Pneumonia incidence in children under five in Indonesia: A spatial analysis before, during and transition period of the COVID-19 pandemic

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ABSTRACT

Background: Pneumonia has consistently remained one of the leading causes of mortality among children under five, spanning the periods before, during and in the transition periods of the COVID-19 pandemic.

Objectives: This study investigated the spatial association between healthcare, socioeconomic, environmental factors and the pneumonia incidence rate per 10,000 populations in children under five at the provincial level, comparing 2019 (before COVID-19 pandemic), 2021 (during COVID-19 pandemic) and 2023 (transition period of the COVID-19 pandemic) in Indonesia.

Methods: This study utilized secondary data from the Annual Indonesian Health Profile Books (2019, 2021 and 2023), Statistical Yearbook of Indonesia (2020, 2022 and 2024), Central Statistical Agency's website and Google Earth Engine. This spatial analysis applied global and local Moran's I and advanced spatial regression techniques.

Results: The incidence rate of pneumonia in children under five before, during and in the transition period of COVID-19 were 158.10, 80.82 and 129.39 per 10,000 population. Meanwhile, Moran's I values were -0.130, -0.103 and 0.087, respectively indicating a shift from dispersed to clustered spatial autocorrelation, particularly in Java Island. Negative correlations were observed between pneumonia incidence and the number of midwives (across all periods), access to proper sanitation facilities (latrines) (during the COVID-19 pandemic), and precipitation (during the transition period of the COVID-19 pandemic). In contrast, sulphur dioxide levels exhibited a positive spatial autocorrelation both before and during the COVID-19 pandemic.

Conclusion: To reduce pneumonia in children under five in Indonesia, efforts should focus on strengthening midwife availability, access and expanding midwife training programs. Additionally, improving access to sanitation facilities and implementing air quality control measures will also play a key role in reducing pneumonia incidence.

Keywords: Child health, COVID-19, Environmental health, Pneumonia, Spatial analysis

1. Introduction

Pneumonia is the leading infectious diseases contributing to child mortality globally, particularly among children under-fives and can be caused by bacteria (e.g., *Streptococcus pneumoniae* and *Haemophilus influenzae* type b (Hib)), viruses (e.g., Respiratory syncytial virus (RSV) and *Pneumocystis jiroveci*) and fungi [1]. In 2017, pneumonia caused 808,000 mortality, accounting for 15% of total mortality in children under five and remained the leading infectious cause of mortality for 740,180 children (14%) in 2019 [2, 3]. In Indonesia, pneumonia is the leading cause of mortality in children under-five, accounting for 9.5%,9.4% and 1.6% of under-five mortality in 2019, 2021 and 2023, respectively [4-6]. The sharp decline in pneumonia mortality in 2023 is most likely attributed to the implementation of the National Pneumonia and Diarrhoea Control Program 2023-2030 [7].

Numerous studies have identified key determinants of pneumonia in children under five, such as the availability of health workers [8-10], housing condition [11], access to sanitation facilities (latrines) [12, 13], exposure to Sulphur Dioxide [14], and impact of precipitation pattern [15-17]. The COVID-19 pandemic has affected the detection rate of pneumonia, with research highlighting its impact on pneumonia cases in Brazil and China [18-20].

Indonesia's unique geography, culture, and socio-economic conditions contribute to varying factors influencing pneumonia cases in children under five across the country. While many studies have examined pneumonia in Indonesia, there are significant gaps in the use of recent spatial analysis to identifying geographic patterns and disparities of pneumonia among children under five. This study aims to fill the gap by mapping spatial variations and assessing factors by comparing data from before, during, and in the transition period of the COVID-19. Understanding the spatial distribution of pneumonia incidence in children under five is crucial for informing health policies and developing effective strategies to reduce pneumonia's burden on this population.

2. Methods

2.1 Study Area

The study was conducted in Indonesia. Astronomically, Indonesia is located in 6.08° N to -11.01° S latitude and 94.97° E to 141.02° E longitude [21]. Bordered to the

north by Malaysia, Singapore, Vietnam, Philippines, Palau and the South China Sea; to the east by Papua New Guinea and the Pacific Ocean; to the south by Timor-Leste, Australia, and the Indian Ocean; and to the west by the Indian Ocean [22].

This study analysed data from three distinct time periods: before COVID-19 period (2019), during COVID-19 pandemic period (2021), and the transition period of COVID-19 (2023). The dataset covered 34 provinces, as the four newly established provinces (created in 2023 through administrative changes) did not have available data and were therefore excluded to ensure consistency across time periods [23]. Indonesia has total land area of 1,892,555.47 km², consists of over 17,000 islands [24].

2.2 Data Preparation

This study employed a dataset of pneumonia in children under-five cases reported by Ministry of Health of the Republic of Indonesia, included a total of 468,172, 278,261 and 416,435 pneumonia case

detection. The incidence rate of pneumonia in children under-five for each province was calculated by dividing the number of case detection by the total of that province's population and multiplying by 10,000.

The independent variables included healthcare, socio-economic, and environmental factors. The healthcare factor (represented by the number of midwives per 10,000 population) and socio-economic factor of access to proper sanitation facilities were obtained from the Indonesia Health Profile Book [4-6]. Socio-economic factor of access to decent and affordable housing, sourced from the Central Statistics Agency's website [25]. Environmental factors, such as average Sulphur Dioxide levels [26] and average precipitation [27] were derived from the Google Earth Engine.

