

Environmental Determinants and Spatial Distribution of Pediatric Pneumonia in Padang City

Diva Maharani¹, Masrizal², Yudi Pradipta³, Randy Novirsa⁴

^{1,2,3,4} Master of Epidemiology, Faculty of Public Health, Andalas University, Indonesia

Article Info

Article history:

Received Jun 4th, 2025
Revised Oct 20th, 2025
Accepted Apr 28th, 2026

Keyword:

Pediatric pneumonia
PM2.5
Wind speed
Ecological study
Spatial analysis

ABSTRACT

Background: Pneumonia remains the leading infectious cause of death in children under five globally. In Padang City, Indonesia, pediatric pneumonia cases increased sharply from 2021 to 2023, yet the environmental and host-related determinants driving this trend remain poorly understood in the local tropical urban context.

Objective: This study aimed to analyze the correlation between physical environmental factors humidity, wind speed, temperature, rainfall, PM10, and PM2.5 and pediatric pneumonia incidence in Padang City from 2021 to 2023, and to spatially map host-related intervention coverage across sub-districts.

Methods: An ecological study design was employed using monthly secondary data aggregated at the city level ($n = 36$ months). Pneumonia case data were obtained from the Padang City Health Office, meteorological data from BPS, and air quality data from the Environmental Agency. Pearson correlation and multiple linear regression were used for statistical analysis following assumption testing. Spatial overlay mapping was conducted using QGIS to examine the geographic distribution of cases in relation to exclusive breastfeeding, vitamin A supplementation, and complete basic immunization coverage.

Results: A total of 5,428 cases were recorded (mean: 150.78 cases/month). Wind speed showed a significant positive correlation ($r = 0.436$, $p = 0.008$) and PM2.5 a significant negative correlation ($r = -0.516$, $p = 0.003$) with pneumonia incidence. PM2.5 was the most dominant predictor ($R^2 = 0.463$). Spatial analysis identified Kuranji and Lubuk Begalung as persistently high-burden sub-districts, consistently associated with inadequate host-factor intervention coverage.

Conclusion: Wind speed and PM2.5 are significant environmental determinants of pediatric pneumonia in Padang City. Integrated strategies combining air quality monitoring, vitamin A supplementation, immunization programs, and strengthened Posyandu-based interventions are essential to reduce pneumonia burden in tropical urban settings.



© 2025 The Authors. Published by Jurnal Ilmu Kesehatan.
This is an open access article under the CC BY license
(<https://creativecommons.org/licenses/by/4.0>)

Corresponding Author:

Diva Maharani
Master of Epidemiology, Faculty of Public Health, Andalas University, Indonesia
Email: divamaharani0505p@gmail.com

Introduction

Pneumonia remains the single largest infectious cause of death in children under five years of age worldwide, responsible for approximately 14% of all deaths in this age group (World Health Organization [WHO], 2022). Globally, more than 700,000 children die from pneumonia each year, with the greatest burden borne by sub-Saharan Africa and South and Southeast Asia (UNICEF, 2022). The disease is defined as an acute inflammation of lung parenchyma, predominantly caused by bacterial, viral, or fungal pathogens, including *Streptococcus pneumoniae*, *Haemophilus influenzae*, respiratory syncytial virus, and *Mycoplasma pneumoniae* (McAllister et al., 2019). Young children are especially susceptible owing to their immature immune systems, incomplete immunization histories, and nutritional vulnerabilities, collectively making pneumonia a major threat to child survival despite existing preventive tools (Troeger et al., 2018).

In Indonesia, pneumonia constitutes a significant proportion of pediatric morbidity and mortality. National data indicate more than 1,400 cases per 100,000 children annually, with wide subnational variation (Ministry of Health Republic of Indonesia [Kemenkes RI], 2023). West Sumatra Province has experienced a notable increase in pediatric pneumonia, with reported cases rising from 3,554 in 2021 to 6,405 in 2023. Within this province, Padang City its capital and most densely populated urban center recorded the highest district-level prevalence, with rates escalating sharply from 89 per 10,000 children in 2021 to 334 per 10,000 in 2023 (Padang City Health Office, 2022). This accelerating trend underscores the urgent need for comprehensive, evidence-based investigation into the local determinants driving pneumonia burden.

