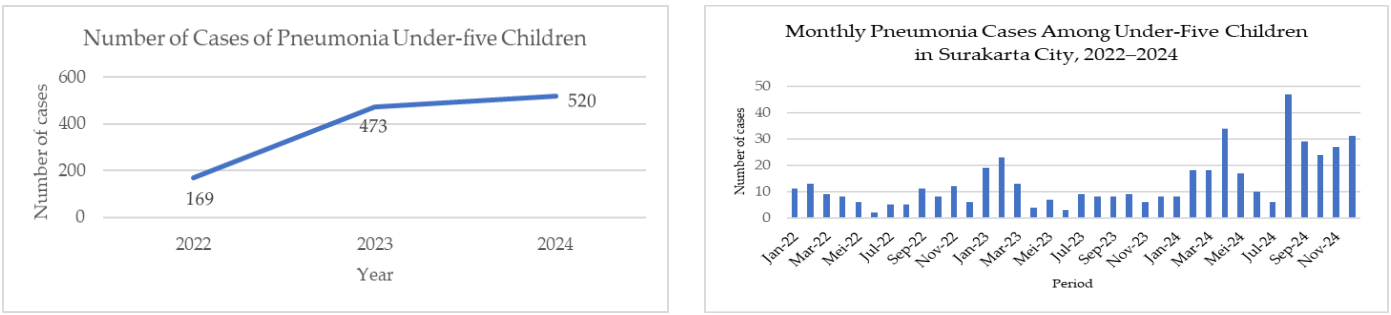


Figure 1. Map of Pneumonia Prevalence Among Under-Five Children in Surakarta City, 2022–2024

Figure 1. illustrates yearly variations in the distribution of pneumonia cases among under-five children in Surakarta. Central subdistricts consistently showed no cases. In 2022, Kemlayan had the highest prevalence (4.55) and was the only area in the "very high" category. In 2023, dark red areas indicating high prevalence spread, especially in the west, with Jajar (11.67), Purwosari (8.53), Kerten (6.74), Banyuanyar (4.11), and Sangkrah (4.10) among the most affected. In 2024, very high prevalence was recorded in Kedunglumbu (21.67), Sangkrah (13.54), Mojo (10.77), Semanggi (7.84), and Nusukan (5.44), mostly in the southern part of the city. To control the spread, the Surakarta Health Office has strengthened IMCI at community health centers, as this approach has been shown to improve recovery in children with pneumonia [13]

3.2. Trend Analysis of Pneumonia Cases in Surakarta City in 2022 – 2024



(**a**) (**b**)

Figure 2. (a) Number of cases of pneumonia under-five children yearly in Surakarta City; **(b)** Monthly pneumonia cases among under-five children in Surakarta City

Figure 2. (a) shows that the number of cases among under-five children in Surakarta City from 2022 to 2024 shows a steady increase in the number of cases over the years. From 2022 to 2023, the number of cases rose by 179.88%, equivalent to an increase of 304 cases. Meanwhile, from 2023 to 2024, there was a further increase of 9.94%, or 47 additional cases. The highest peak in pneumonia cases among under-five children occurred in 2024, with a

total of 520 reported cases. According to the monthly reports from community health centers (Puskesmas) in Figure 2. (b), increases in pneumonia cases among under-five children often occur around the turn of the year. The dynamic variation in the number and prevalence of pneumonia cases each year may be influenced by several factors, including weather conditions, air pollution levels, and the presence of seasonal allergens [14].