The raw dataset for this study was prepared, validated and cleaned to ensure accuracy and reliability. Following validation, the data was imported into Quantum GIS (QGIS) version 3.40.1 (Bratislava) to integrate spatial and non-spatial data, resulting in a shapefile for analysis [28]. QGIS was then used to visualize the incidence rate if pneumonia in children under five before, during, and in the transition period of COVID-19 pandemic. Subsequently, comprehensive spatial

analysis was performed using GeoDa, version 1.22.0.10 8 [29].

2.3 Data Analysis

This study analysed the spatial pattern of pneumonia in children under five in Indonesia using Moran's I statistics, which detects spatial autocorrelation. Moran's I helps to determine whether the incidence rate of pneumonia in children under five is randomly distributed across the country or if there are clusters of high or low incidence rate [30]. The Moran's I test is calculated by considering the spatial relationship between regions, evaluating whether the values for neighbouring areas are more similar than expected by chance, which helps to identify regions with clustered high or low incidence rates. Additionally, Moran's I can reveal the specific areas where clusters of high and low incidence rate occur [31].

The Local Indicators of Spatial Association (LISA) were used. LISA helps assess both global and local spatial autocorrelation in the incidence rate of pneumonia in children under five years and its associated factors. Within the LISA framework, we utilized Moran's I to determine whether individual regions were part of spatial cluster with similar incidence rate (e.g., high-high or low-

low clusters) or to identify outliers (e.g., high-low or low-high clusters). The analysis used weight matrix based on Euclidean distance (6.29° before and during COVID-19, and 4.88° in the transition period) calculated using EPSG:4326 (WGS 84). A significant threshold of P-value < 0.05 was applied, with 999 permutations to test assess the sensitivity of significant locations. A small P-value (< 0.05) indicates a significant spatial pattern, while higher P-value means that the distribution is likely random [32, 33].

To explore the relationship between the incidence rate of pneumonia in children under five and independent variables, spatial regression models were used. These models account for spatial dependencies between regions. Three common types of regression models used in spatial analysis are (OLS), whereas Spatial Lag Model (SLM) and Spatial Error Model (SEM) specifically address spatial dependencies. SLM, which allows the dependent variable of surrounding provinces influences the dependent variable in the area being estimated (the province of interest) and SEM, which allows the error term of adjacent provinces to influence that of the province under study. When significant spatial dependence was identified, OLS was not used, and a spatial model was applied

instead. The robust Lagrange Multiplier (LM) test was conducted to determine whether the SLM or the SEM was more appropriate. If both models showed statistically significant LM values, the one with the lower value was selected. The Akaike Information Criterion (AIC) was then used to determine the best-fitting model, with the lowest AIC value indicating the most appropriate model [34].

3. Results

The reported incidence of pneumonia declined during the COVID-19 period, dropping from 158.10 to 80.82 per 10,000 population. However, this figure increased during the transition period of COVID-19 to 129.39, although it remained lower than the pre-COVID-19 period (Figure 1).
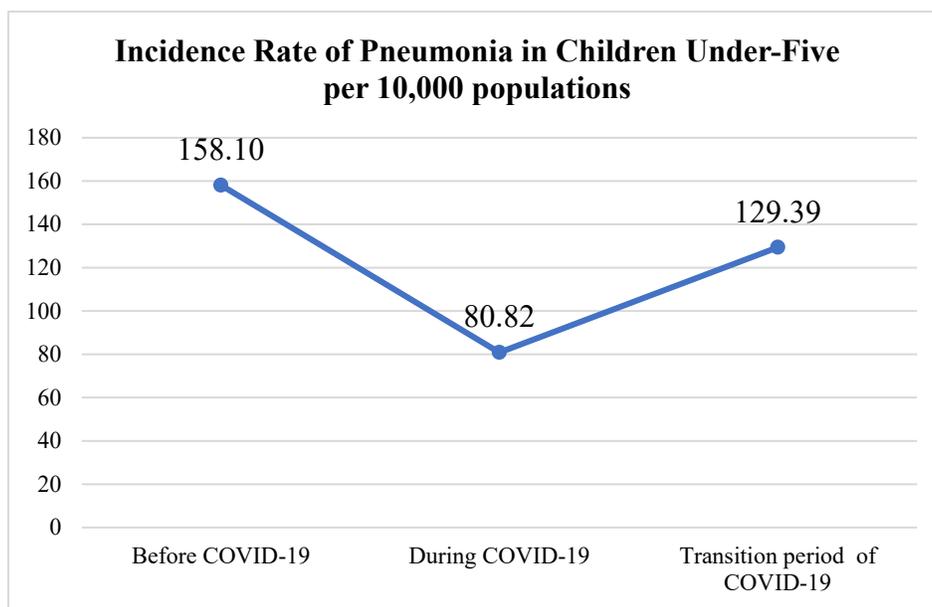

Figure 1:   Trend of the Incidence Rate of Pneumonia in Children Under-Five per 10,000 Population

The distribution of pneumonia in children under five, categorized by the number of incidence rate per 10,000 population (displayed as 5 levels, each in different colour) among the provinces in Indonesia before, during, and in the transition period of COVID-19 pandemic. Before the COVID-19 pandemic, the highest incidence was found in DKI Jakarta with a rate of 443.27 cases per 10,000 population, while the lowest incidence was found in Papua with a rate of 0.53 cases per 10,000 population. The quantile map indicates the top quintile (270 - 443 cases per 10,000 population) in 7

provinces, including Kepulauan Bangka Belitung, Banten, DKI Jakarta, Kalimantan Selatan, Nusa Tenggara Barat, Sulawesi Utara, and Papua Barat. During the COVID-19 pandemic, the highest incidence was found in Papua Barat with a rate of 280.66 cases per 10,000 population, while the lowest incidence was found in Sulawesi Utara with a rate of 11.79 cases per 10,000 population. The quantile map indicates the top quintile (135 - 281 cases per 10,000 population) in 7 provinces, including Banten, Jawa Barat, Jawa Tengah, Jawa Timur, Nusa Tenggara