The epidemiological understanding of pneumonia is framed through the classical triangle of host, agent, and environment (Merrill, 2021). Host-side determinants including nutritional status, birth weight, breastfeeding history, and immunization completeness have been extensively studied. Environmental factors, particularly the physical environment, have received growing scientific attention in recent decades. Temperature, humidity, wind speed, rainfall, and particulate matter pollution have all been proposed as modifiers of pathogen survival, aerosol transmission dynamics, and host susceptibility (Islam et al., 2024; Chang et al., 2024). Urban environments in tropical regions present a unique confluence of these factors: high baseline humidity, variable rainfall patterns, and increasing ambient air pollution from motorized transport and industrial activity can create conditions favorable to both respiratory pathogen transmission and physiological vulnerability in children (Luo et al., 2023).

Despite a growing body of international evidence linking air pollutants and meteorological variables to respiratory infections, research specific to Indonesian urban settings particularly in the context of Padang City's tropical highland climate remains sparse. Previous local studies have generally examined these factors in isolation, without integrating spatial analysis or considering host-related indicators simultaneously. Ecological and spatial epidemiology approaches offer a methodologically appropriate framework for identifying area-level associations and geographic disparities, thereby informing the targeting of public health interventions (Waller & Gotway, 2004; Rahmadani & Nasriyah, 2022).

This study, therefore, pursues two complementary objectives: (1) to examine the statistical association between physical environmental factors (humidity, wind speed, temperature, rainfall, PM10, and PM2.5) and the monthly incidence of pediatric pneumonia in Padang City from 2021 to 2023; and (2) to spatially map the distribution of pneumonia cases in relation to host-related coverage indicators exclusive breastfeeding, vitamin A supplementation, and complete basic immunization across sub-districts. By integrating ecological correlation analysis with geographic visualization, this study contributes novel, locally grounded evidence relevant to the design of multi-sectoral pneumonia prevention strategies in tropical urban Indonesia.

Method

Study Design: This study employed a quantitative ecological study design, in which the unit of analysis is a population group (monthly aggregated data at the city level and spatially aggregated sub-district data) rather than individual-level observations. Ecological designs are appropriate for this context because environmental exposures such as ambient temperature, rainfall, and air quality are inherently population-level phenomena that cannot be meaningfully disaggregated to individuals (Morgenstern, 2020). While this design precludes causal inference at the individual level and is susceptible to ecological fallacy the risk of incorrectly inferring individual-level relationships from group-level data it is well-suited for hypothesis generation, surveillance, and informing public health priority-

setting (Pearce, 2021). Temporal ecological analysis using monthly time-series data (n = 36 months) enabled examination of within-city trends over a three-year observation period.

Study Setting: The study was conducted in Padang City, the capital of West Sumatra Province, Indonesia. The city covers an area of approximately 694.96 km² and is divided into 11 sub-districts (*kecamatan*). Located at 0°44'–1°08' S latitude and 100°05'–100°34' E longitude at the equator, Padang has a tropical rainforest climate (Köppen Af classification) characterized by high annual rainfall (averaging over 4,000 mm/year), consistently elevated humidity, and relatively stable temperatures year-round. The city had a registered population of approximately 939,112 as of 2022, including around 70,000 children under five years of age. Air quality is influenced primarily by road traffic emissions, given its role as a major regional commercial hub.

Population and Data Sources: The study population comprised all recorded cases of pediatric pneumonia (children aged 0–59 months) in Padang City between January 2021 and December 2023 (36 months). Case data were extracted from official monthly reports submitted to the Padang City Health Office by primary healthcare facilities. No sampling was applied; the entire population of recorded cases formed the analytical dataset, ensuring completeness of case enumeration. Environmental and meteorological data including monthly mean values for relative humidity (%), wind speed (knots), air temperature (°C), and total rainfall (mm) were obtained from Padang City publications of the Central Statistics Agency (BPS). Ambient air quality data for PM₁₀ (µg/m³) and PM_{2.5} (µg/m³) were sourced from the Padang City Environmental Agency (*Dinas Lingkungan Hidup*), which monitors air quality at fixed stations across the city. Spatial and host-related data including sub-district-level coverage of exclusive breastfeeding, complete basic immunization (*imunisasi dasar lengkap*), and vitamin A supplementation were obtained from annual Padang City Health Office reports for 2021, 2022, and 2023.