3.3. Pneumonia Prevalence Distribution by Risk Factors Among Under-Five Children

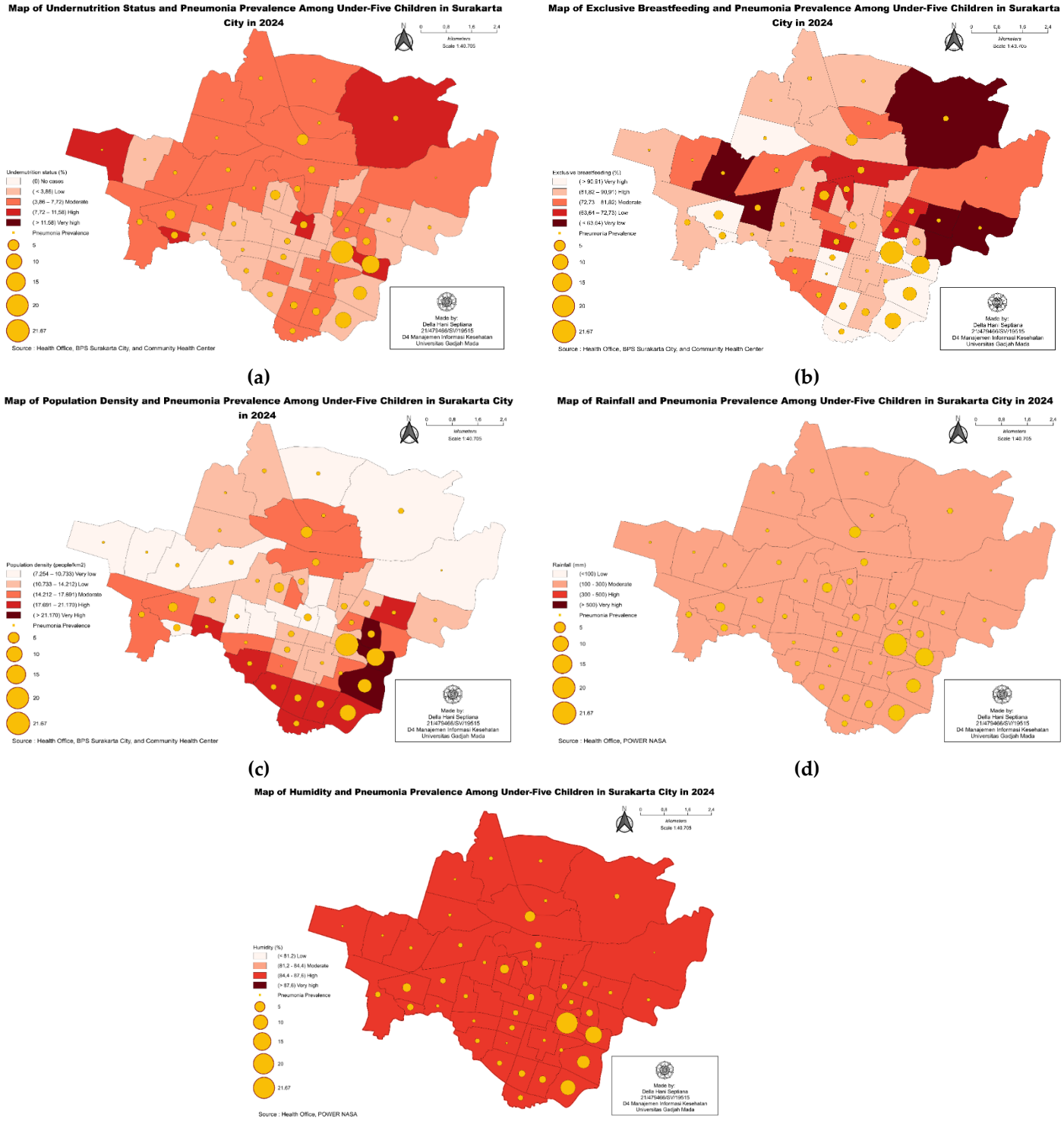


Figure 3. **(a)** Map of Undernutrition Status and Pneumonia Prevalence Among Under-Five Children in Surakarta City in 2024 **(b)** Map of Exclusive Breastfeeding and Pneumonia Prevalence Among

Under-Five Children in Surakarta City in 2024; **(c)** Map of Population Density and Pneumonia Prevalence Among Under-Five Children in Surakarta City in 2024; **(d)** Map of Rainfall and Pneumonia Prevalence Among Under-Five Children in Surakarta City in 2024; **(e)** Map of Humidity and Pneumonia Prevalence Among Under-Five Children in Surakarta City in 2024