Barat, Sulawesi Tengah, and Papua Barat. In the transition period of the COVID-19, the highest incidence was found in Kalimantan Selatan with a rate of 318.53 cases per 10,000 population, while the lowest incidence was found in Sulawesi Utara with a rate of 5.61 cases per 10,000 population. The quantile map indicates the top quintile (215 - 319 cases per 10,000 population) in 7 provinces, including Banten, DKI Jakarta, Jawa Timur, Nusa Tenggara Barat, Kalimantan Selatan, Sulawesi Tengah, Gorontalo, and Papua Barat) (Figure 2).
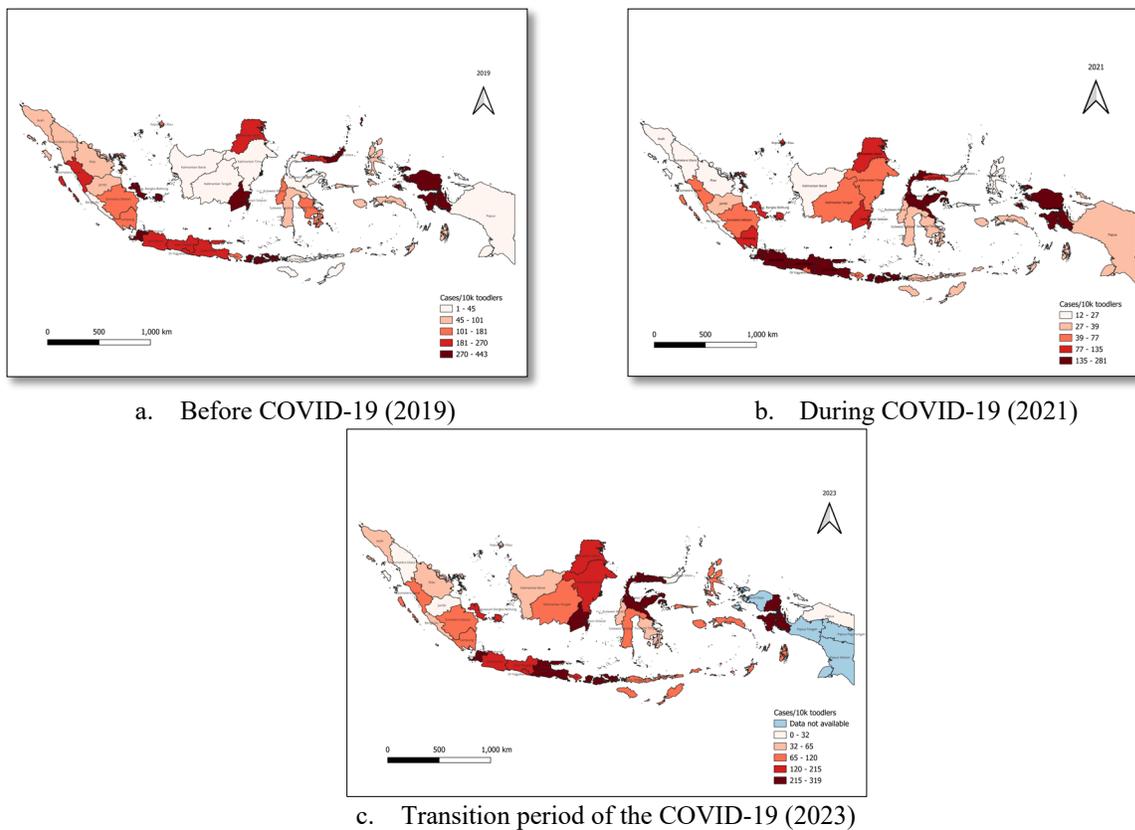

a. Before COVID-19 (2019)

b. During COVID-19 (2021)

c. Transition period of the COVID-19 (2023)

Figure 2: Distribution of The Incidence Rate of Pneumonia in Children Under-Five per 10,000 Population

3.1 Moran's I among the incidence rate of pneumonia in children under five before, during, and in the transition period of COVID-19 pandemic

The univariate analysis of pneumonia incidence rates in children under five per 10,000 population revealed a shift in spatial patterns before, during, and in the transition period of the COVID-19 pandemic. Before the pandemic, Moran's I was -0.130, indicating a dispersed spatial pattern, with four High-High/ HH areas (Jawa Barat, Jawa Tengah, DI Yogyakarta and Jawa Timur), one Low-High/LH area (Bali) and two High-Low/ HL areas (Sumatera Barat and Papua Barat). During the pandemic, Moran's I remained negative at -0.103, with three HH areas (Jawa Barat, Jawa Tengah, and Jawa Timur), one Low-Low/ LL area (Sumatera Barat), three LH areas (DI Yogyakarta, Bali and Papua), suggesting continued spatial dispersion. However, in the transition period, Moran's I became positive at 0.087, with four HH areas (Jawa Barat, Jawa Tengah, DI Yogyakarta and Bali) and three LL areas (Sumatera Barat, Riau and Maluku Utara), signifying a shift from a dispersed to a more clustered spatial distribution of pneumonia incidence across Indonesian provinces (Table 1 and Figure 3).