Variables and Measurements: The dependent variable was the monthly count of pediatric pneumonia cases in Padang City. Independent variables were six physical environmental parameters measured monthly: (1) relative humidity (%); (2) wind speed (knots); (3) mean air temperature (°C); (4) total monthly rainfall (mm); (5) mean PM₁₀ concentration (µg/m³); and (6) mean PM_{2.5} concentration (µg/m³). For the spatial analysis component, host-related coverage indicators were measured at the sub-district level on an annual basis: exclusive breastfeeding coverage (threshold ≥80%), complete basic immunization coverage (threshold ≥90%), and vitamin A supplementation coverage (threshold ≥90%). Environmental PM_{2.5} data were available from monitoring stations located across the city. For sub-districts without direct monitoring stations, concentrations were estimated using spatial interpolation of the nearest available monitoring points, a standard procedure in environmental epidemiology though one that introduces uncertainty in interpolated values and should be interpreted accordingly (Beelen et al., 2009).

Data Analysis: Univariate analysis was conducted to describe the distribution of the dependent and all independent variables, reporting mean, standard deviation (SD), minimum, maximum, sum, and 95% confidence interval (95% CI). **Bivariate analysis** used Pearson product-moment correlation to examine linear associations between each environmental variable and monthly pneumonia incidence. Pearson correlation was selected following confirmation that both the dependent variable and each independent variable were approximately normally distributed (assessed via the Shapiro-Wilk test) and that the relationships were approximately linear (assessed via scatterplot inspection). The correlation coefficient (r) and two-tailed p-value were reported; statistical significance was set at p < 0.05. Pearson correlation is appropriate for ecological time-series data when distributional assumptions are satisfied, though it must be interpreted at the ecological rather than individual level (Morgenstern, 2020). **Multivariate analysis** employed multiple linear regression to identify the most influential predictors of pneumonia incidence when controlling for other variables. Variables with p < 0.25 in bivariate analysis were eligible for inclusion. Model assumptions were tested: residual normality (Shapiro-Wilk test), homoscedasticity (Breusch-Pagan test), absence of multicollinearity (variance inflation factor [VIF] < 10), and independence of residuals (Durbin-Watson statistic). The coefficient of determination (R²) was reported to indicate the proportion of variance explained by the model. **Spatial analysis** utilized geographic information system (GIS)-based overlay mapping. Sub-district-level pneumonia case counts were represented using proportional symbol maps (circle size proportional to case count), while host-factor coverage was categorized as adequate (green) or inadequate (red) according to established national thresholds. Overlay maps were produced for each year (2021, 2022, 2023) to identify spatial patterns and temporal changes in the distribution of pneumonia burden in relation to host-related intervention coverage. Analysis was conducted using QGIS software (version 3.x) and statistical analysis with SPSS version 25.

Ethical Considerations: This study used secondary, de-identified, routinely collected public health data and was conducted with approval from the relevant institutional authorities at Andalas University and the Padang

City Health Office. No individual patient data were accessed; all analyses were performed on aggregated, population-level data. Informed consent was not required due to the secondary, ecological nature of the study.

Results and Discussions

Univariate Analysis

Over the 36-month study period (January 2021–December 2023), a total of 5,428 pediatric pneumonia cases were recorded in Padang City, with a mean of 150.78 cases per month (SD = 100.31). The wide range (minimum: 26 cases; maximum: 425 cases) and high standard deviation reflect considerable temporal variability in pneumonia incidence, likely reflecting both seasonal fluctuations in environmental conditions and year-on-year increases in case burden. Cases increased annually, from approximately 1,200 in 2021 to over 2,000 in 2023, consistent with the provincial trend. Descriptive statistics for all variables are presented in Table 1.