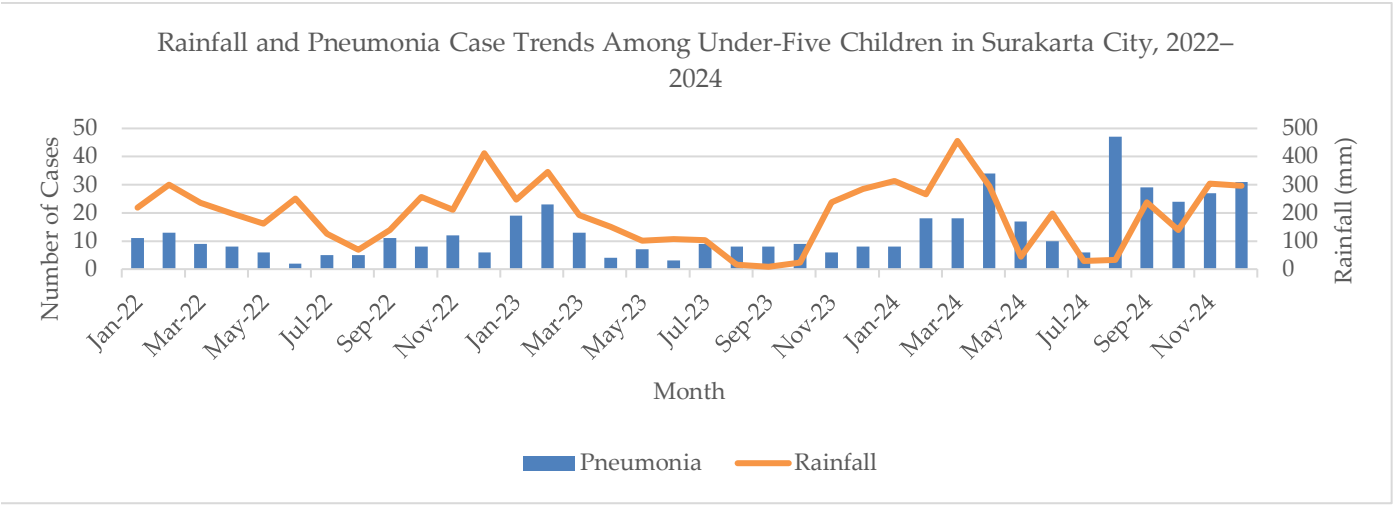
Based on the overlay Figure 3. (a), subdistricts with very high pneumonia prevalence—such as Kedunglumbu (21.67), Semanggi (7.84), and Mojo (10.77)—were located in areas with low undernutrition rates. In contrast, Sangkrah (13.54) had both very high pneumonia and undernutrition rates, while Nusukan (5.44) fell under the moderate undernutrition category. Nutrition plays a vital role in child health, as inadequate intake can lead to undernutrition and weaken the immune system, increasing susceptibility to infections like pneumonia [15][16]. However, undernutrition is not the sole cause of pneumonia. Previous study shows that children with good nutritional status could still develop pneumonia [17], indicating areas with a high prevalence of pneumonia may be influenced by other contributing factors.

According to the overlay Figure 3. (b), subdistricts with a very high pneumonia prevalence—namely Kedunglumbu, Sangkrah, Mojo, and Semanggi—were located in areas classified under the very high exclusive breastfeeding category. Nusukan, another high-prevalence area, also had high breastfeeding rates. This finding is consistent with research indicating no significant association between exclusive breastfeeding and the incidence of pneumonia, as evidenced by the comparable number of infants with and without pneumonia in the group that was not exclusively breastfed [18][19]. Misclassification by parents who believed they practiced exclusive breastfeeding, despite early introduction of other foods or liquids, is a possible explanation [20].