Table 1: Univariate analysis of the incidence rate of pneumonia in children under five per 10,000 population

Period	LISA				Moran's I (z-score)
	High-High (HH)	Low-Low (LL)	High-Low (HL)	Low-High (LH)	
Before COVID-19	Jawa Barat* Jawa Tengah* DI Yogyakarta* Jawa Timur**		Sumatera Barat* Papua Barat*	Bali*	-0.130 (-0.013)
During COVID-19	Jawa Barat* Jawa Tengah* Jawa Timur*	Sumatera Barat*		DI Yogyakarta* Bali* Papua***	-0.103 (-0.778)
Transition period COVID-19	Jawa Barat* Jawa Tengah** DI Yogyakarta** Bali*	Sumatera Barat** Riau* Maluku Utara*			0.087 (0.941)

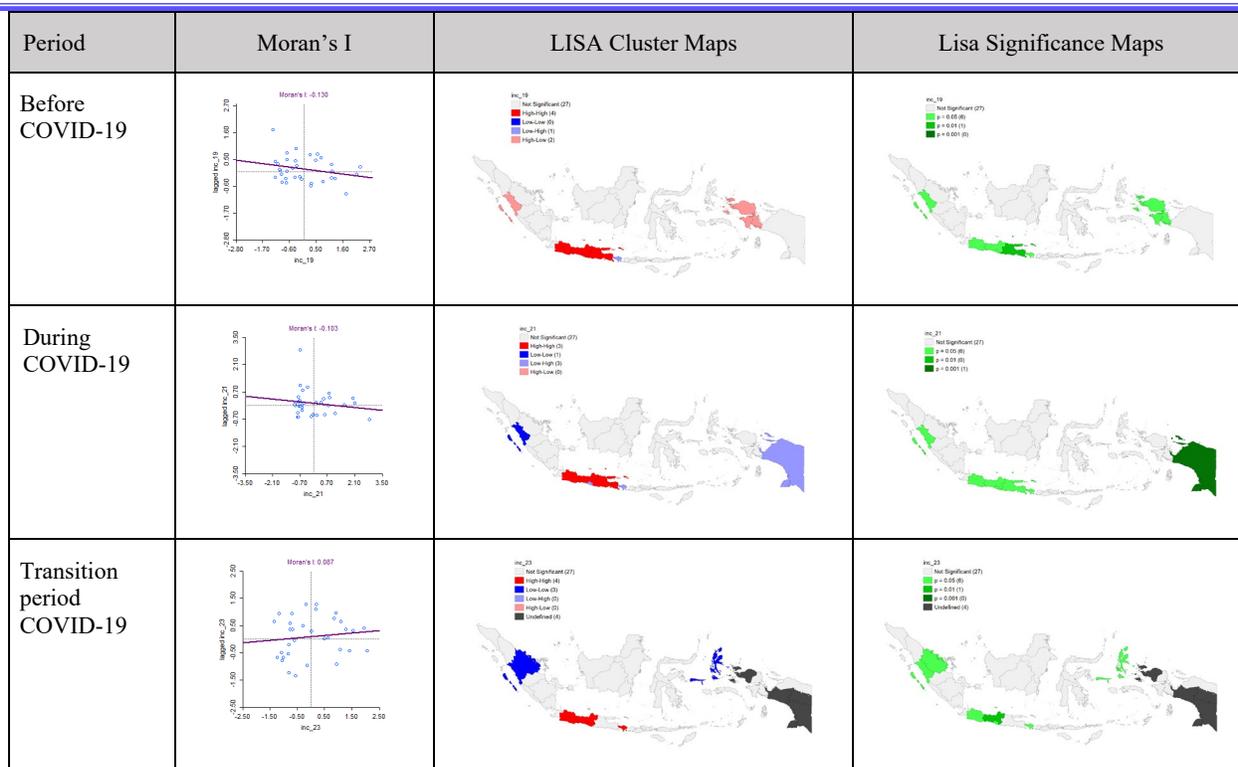| Period	Moran's I	LISA Cluster Maps	Lisa Significance Maps
Before COVID-19			
During COVID-19			
Transition period COVID-19			

Figure 3:   Univariate Analysis of Pneumonia Incidence Rate per 10,000 Children Under-Five

3.2 Bivariate analysis of healthcare, socio-economic, and environmental factors with the incidence rate of pneumonia in children under five

Table 2 presented the bivariate Moran's I values assessing spatial associations between healthcare, socio-economic, and environmental factors and the incidence of pneumonia among children under five across three periods: before, during, and in the transition period of COVID-19 pandemic.