Table 1. Descriptive Statistics of Dependent and Independent Variables, Padang City, 2021–2023 (n = 36 months)

Variable	Mean	SD	Min	Max	Sum	95% CI
Pediatric pneumonia (cases/month)	150.78	100.31	26	425	5,428	116.84–184.72
Humidity (%)	80.84	3.22	73.90	88.41	2,910.06	79.75–81.93
Wind speed (knots)	1.39	0.37	1.00	2.00	50.10	1.27–1.52
Temperature (°C)	27.56	0.55	26.4	28.7	992.2	27.37–27.74
Rainfall (mm)	358.16	177.51	44.8	816.6	12,893.9	298.10–418.23
PM10 concentration ($\mu\text{g}/\text{m}^3$)	13.14	2.07	8.11	16.65	394.31	12.37–13.92
PM2.5 concentration ($\mu\text{g}/\text{m}^3$)	11.73	2.35	6.20	16.99	352.02	10.86–12.61

Physical environmental factors displayed a relatively stable distribution with seasonal fluctuations consistent with Padang's equatorial climate. Mean relative humidity of 80.84% reflects the persistently high atmospheric moisture characteristic of the region. Wind speed varied minimally (1.00–2.00 knots), while temperature remained within a narrow range (26.4–28.7°C). Rainfall exhibited the greatest variability (SD = 177.51 mm), reflecting seasonal monsoon patterns. Both PM10 (mean: 13.14 $\mu\text{g}/\text{m}^3$) and PM2.5 (mean: 11.73 $\mu\text{g}/\text{m}^3$) concentrations remained below WHO 24-hour guideline values of 45 $\mu\text{g}/\text{m}^3$ and 15 $\mu\text{g}/\text{m}^3$ respectively; however, chronic low-level PM2.5 exposure remains clinically significant, as evidence increasingly suggests adverse respiratory effects even at concentrations below established thresholds (Shi et al., 2020; Chen et al., 2021).

Bivariate and Multivariate Analysis

The results of the Pearson correlation and multiple linear regression analyses are presented in Table 2.

Table 2. Pearson Correlation and Multiple Linear Regression Analysis of Physical Environmental Factors with Pediatric Pneumonia Incidence, Padang City, 2021–2023

Variable	Pearson r	p-value (bivariate)	Regression coefficient (B)	p-value (regression)	VIF
Humidity (%)	-0.008	0.965	—	—	—
Wind speed (knots)	0.436	0.008*	—	0.171	—
Temperature (°C)	-0.221	0.196	—	—	—
Rainfall (mm)	0.087	0.615	—	—	—
PM10 concentration ($\mu\text{g}/\text{m}^3$)	-0.291	0.119	-22.14	0.004*	3.21

Variable	Pearson r	p-value (bivariate)	Regression coefficient (B)	p-value (regression)	VIF
PM2.5 concentration (µg/m ³)	-0.516	0.003*	-35.67	<0.001*	3.21

*Significant at $p < 0.05$. $R^2 = 0.463$ (model includes PM10 and PM2.5).

Wind speed showed a statistically significant moderate positive correlation with pneumonia incidence ($r = 0.436$, $p = 0.008$), indicating that months with higher wind speed were associated with more pneumonia cases. PM2.5 concentration showed a statistically significant moderate negative correlation ($r = -0.516$, $p = 0.003$), indicating that higher PM2.5 concentrations were paradoxically associated with fewer recorded pneumonia cases — a finding that warrants careful contextual interpretation (see Discussion). Humidity, temperature, rainfall, and PM10 did not show statistically significant associations with pneumonia incidence (all $p > 0.05$).

In the final multiple linear regression model, PM10 and PM2.5 were retained as the explanatory variables (both having been eligible for inclusion on theoretical grounds). The model explained 46.3% of the variance in monthly pneumonia case counts ($R^2 = 0.463$). PM2.5 emerged as the dominant predictor, with a larger absolute regression coefficient ($B = -35.67$) compared to PM10 ($B = -22.14$). VIF values (3.21 for both) indicated acceptable levels of multicollinearity. Residual diagnostics confirmed approximate normality and homoscedasticity.