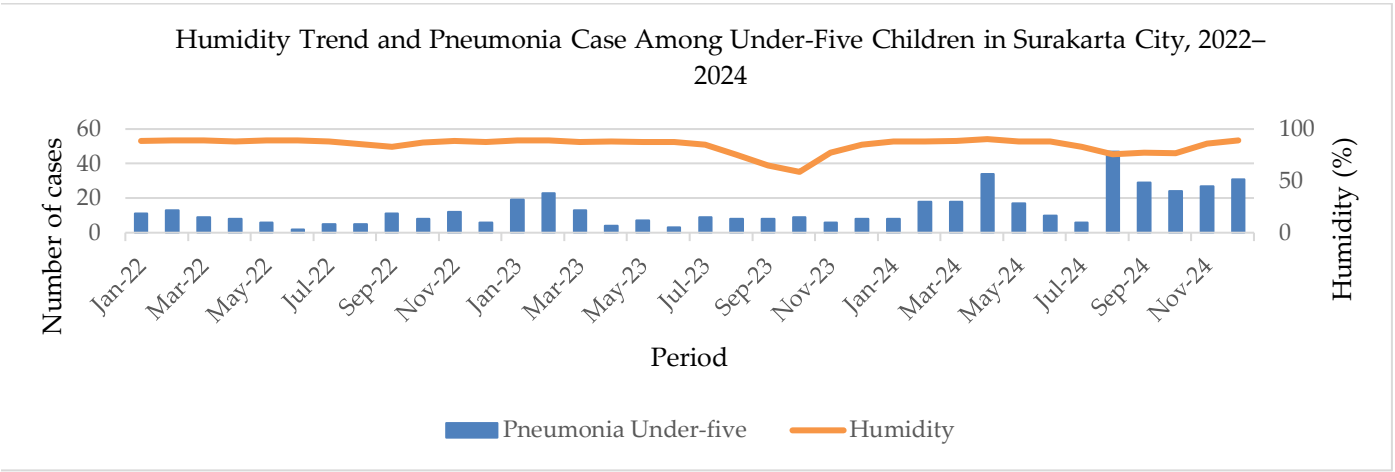
Figure 3. (c) shows that Kedunglumbu, the subdistrict with the highest pneumonia prevalence, was located in a low-density area, while Sangkrah and Semanggi fell under the very high-density category, Mojo under high density, and Nusukan under moderate density. Epidemiologically, higher density increases person-to-person contact and facilitates airborne transmission of infectious diseases such as pneumonia [8][21]. However, the finding in Kedunglumbu suggests that high prevalence can occur even in low-density areas, likely due to other contributing factors such as housing quality, air pollution, or individual host vulnerabilities. This aligns with researcher who reported no significant relationship and even a negative correlation between population density and pneumonia among under-five children [22].

Figure 3. (d) showed relatively uniform rainfall across subdistricts, limiting the ability of overlay maps in linking rainfall to pneumonia prevalence. Nevertheless, seasonal patterns in rainfall (Figure 4. (a)) aligned with pneumonia case trends from 2022–2024, supporting earlier findings that cases increase during the rainy season [23]. Increased rainfall may raise infection risk due to water contamination [24], whereas in the dry season, air pollution exposure can damage lung tissue and increase vulnerability to pathogens [25].

Similarly, humidity data from NASA POWER were uniform across subdistricts (Figure 3. (e)), reducing their utility for spatial overlay analysis. Monthly trend comparisons (Figure 4. (b)) indicated that humidity levels did not align with pneumonia case patterns, in contrast to rainfall. Although high humidity may support microorganism growth [26], prior research in Semarang found no correlation between humidity and pneumonia incidence among under-five children indicating prevalence of pneumonia may be influenced by other contributing factors [27].