Table 2: Bivariate Moran's I between healthcare, socio-economic, and environmental factors and under-five pneumonia incidence across study periods

Variables	Moran's I (P-value)		
	Before COVID-19	**During COVID-19**	**Transition period COVID-19**
Healthcare factor			
Number of midwives per 10,000 population	-0.172 (0.012)	-0.271 (0.001)	-0.322 (0.001)
Socio-economic factors			
Access to proper sanitation facilities	-0.123 (0.048)	-0.131 (0.034)	0.046 (0.289)
Access to decent and affordable housing	-0.058 (0.199)	-0.180 (0.010)	-0.022 (0.405)
Environmental factors			
Sulphur dioxide levels	0.211 (0.010)	0.145 (0.003)	0.300 (0.002)
Average precipitation	-0.099 (0.092)	-0.014 (0.410)	-0.347 (0.002)

3.3 Spatial regression of explanatory variables with the incidence rate of pneumonia in children under five

Variables that were found to be significant (P-value < 0.05) in the bivariate analysis were included in the regression analysis. The analysis revealed significant spatial autocorrelation across all three study periods, indicating that the Ordinary Least Squares (OLS) model was not suitable. The Lagrange Multiplier (LM) test showed significant values for both the Spatial Lag Model (SLM) and the Spatial Error Model (SEM). Before COVID-19, the LM test reported P-values of 0.008 and <0.001 for SLM and SEM, respectively, and the SEM outperformed SLM based on R-squared (0.59), lower Akaike Information Criterion (AIC) likelihood values. During the pandemic, the LM test continued to support significant spatial dependence, with P-values of 0.005

for SLM and <0.001 for SEM. Consistently, SEM showed better performance, achieving a higher R-squared value of 0.52 and lower AIC scores. In the transition period of COVID-19, the LM test confirmed spatial dependence in SEM with a p-value of 0.036, establishing SEM as the best-performing model for this period as well.

The SEM analysis indicated that, before COVID-19 pandemic, the number of midwives and sulphur dioxide levels explaining approximately 59% of the spatial variation in pneumonia incidence. During the pandemic, the number of midwives, access to proper sanitation facilities (latrines), and sulphur dioxide levels accounted for 52% of the incidence rate. In the transition period, the number of midwives and precipitation levels explained 35% of the variation in pneumonia incidence.

Table 3: Estimated parameters obtained from ordinary least square model, spatial lag model, and spatial error model

Value	Before the COVID-19 (2019)			During the COVID-19 (2021)			Transition period of C0VID-19 (2023)		
	OLS	Spatial Regression		OLS	Spatial Regression		OLS	Spatial Regression	
		SLM	SEM		SLM	SEM		SLM	SEM
Constant	224.85	372.45	**238.93**	224.77	394.08	**339.05**	338.11	427.21	**361.32**
Number of Midwives per 10,000 population	-7.96 (SE = 6.069)	-10.10* (SE = 4.852)	**-9.02* (SE = 4.563)**	-2.39 (SE = 2.028)	-4.31* (SE = 2.028)	**-4.07* (SE = 1.585)**	-4.23* (SE = 1.858)	-5.18** (SE = 1.717)	**-5.00*** (SE = 1.497)**
Access to proper sanitation facilities (latrines)	-	-	-	-1.42 (SE = 1.30632)	-2.46* (SE = 1.07183)	**-2.44*** (SE = 0.689)**	-	-	-

Value	Before the COVID-19 (2019)			During the COVID-19 (2021)			Transition period of C0VID-19 (2023)		
	OLS	Spatial Regression		OLS	Spatial Regression		OLS	Spatial Regression	
		SLM	SEM		SLM	SEM		SLM	SEM
Average Sulphur Dioxide	1335.06 (SE = 768.466)	1870.41** (SE = 622.223)	**1677.01*** (SE = 498.437)**	971.52* (SE = 417.39)	1169.39* (SE = 343.417)	**1103.33*** (SE = 313.123)**	-	-	-
Average Precipitation	-	-	-	-	-	-	20.89* (SE = 9.592)	26.27** (SE = 9.26)	**-22.30** (SE = 7.047)**
ρ		-0.762			-0.611			-0.27	
λ			**-0.969**			**-0.831**			**-0.333**
R - squared	0.234	0.465	**0.598**	0.235	0.417	**0.529**	0.263	0.317	**0.353**
Log likelihood	-206.884	-202.315	**-198.452**	-187.726	-184.100	**-181.309**	-196.036	-195.106	**-194.370**
AIC	419.767	412.63	**402.903**	383.451	378.201	**370.617**	398.072	398.212	**394.741**
BIC	424.346	418.735	**407.482**	389.557	385.833	**376.722**	402.651	404.317	**399.32**
Lagrange Multiplier		0.008	**0.001**		0.006	**0.001**		0.134	**0.036**

*Correlation is significant at the 0.05 level
**Correlation is significant at the 0.01 level
***Correlation is significant at the 0.001 level

4. Discussion

This study examined the distribution of the incidence rate of pneumonia in children under-five in Indonesia before, during, and in the transition period of the COVID-19 pandemic. The reported incidence of pneumonia declined during COVID-19 period, but increase slightly in the transition period of COVID-19, although it remained lower than before COVID-19 period. This decline could be attributed to the fact that during the COVID-19 pandemic, many parents avoided taking their children to health facilities due to fear of COVID-19 exposure and the misdiagnosis of pneumonia as COVID-19 [35, 36]. During the pandemic, the concentration of cases in Java, where 4 out of 6 provinces were in the top quintile, aligned with the rise in COVID-19 cases, as Java became the largest contributor to the increase in cases [37].

Changes in the incidence rate were mirrored in spatial patterns, with Moran's I shifting from negative before and during COVID-19 periods to positive during the transition period, indicating a clustering effect. This may relate to improved reporting and treatment access, the nationwide rollout of

the PCV (Pneumococcal Conjugate Vaccine) immunization program, which began to be implemented nationwide in 2023 and COVID-19 related disruption like regional restrictions, which may have influenced the changes in the spatial distribution pattern [38].