Spatial Distribution Analysis

Exclusive breastfeeding coverage. Overlay maps for 2021, 2022, and 2023 (Figure 1) showed that in 2021 and 2022, the sub-districts with the highest pneumonia case counts Kuranji (2021) and Lubuk Begalung (2022) both had exclusive breastfeeding coverage below the 80% threshold. In 2023, however, the highest case burden (Lubuk Begalung) was recorded in a sub-district that had achieved above-80% coverage, suggesting that the relationship between breastfeeding coverage and pneumonia is not uniform and may be confounded by other factors including population density, socioeconomic conditions, and improvements in case detection and reporting.

Vitamin A supplementation coverage. Across all three years, sub-districts with the highest pneumonia burdens consistently had vitamin A supplementation coverage below 90% (Figure 2). Kuranji (2021) and Lubuk Begalung (2022 and 2023) the sub-districts with the highest case counts in their respective years all fell below this threshold. This pattern suggests a consistent spatial association between insufficient vitamin A supplementation and higher pneumonia incidence.

Complete basic immunization coverage. The spatial distribution showed mixed results (Figure 3). In 2021, Kuranji the highest-burden sub-district had immunization coverage above 90%, suggesting adequate immunization does not fully protect against pneumonia in the presence of other risk factors. In 2022 and 2023, Lubuk Begalung had immunization coverage below 90%, consistent with a pattern in which suboptimal immunization may contribute to elevated case counts. Across the study period, the overlap between sub-districts with inadequate host-factor intervention coverage and high pneumonia incidence was consistent and geographically concentrated.

Wind Speed and Pneumonia Incidence

The significant positive association between wind speed and pediatric pneumonia incidence ($r = 0.436$, $p = 0.008$) is consistent with mechanistic hypotheses regarding aerosol and pathogen dispersal. Higher wind velocities can mobilize respiratory droplets and re-suspend fine particulate matter, thereby facilitating the airborne transmission of respiratory pathogens such as *Streptococcus pneumoniae* and influenza viruses over greater distances (Fernstrom & Goldblatt, 2013). Furthermore, wind enhances the evaporation of respiratory droplets, potentially reducing their size to droplet nuclei that remain suspended in air for extended periods an important transmission pathway for many pediatric respiratory infections (Li et al., 2022). The relatively low absolute wind speeds recorded in Padang (1.00–2.00 knots) suggest that even modest increases in wind velocity may meaningfully influence transmission dynamics in a densely populated urban setting. These findings align with those of Ekasari et al. (2018), who reported wind speed as a significant predictor of acute respiratory infections in Jakarta, and with Khairiyati et al. (2020), who documented similar relationships in Banjarmasin.

PM2.5 and the Counterintuitive Negative Correlation

The negative correlation between PM2.5 concentration and pneumonia incidence ($r = -0.516$, $p = 0.003$) indicating that higher PM2.5 levels were associated with fewer recorded cases is a counterintuitive finding that

requires careful interpretation and cannot be read as a protective effect of fine particulate matter. Several plausible explanations exist.

First, this finding likely reflects a **seasonal confounding** effect. In Padang City, periods of high rainfall (the wet season) correspond to elevated PM_{2.5} scavenging by precipitation, resulting in lower ambient PM_{2.5} concentrations. Concurrently, high rainfall periods are associated with reduced outdoor activity and potentially altered transmission dynamics that may affect case detection and reporting rates (Munggaran et al., 2024). Conversely, drier periods with higher PM_{2.5} may coincide with reduced healthcare-seeking behavior or lower pneumonia surveillance intensity.

Second, the ecological study design aggregates data across the entire city, masking the heterogeneity of indoor air quality which may be the more relevant exposure pathway for young children who spend the majority of their time indoors. Indoor sources of fine particulate matter including household solid fuel combustion, tobacco smoke, and cooking fumes may be far more important contributors to pediatric PM_{2.5} exposure than ambient outdoor concentrations, yet these are not captured in this dataset (Adaji et al., 2019; Islam et al., 2024).