(a)



(b)

Figure 4. **(a)** Rainfall Trend and Pneumonia Case Among Under-Five Children in Surakarta City, 2022–2024; **(b)** Humidity Trend and Pneumonia Case Among Under-Five Children in Surakarta City, 2022–2024

3.4. Mapping of Priority Intervention Areas for Under-Five Pneumonia in Surakarta City

Priority area mapping for pneumonia intervention was carried out using a scoring method, which is a form of modeling within Geographic Information Systems (GIS). This approach involves modeling the distribution of parameters such as undernutrition status, exclusive breastfeeding, population density, rainfall, and humidity. This method is particularly useful in disease-related research, as it helps identify areas with high vulnerability, enabling a focused intervention in regions with a high risk of disease occurrence.

Table 2. Classification and Variables Score

Variabel	Category	Score
Pneumonia Prevalence Among Under-Five Children (per 100)	No Cases (0)	1
	Low (<1.34)	2
	Moderate (1.34 – 2.67)	3
	High (2.67 – 4.01)	4
	Very High (>4.01)	5
Undernourished status (%)	No Cases (0)	1

Variabel	Category	Score
	Low (< 3,86)	2
	Moderate (3,86 – 7,72)	3
	High (7,72 – 11,58)	4
	Very High (>11,58)	5
Exclusive Breastfeeding (%)	Very High (>90,91)	1
	High (81,82 – 90,91)	2
	Moderate (72,73 – 81,82)	3
	Low (63,64 – 72,73)	4
	Very Low (<63,64)	5
Population Density (people/km²)	Very Low (7.254 – 10.733)	1
	Low (10.733 – 14.212)	2
	Moderate (14.212 – 17.691)	3
	High (17.691 – 21.170)	4
	Very High (>21.170)	5
Rainfall (mm)	Low (<100)	1
	Moderate (100 – 300)	2
	High (300 – 500)	3
	Very High (>500)	4
Air Humidity (%)	Low (<81,16)	1
	Moderate (81,16 – 84,40)	2
	High (84,40 – 87,64)	3
	Very High (>87,64)	4

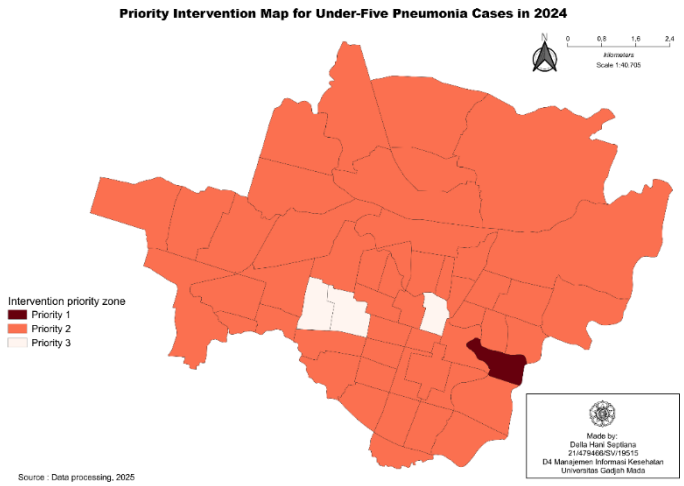


Figure 8. Priority Intervention Map for Under-Five Pneumonia Cases in 2024

Based on the results of the study in mapping the priority intervention areas, Sangkrah Subdistrict was identified as the only area classified under Priority Level 1, with a total score of 20. This classification is attributed to its very high pneumonia prevalence of 13.54 and a very high population density of 27,882.6 people/km². Overall, the average score across all subdistricts was 15. Further intervention is necessary in Priority 1 areas. According to the Ministry of Health of the Republic of Indonesia (2025), medical personnel and other healthcare workers play a crucial role in managing pneumonia through promotive, preventive, curative, and rehabilitative efforts [28]

3.5. Analysis of the Association Between Undernutrition, Exclusive Breastfeeding, Population Density, Rainfall, and Air Humidity and the Prevalence of Pneumonia Among Under-Five Children

3.5.1. Data Imputation

The data in this study contained missing values, particularly for the variables of undernutrition status and exclusive breastfeeding. Each of these variables had the same proportion of missing data, amounting to 9%. The missing data were addressed using proportional allocation imputation and mean imputation.