Similar findings have been reported in previous studies of pneumonia in children under five [39-43] emphasizing the value of analysing spatial-temporal patterns for informing prevention, control measures, and policy development

This analysis showed that healthcare, socioeconomic and environmental factors play crucial role in pneumonia incidence. The important factors varied in their impact in each period. The number of midwives consistently showed a significant negative relationship, underscoring the role of community care, health education, and preventive serviced and telemedicine by during the pandemic [10, 44, 45]. The levels of SO_2 exhibited a positive spatial autocorrelation, indicating that areas with higher SO_2 concentrations tended to have higher pneumonia incidence. Sulphur dioxide in gas form can cause irritation to the lungs, leading to difficulty in breathing, especially in vulnerable groups such as children. SO_2

can also react with other chemical compounds to form sulphate particles, which, if inhaled, can accumulate in the lungs and cause breathing difficulties, respiratory diseases, and even potentially lead to death. This relationship was evident before and during the pandemic, suggesting that vehicle emissions, industrial activities, and other anthropogenic factors contributed to increased respiratory risks, further exacerbating health issues in these areas [46-48].

During the pandemic, access to proper sanitation facilities (latrines) demonstrated a negative spatial autocorrelation with pneumonia incidence. People who do not have toilets in their homes use public or shared toilets that are used by several households. The poor sanitation of public toilets enhanced the possibility of pathogen transmission through splashing toilet water and the formation of aerosols [12]. A toilet that is not properly maintained is closely related to the cleanliness of the toilet area. Contamination outside the urinal can occur from the aerosol produced during flushing, which increases the potential for transmission through inhalation or direct contact with the hands and body with surfaces inside the toilet. Pathogens such as *E. coli* and MS2

bacteriophage can remain in the toilet bowl even after several flushes and can be spread through airborne particles small enough to reach the lower respiratory tract [49]. Previous studies have reported a strong association between inadequate sanitation and the prevalence of acute respiratory infections (ARI), particularly in households without access to improved, non-shared sanitation facilities [12, 13, 50, 51]. This underscores the importance of proper hygiene and sanitation in respiratory disease prevention.

In the transition period of COVID-19, average precipitation emerged as a significant factor with a negative relationship to pneumonia incidence. This suggests that rainfall may have contributed to reducing air pollution levels, particularly fine particulate matter ($PM_{2.5}$ and PM_{10}), which are known to exacerbate respiratory conditions [15-17].

The strengths of this study derive from its use of spatial analysis and the consideration of healthcare, socioeconomic, and environmental factors. These aspects make the study comprehensive and reliable in understanding the distribution of pneumonia and its associated determinants. However, this study is limited by data availability, which may have led to the omission of certain factors influencing pneumonia incidence in toddlers. Additionally, the reliance on secondary data poses a potential limitation, as it may not fully reflect the current situation or may contain inaccuracies.

5. Conclusion

The findings highlighted that the COVID-19 pandemic significantly impacted pneumonia incidence. In regions with limited healthcare infrastructure, the reporting and management of pneumonia were hindered. Conversely, areas with stronger healthcare systems experienced more robust responses and better pneumonia management. Moving forward, it is critical that future public health strategies focus on building flexible healthcare systems capable of quickly adapting to health crises. The findings also found significant healthcare, socioeconomic, and environmental factors contributing to pneumonia incidence. High-incidence clusters were identified in several provinces on Java Island, with healthcare factors, particularly the number of midwives, playing a critical role in pneumonia incidence. Socioeconomic determinants, including access to proper sanitation facilities, also had a substantial impact. Additionally, environmental factors such as sulphur dioxide levels and precipitation were key

contributors. Based on the research findings, specific recommendations to reduce pneumonia incidence among children include strengthening midwife availability and access, expanding midwife training programs to enhance early detection and management of pneumonia. Additionally, improving access to sanitation facilities, such as clean water and adequate toilets, is crucial. Implementing air quality control measures, such as reducing the use of motor vehicles and promoting the growth of green spaces at home, can help mitigate air pollution and lower the risk of respiratory diseases. Strategies to manage and improve environmental conditions during dry periods, when air pollution is higher, are essential. By adopting these targeted measures, policymakers can effectively reduce the burden of childhood pneumonia and improve overall child health outcomes.

Author contributions

MSD: Conceptualization, data curation, formal analysis, methodology, writing original draft, writing review and editing. KS: Conceptualization, methodology, supervision, writing original draft, writing review and editing.

Declaration

Ethics approval and consent to participate

The study was exempted for ethic review by Khon Kaen University Ethic Committee for Human Research (HE672180). The exemption was granted on September 18, 2024.

Competing interests

We declared that we have no competing interests

References

[1] WHO. Pneumonia in Children 2022 [cited 2025 29 January]. Available from: https://www.who.int/news-room/fact-sheets/detail/pneumonia.

[2] WHO. Pneumonia 2024 [Available from: https://www.who.int/health-topics/pneumonia#tab=tab_1.

[3]   WHO. Pneumonia in children 2022 [Available from: https://www.who.int/news-room/fact-sheets/detail/pneumonia#:~:text=In%20children%20under%205%20years,the%20chest%20expands%20during%20inhalation).

[4]   Kemenkes RI. Profil Kesehatan Indonesia 2019. Jakarta: Kemenkes RI; 2020.

[5]   Kemenkes RI. Profil Kesehatan Indonesia 2021. Jakarta: Kemenkes RI; 2022.

[6]   Kemenkes RI. Profil Kesehatan Indonesia 2023. Jakarta: Kemenkes RI; 2024.