Third, **reporting bias** cannot be excluded: months with higher PM_{2.5} may coincide with dry seasons when overall child morbidity (including pneumonia) is diagnostically attributed to other causes (e.g., upper respiratory infections), while wet season increases in pneumonia diagnosis may artificially inflate case counts independent of PM_{2.5} dynamics.

Despite this negative ecological correlation, the international literature strongly supports PM_{2.5} as a causal risk factor for pneumonia in children. Chen et al. (2021) demonstrated a significant dose-response relationship between long-term PM_{2.5} exposure and pneumonia hospitalization rates in children across Chinese cities, and Shi et al. (2020) confirmed associations between PM_{2.5} exposure and lower respiratory morbidity in children under five in multiple countries. The multivariate regression finding that PM_{2.5} was the dominant predictor in the model ($B = -35.67$, $p < 0.001$) should therefore be interpreted cautiously within this ecological framework, recognizing that the direction of the observed association may be driven by the confounders described above rather than a true protective biological mechanism.

Non-Significant Variables: Humidity, Temperature, and Rainfall

Relative humidity did not show a significant association with pneumonia incidence ($r = -0.008$, $p = 0.965$). This finding is consistent with several prior studies in Indonesian settings (Khairiyati et al., 2020; Ekasari et al., 2018) and may reflect the narrowly bounded humidity range observed in Padang (73.9%–88.4%), which may be insufficient to produce detectable variation in pathogen survival or host susceptibility within the study period. In contexts where humidity remains persistently high as in equatorial cities its epidemiological relevance as an independent driver of respiratory infection may be diminished (Zhang et al., 2021).

Air temperature similarly showed no significant association ($r = -0.221$, $p = 0.196$). The narrow thermal range characteristic of Padang's tropical climate (26.4–28.7°C) likely limits the capacity to detect temperature-related effects on pneumonia incidence that are more prominent in temperate or sub-tropical contexts. Chang et al. (2024) documented significant pneumonia mortality risk associated with cold waves and low temperatures in elderly populations in China a finding that reflects temperate-climate dynamics not directly applicable to Padang's thermal profile.

Rainfall was not significantly associated with pneumonia incidence ($r = 0.087$, $p = 0.615$), consistent with Khairiyati et al. (2020). As noted above, high rainfall in Padang may paradoxically reduce outdoor transmission risk by keeping people indoors and reducing aerosol concentrations, though indoor crowding during extended rainy periods could offset these effects. The absence of significance may also reflect that behavioral and housing factors mediate the relationship between rainfall and transmission more strongly than rainfall itself.

PM₁₀ concentrations showed no significant bivariate association ($r = -0.291$, $p = 0.119$), consistent with the relatively low PM₁₀ levels recorded (mean 13.14 $\mu\text{g}/\text{m}^3$, well below national and WHO thresholds). Low overall PM₁₀ exposure may reduce the likelihood of detecting a statistically significant effect at the ecological level, and individual-level genetic susceptibility, pre-existing health conditions, and indoor PM₁₀ sources may be more relevant determinants than outdoor concentrations at this city-wide scale (Naidoo et al., 2022).

Spatial Patterns and Host-Factor Interactions

The spatial overlay analysis revealed that sub-districts with consistently high pneumonia case counts principally Kuranji and Lubuk Begalung tended to have deficient coverage of key host-protective interventions.

Vitamin A supplementation coverage below 90% was the most consistent spatial correlate of high case burden across all three study years. Vitamin A is a critical immune micronutrient: deficiency compromises mucosal immunity in the respiratory tract and increases susceptibility to bacterial and viral pulmonary infections, including pneumonia (Puspitasari & Syahrul, 2015; Fauziah et al., 2022). The spatial co-occurrence of vitamin A insufficiency and elevated pneumonia burden reinforces the importance of this intervention.

Immunization coverage showed a more complex spatial pattern, with the highest-burden sub-district (Kuranji, 2021) having above-threshold immunization coverage, while Lubuk Begalung (2022–2023) had below-threshold coverage. This heterogeneity suggests that immunization alone is insufficient when other risk factors including environmental exposures, household poverty, and healthcare access are present. Vaccine-preventable pneumonia caused by *S. pneumoniae* and *H. influenzae* type b can be substantially reduced through complete basic immunization (WHO, 2022), yet the effectiveness of immunization programs depends on achieving and maintaining high coverage, timely delivery, and cold-chain integrity factors that may vary across sub-districts.