Table 3. Summary of Variable Statistics

Variable	Min	Max	Range	Sum	Mean	Median	SE.Mean	Variance	Std.Dev
x_0	0.00	21.67	21.67	229.23	1.42	0.62	0.21	6.83	2.61
x_1	0.00	27.82	27.82	656.76	4.05	3.33	0.25	10.26	3.20
x_2	50.81	100.00	49.19	13629.72	84.13	85.15	0.90	130.87	11.44
x_3	7254.21	27882.60	20628.39	2257894.20	13937.62	12908.15	379.92	23383420.00	4835.64
x_4	151.41	217.44	66.03	31510.08	194.51	214.67	2.40	935.72	30.59
x_5	81.16	87.64	6.48	13697.64	84.55	84.86	0.21	7.09	2.66

Correlation between the variable y and each variable x_1, x_2, x_3, x_4, and x_5 Is given in table below.

Table 4. Correlation of independent variables to the prevalence of pneumonia under-five children

Variable	Correlation	p-Value
x_1	0.2470	0.0015 *
x_2	0.0480	0.5460
x_3	0.2870	0.0002 *
x_4	0.0270	0.7310
x_5	-0.2220	0.0046 *

Note: (*) = significant at 5% significance level.

The table above indicates a correlation between undernutrition, population density, and humidity with pneumonia prevalence. Among the independent variables, population density shows the strongest correlation with pneumonia prevalence.

3.5.2. Model Estimation Selection

The selection of the appropriate regression model for panel data requires conducting three tests: the Chow test, the Hausman test, and the Lagrange Multiplier test. These tests are used to determine whether the most suitable model approach is the Common Effect, Fixed Effect, or Random Effect model.

Table 5. Testing for estimation model

Test	p-Value	Result	Description
Chow	0.608	reject H_0	The common effect model provides a better representation of the data compared to the fixed effect model
Hausman	0.4293	reject H_0	The random effect model represents the data better than the fixed effect model
Lagrange Multiplier	0.1837	reject H_0	The common effect model is superior to the random effect model in representing the data.

The results in Table 5 indicate that the appropriate model approach is the common effect model. This approach employs the Pooled Ordinary Least Squares (Pooled OLS) method, or the least squares technique, to estimate the panel data model.

3.5.3. Assumption Tests

The results of the multicollinearity test in Table 5 show that all variables had VIF value < 10 thus all predictor variables had no multicollinearity

Table 6. Multicolinearity Test

Predictor Variable	VIF
x_1	1.02932
x_2	1.049994
x_3	1.014022
x_4	4.902809
x_5	4.947373

The results of the Breusch-Pagan Test in Table 7 indicate a *p*-value of 0.3357, which is greater than α (0.05). This means that the null hypothesis (H_0) fails to be rejected, leading to the conclusion that the variance is constant, or in other words, the data exhibits homoscedasticity.

Table 7. Heteroscedacity test value

Breusch-Pagan	*p*-Value
5.6132	0.3357

The results of residual normality using Kolmogorov-Smirnov test in Table 8 show a *p*-value of 2.2e-16, which is less than α (0.05). This leads to the rejection of the null hypothesis (H_0), indicating that the model residuals are not normally distributed.

Table 8. Normality test value

D	*p*-Value
0.42337	2.2e-16

The results of the spatial autocorrelation test on the residuals using Moran's Index in Table 9, with rook contiguity weighting, show a p-value of 0.256, which is greater than α (0.05). This means that the null hypothesis (H_0) fails to be rejected, indicating no spatial autocorrelation in the model residuals. This outcome satisfies the assumptions of regression analysis.

Table 9. Spatial Autocorrelation residual test value

Moran's I	*p*-Value
0.033884778	0.256

The results of the Durbin-Watson test presented in Table 10 show a p-value of 0.6313, which is greater than α (0.05). This means that the null hypothesis (H_0) fails to be rejected, indicating that there is no evidence of serial autocorrelation in the model. This result is consistent with the regression model assumption that the model should be free from serial autocorrelation.