[7]   Kemenkes RI. Rencana Aksi Nasional Penanggulangan Pneumonia Dan Diare 2023-2030. Jakarta: Kemenkes RI; 2023.

[8]   Nalwanga D, Opoka RO, Ssemata AS, Kakooza L, Kiggwe A, Musiime V, Kiguli S. Attitudes, Practices and Understanding of health workers and caregivers regarding the relationship between severe pneumonia and malnutrition in children: A Qualitative Study. Research Square. 2023.

[9]   Fatimah SN, Rindu R, Putri MT. Hubungan Peran Tenaga Kesehatan dan Pengetahuan Ibu Terhadap Motivasi Pemberian Imunisasi PCV Pada Bayi Usia 0-11 Bulan di Wilayah Kerja UPT Puskesmas Poris Gaga Lama Kota Tangerang Tahun 2024. Jurnal Ilmiah Global Education. 2024;5(2):977-87.

[10]   You W, Donnelly F. A greater nurse and midwife density protects against infant mortality globally. Journal of Pediatric Nursing. 2024.

[11]   Pangaribuan S, Siagian JL, Sanoy YD, Talakua F, Artafella A. The risk of physical environment on the incidence of pneumonia in the Puskesmas Remu Sorong City. Journal of Midwifery and Nursing. 2024;6(2):404-10.

[12]   Sulistyorini L, Li C-Y, Lutpiatina L, Utama RD, Nurlailah. Gendered impact of age, toilet facilities, and cooking fuels on the occurrence of acute respiratory infections in toddlers in Indonesia and the philippines. International journal of environmental research and public health. 2022;19(21):14582.

[13]   Balasubramani K, Prasad KA, Kodali NK, Abdul Rasheed NK, Chellappan S, Sarma DK, et al. Spatial epidemiology of acute respiratory infections in children under 5 years and associated risk factors in India: District-level analysis of health, household, and environmental datasets. Frontiers in Public Health. 2022;10:906248.

[14]   Choo ELW, Janhavi A, Koo JR, Yim SH, Dickens BL, Lim JT. Association between ambient air pollutants and upper respiratory tract infection and pneumonia disease burden in Thailand from 2000 to 2022: a high frequency ecological analysis. BMC Infectious Diseases. 2023;23(1):379.

[15]   Lu C, Yang W, Lan M, Li B, Wang F. Effects of intrauterine and postnatal exposure to meteorological factors on childhood pneumonia. Building and Environment. 2023;244:110800.

[16]   Muharrami R, Hidayati R, Turyanti A. Acute Respiratory Infections (Pneumonia) Incidence Rate in Children due to Climate Variables and Air Quality in Bogor. Agromet. 2021;35(1):39-48.

[17]   Nurjazuli N. Faktor-Faktor Lingkungan Rumah yang Berhubungan dengan Kejadian Pneumonia pada Balita : Sebuah Kajian Sistematis. Sanitasi: Jurnal Kesehatan Lingkungan. 2022;15(1):20-8.

[18]   Fonseca Lima EJ, Araújo LCCd, Agra KF, Mendoza AJX, Siebra JPdB, Dos Santos CS. Analysis of Childhood Pneumonia: A Comparison Between the Pre-and During the COVID-19 Pandemic in a Reference Hospital in Brazil. Pediatric Health, Medicine and Therapeutics. 2024:103-10.

[19]   Yang J, Li J, Lv R, Wang X, Zheng C, Gu Y, Zhang M. Analyzing the epidemic situation and influencing factors of childhood pneumonia during the COVID-19 epidemic period in Laiwu, China. Medicine. 2023;102(35):e35052.

[20]   Huang C. Pediatric non-COVID-19 community-acquired pneumonia in COVID-19 pandemic. International Journal of General Medicine. 2021:7165-71.

[21]   Latitude.to. Indonesia – Map, Latitude, and Longitude n.d [cited 2025 2 January 2025]. Available from: https://latitude.to/map/id/indonesia.

[22]   BPS-Statistics Indonesia. Statictical Yearbook of Indonesia 2024. Jakarta: BPS-Statistics Indonesia, ; 2024 February, 2024.

[23]   Sekretariat Kabinet Republik Indonesia. Provinsi Papua Barat Daya Diresmikan, Indonesia Sekarang Memiliki 38 Provinsi 2022 [cited 2022 9 December]. Available from: https://setkab.go.id/provinsi-papua-barat-daya-diresmikan-indonesia-sekarang-miliki-38-provinsi/.

[24]   The World Bank. Climate Action for Development. Washington DC2023.

[25]   Badan Pusat Statistik. Persentase Rumah Tangga yang Memiliki Akses Terhadap Hunian Yang Layak Menurut Provinsi (Persen) 2024 [cited 2025 30 January]. Available from: https://www.bps.go.id/id/statistics-table/2/MTI0MSMy/persentase-rumah-tangga-yang-memiliki-akses-terhadap-hunian-yang-layak-menurut-provinsi.html.

[26] Google Developers. Sentinel-5P NRTI SO2: Near Real-Time Sulfur Dioxide 2025 [cited 2025 30 January]. Available from: https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S5P_NRTI_L3_SO2.

[27] Google Developers. CHIRPS Daily: Climate Hazards Center InfraRed Precipitation With Station Data (Version 2.0 Final) 2025 [cited 2025 30 January]. Available from: https://developers.google.com/earth-engine/datasets/catalog/UCSB-CHG_CHIRPS_DAILY.