Table 10. Serial Autocorrelation test value

Durbin-Watson	*p*-Value
4.9136	0.1782

3.5.4. Data Transformation

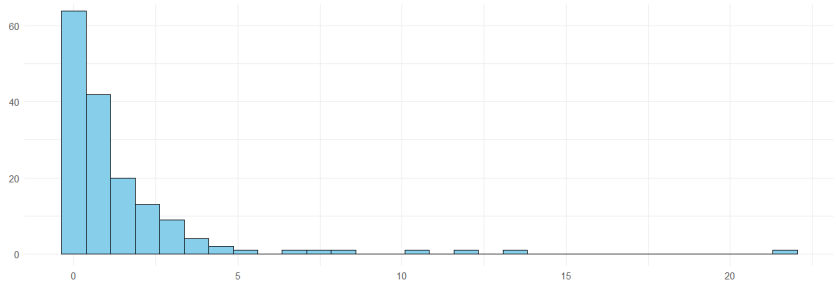


Figure 9. Pneumonia prevalence histogram

Based on the assumption tests, there is a violation of the assumptions, specifically in the normality test of the residuals. To meet the normality assumption, a data transformation was performed. Figure 9 shows a histogram of pneumonia prevalence, displaying a severely positively skewed distribution concentrated around a value of 0. An appropriate transformation for data with a positively skewed distribution and the presence of zero values is the log transformation of the form log $(x + C)$, where C is a constant with a value of 1. For further clarification, the results of the data transformation are presented in the following table.

Data transformation using log $(x + 1)$ has been employed by several other researchers. In general, researchers tend to preserve the value of "0" by adding either 1 or another positive constant to the dependent variable (48%), using Poisson-type estimators (35%), applying the hyperbolic inverse sine (HIS) transformation (15%), or choosing to exclude the zeros from the analysis altogether (31%) (Bellégo et al., 2022).

Table 11. Log transformed model normality test value

D	***p*-Value**
0. 086925	0.1728

The results of the normality test using the Kolmogorov-Smirnov test in Table 21 show a p-value of 0.1728, which is greater than α (0.05). This means that the null hypothesis (H_0) fails to be rejected, indicating that the residuals of the transformed model are normally distributed. The Pooled OLS model with logarithmic transformation satisfies the regression assumptions.

3.5.4. Estimation of Log Transformed Regression Model

The analysis of the log transformed regression model estimation uses Equation (1) where *i* represent the i-th location, where the location i = 1, 2, ..., 54 represents the initials for 54 subdistricts in Surakarta, and *t* time is 1 for 2022, 2 for 2023, and 3 for 2024. The estimation results of the regression model are given in Equation (1).

$$log(y_{it} + 1) = \beta_0 + \beta_1 x_{1,it} + \beta_2 x_{2,it} + \beta_3 x_{3,it} + \beta_4 x_{4,it} + \beta_5 x_{5,it} + \varepsilon_{it} \quad (1)$$

, i = 1, 2, …, 54; t = 1, 2, 3

The symbol "β" represents the coefficient indicating its effect on pneumonia prevalence, and "ε" denotes the residual for each variable at a specific time and location. The results of the pooled OLS regression are presented in the following table.

Table 12. Log Transformed Model Estimation Value

Variabel	Coefficient (Est)	Std.Error	T-value	P-value
(Intercept)	9.1197	2.5839	3.5295	0.0005 *
(x_1)	0.0402	0.0141	2.8460	0.0050 *
(x_2)	0.0030	0.0040	0.7400	0.4604
(x_3)	0.0000	0.0000	4.1880	0.0000 *
(x_4)	0.0071	0.0032	2.2046	0.0289 *
(x_5)	-0.1282	0.0372	-3.4409	0.0007 *

Note: (*) = significant at 5% significance level.

Table 22 shows that the variables of undernutrition (p-value = 0.0005), population density (p-value = 0.0000), rainfall (p-value = 0.0289), and humidity (p-value = 0.0007) have a significant effect on pneumonia prevalence. Conversely, exclusive breastfeeding does not show a significant effect (p-value = 0.4604) on pneumonia prevalence.

To interpret the regression results using the logarithmic transformation $(x + 1)$, the estimated coefficient values need to be exponentiated to return them to their original scale. The percentage change is obtained using the logarithmic formula.

Table 13. Estimation Paramater Result

Variabel	Estimated Coefficient (β)	Exponent (e^{β})	Percentage Change ($(e^{\beta}-1) \times 100\%$)
(x_1)	0.0402	1.04102	4.10%
(x_2)	0.0030	1.00296	0.30%
(x_3)	0.0000	1.000039	0.004%
(x_4)	0.0071	1.0071408	0.71%
(x_5)	-0.1282	0.879707	-12.03%

The regression model indicates a significant relationship between the prevalence of pneumonia in children under five and the rate of undernutrition. The results show that for every 1% increase in the percentage of undernourished children, there is a 4.10% increase in pneumonia prevalence. This finding is consistent with a study conducted at Praya Regional Hospital, which reported a significant association between undernutrition and pneumonia incidence in children under five [29].

Exclusive breastfeeding is the only variable that does not show a significant relationship with the prevalence of pneumonia in children under five. This result is inconsistent with the findings of Riyanto and Megasari (2021), who reported that children who were not exclusively breastfed during infancy had a 2.3 times higher risk of developing pneumonia compared to those who were exclusively breastfed during the first six months of life [30].

A significant relationship is also observed between population density and pneumonia prevalence in children under five. The results indicate that an increase of 1 person per km² in population density leads to a 0.004% increase in pneumonia prevalence among children in the area. This is in line with a study conducted in Bandung City, which found a significant influence of population density on pneumonia cases in children under five [31].

Regarding the rainfall variable, the regression model shows a significant effect. An increase of 1 mm in rainfall can raise the prevalence of pneumonia by 0.71%. This finding aligns with the study by Kim et al. (2016), which found a significant

association between rainfall and pneumonia incidence in children under five in Papua New Guinea [32].

Humidity shows the highest significant effect, despite being negative. The results indicate that a 1% increase in humidity leads to a 12.03% decrease in pneumonia prevalence. This finding is consistent with the study by Fitriani (2025), which showed that increased humidity can reduce pneumonia incidence in children under five [33].

4. Conclusions

Pneumonia cases among under-five children in Surakarta increased from 2022 to 2024, reaching a peak of 520 cases in 2024, with the highest prevalence recorded in Kedunglumbu, followed by Sangkrah, Mojo, Semanggi, and Nusukan. Overlay mapping showed that high-prevalence areas such as Kedunglumbu, Mojo, and Semanggi had low undernutrition rates, while Sangkrah had very high undernutrition and Nusukan moderate. In terms of exclusive breastfeeding, most high-prevalence areas, including Kedunglumbu, Sangkrah, Mojo, and Semanggi, fell into the very high category, with Nusukan in the high category. Population density mapping indicated that Kedunglumbu had low density, Sangkrah and Semanggi very high, Mojo high, and Nusukan moderate. Overlay mapping with rainfall and humidity was limited due to identical data across subdistricts, though rainfall trends aligned with pneumonia patterns, while humidity trends did not. Priority mapping identified Sangkrah as the top-priority area for intervention. Regression analysis revealed significant effects of undernutrition, population density, rainfall, and humidity on pneumonia prevalence, while exclusive breastfeeding showed no significant effect.

These findings support the prioritization of Sangkrah subdistrict in pneumonia prevention programs through nutritional interventions and environmental health policies. However, this study has several limitations, including reliance on secondary data sources, imputation of missing data, and the inability of rainfall and humidity datasets to capture intra-urban variability across subdistricts. Future research should integrate household-level surveys to capture individual risk factors more accurately, as well as incorporate air pollution monitoring to better explain variations in pneumonia prevalence across different subdistricts.

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