[28] Steiniger S, Hunter AJ. The 2012 free and open source GIS software map–A guide to facilitate research, development, and adoption. 2013;39:136-50.

[29] Anselin L. An introduction to spatial autocorrelation analysis with GeoDa. 2003.

[30] Kusumadewi NNS, Makful MR, Meutia L. Spatial analysis of under five years pneumonia incidence in DIY Province 2020. BKM Public Health and Community Medicine. 2023;39(04):e6669-e.

[31] Anselin L. Local indicators of spatial association—LISA. Geographical Analysis. 1995;27(2):93-115.

[32] Mahato RK, Htike KM, Sornlorm K, Koro AB, Kafle A, Sharma V. A spatial autocorrelation analysis of road traffic accidents by severity using Moran's I spatial statistics: a study from Nepal 2019–2022. BMC Public Health. 2024;24(1):3086.

[33] Sipahutar T, Eryando T, Budhiharsana MP, Siregar KN, Aidi MN, Utari DM, et al. Stunting does not randomly occur in Indonesia: A spatial analysis. 2022.

[34] Poonsiri N, Laohasiriwong W, Puttanapong N, Mahato RK. Spatial Association between Socioeconomic Factors, Physical Geographic Factors, and Suicide in Thailand. The Open Public Health Journal. 2023;16(1).

[35] Unicef Indonesia. 5 reason why you shouldn't worry about vaccinating your children during the COVID-19 pandemic. 2020.

[36] Budhram B, Kobza AO, Mohammed N. Misdiagnosis related to premature diagnostic closure during the COVID-19 pandemic. Cmaj. 2020;192(39):E1129-e31.

[37] Muhammad Faniawan A. Pandemi Covid-19 dan Upaya Pencegahan. DJKN - Kementerian Keuangan Indonesia. 2022.

[38] Kemenkes RI. Kemenkes Tambahkan 4 Jenis Vaksin Baru untuk Perlindungan Anak Indonesia 2023 [Available from: https://sehatnegeriku.kemkes.go.id/baca/umum/20230327/5942664/kemenkes-tambahkan-4-jenis-vaksin-baru-untuk-perlindungan-anak-indonesia.

[39] Wangdi K, Penjor K, Tsheten T, Tshering C, Gething P, Gray DJ, Clements AC. Spatio-temporal patterns of childhood pneumonia in Bhutan: A Bayesian analysis. Scientific reports. 2021;11(1):20422.

[40] Atoloye K, Lawal T, Adebowale A, Fagbamigbe A. A spatio-temporal mapping and bayesian modelling of risk factors of pneumonia symptoms in under-five children in Nigeria. medRxiv. 2022:2022.12. 19.22283675.

[41] Atoloye KA, Lawal TV, Adebowale AS, Fagbamigbe AF. A spatio-temporal mapping and bayesian modelling of fever, cough and short rapid breaths, as symptoms of pneumonia in under-five children in Nigeria. 2023.

[42] Saputri MR, Hasyim H. Analisis Spasial Kejadian Pneumonia pada Balita Berdasarkan Faktor Lingkungan Fisik dan Faktor Demografi di Kota Palembang Tahun 2018-2022. Palembang, Indonesia: Sriwijaya University; 2024.

[43] Tesfaye SH, Seboka BT, Sisay D. Spatial patterns and spatially-varying factors associated with childhood acute respiratory infection: data from Ethiopian demographic and health surveys (2005, 2011, and 2016). BMC Infectious Diseases. 2023;23(1):293.

[44] Isnaini Y. Pemodelan Spatial Autoregressive pada Faktor-Faktor yang Mempengaruhi Penyakit Pneumonia Balita di Provinsi Riau Universitas Islam Negeri Sultan Syarif Kasim Riau; 2022.

[45] Algifnita A, Diah I. Utilization of Telehealth in Midwifery Services during the COVID-19 Pandemic: A Qualitative Study. Indonesian Midwifery and Health Sciences Journal. 2022;6:310-8.

[46] Ranaarif SY, Arief Sabdo. Analisis Sebaran Polutan Sulfur Dioksida (SO2) di Pulau Bali Periode 2011-2020. Bogor: Institute Pertanian Bogor; 2021.

[47] Setiawan HA, Lutfi M, Rahmayani D. Determinant Factors of Air Quality : Empirical Study in Java Island Jurnal REP (Riset Ekonomi Pembangunan). 2022;7(1).

[48]   Global   Atmosphere   Watch.   Sulfur   Dioksida   2025   [Available   from: https://gawpalu.id/index.php/informasi/kimia-atmosfer/gas-reaktif/sulfur-dioksida.

[49]   Zhao M, Zhou L, Wang S. Immune crosstalk between respiratory and intestinal mucosal tissues in respiratory infections. Mucosal Immunology. 2025.

[50]   Sari M, Ridza FWN. Studi Ekologi Faktor Pejamu, Kondisi Fisik Hunian dan Pneumonia pada Balita Provinsi Jawa Barat Tahun 2014-2017: Ecological Study: Host, Physical Conditions Factors and Pneumonia in Toddlers in West Java Province 2014-2017. Jurnal Kesmas Untika Luwuk: Public Health Journal. 2021;12(1):29-40.

[51]   Nurjayanti TN, Maywati S, Gustaman RA. Hubungan Kondisi Fisik Rumah Terhadap Kejadian Pneumonia Pada Balita di Kawasan Padat Penduduk Kota Tasikmalaya. Jurnal kesehatan komunitas Indonesia. 2022;18(1).