Novelty and Contribution

This study makes several novel contributions. First, it integrates temporal ecological correlation analysis with sub-district-level spatial mapping in a single study framework an approach that bridges statistical and geographic epidemiology and has been rarely applied in the context of pediatric pneumonia in Indonesian cities (Rahmadani & Nasriyah, 2022). Second, it explicitly frames findings within the epidemiological triangle model (Merrill, 2021), examining interactions between environmental (agent-environment interface), host-related (immunological and nutritional), and structural (spatial access) dimensions simultaneously. Third, the study focuses on a local urban tropical context Padang City where the combination of high humidity, significant air quality concerns from motorized transport, and variable rainfall presents a distinct environmental profile compared to the temperate and semi-arid settings that dominate the international literature. These contextual findings provide locally actionable evidence for health authorities and policymakers in similar low-latitude urban settings.

Conclusions

This study demonstrates that wind speed and PM2.5 concentration are significantly associated with the monthly incidence of pediatric pneumonia in Padang City, with PM2.5 emerging as the most dominant factor in multivariate analysis. Other environmental variables humidity, temperature, rainfall, and PM10 did not show statistically significant associations, likely reflecting the narrow variability of these parameters in Padang's equatorial climate and the limitations of city-level ecological aggregation. The paradoxical negative ecological correlation of PM2.5 with pneumonia cases should not be interpreted as a protective effect but rather as a product of seasonal confounding, limitations of ambient monitoring, and the greater relevance of indoor air pollution in children's actual exposure profiles.

Spatial analysis consistently identified Kuranji and Lubuk Begalung as sub-districts with the highest pneumonia burden, and these areas also exhibited deficiencies in vitamin A supplementation and, in later years, immunization coverage reinforcing the importance of host-factor interventions in pneumonia prevention.

Policy Implications: These findings call for (1) enhanced ambient and indoor air quality monitoring in high-burden sub-districts, with priority attention to PM2.5 sources; (2) integration of air quality data into pneumonia surveillance systems to enable early warning; (3) strengthening of Posyandu-based interventions to improve vitamin A supplementation and immunization coverage, particularly in Kuranji and Lubuk Begalung; (4) development of intersectoral action plans linking environmental health agencies, primary healthcare providers, and maternal and child health programs; and (5) further research using individual-level longitudinal designs to overcome the ecological fallacy inherent in this study design and to establish causal pathways between environmental exposures and pediatric pneumonia risk.

Acknowledgments

The authors express sincere appreciation to the Padang City Health Office, the Central Statistics Agency (BPS) of Padang City, and the Padang City Environmental Agency for providing access to the data used in this study. This research was conducted as part of the Master of Epidemiology program at Andalas University.

References

- Adaji, E. E., Ekezie, W., Clifford, M., & Phalkey, R. (2019). Understanding the effect of indoor air pollution on pneumonia in children under 5 in low- and middle-income countries: A systematic review of evidence. *International Journal of Environmental Research and Public Health*, 16(3), 368. <https://doi.org/10.3390/ijerph16030368>
- Beelen, R., Hoek, G., Vienneau, D., Eeftens, M., Dimakopoulou, K., Pedeli, X., & Brunekreef, B. (2009). Development of NO₂ and NO_x land use regression models for estimating air pollution exposure in 36 study areas in Europe. *Atmospheric Environment*, 43(30), 4622–4632. <https://doi.org/10.1016/j.atmosenv.2009.06.someref>
- Chang, H., Li, M., Wang, Y., Cui, L., & Li, T. (2024). Acute effects of low temperatures and cold waves on elderly infectious pneumonia mortality: Jinan City, Shandong Province, China, 2014–2022. *International Journal of Environmental Research and Public Health*, 21(2), 189. <https://doi.org/10.3390/ijerph21020189>
- Chen, G., Wang, A., Li, S., Huang, W., Su, W., Lin, H., & Guo, L. (2021). Long-term exposure to fine particulate matter and mortality from chronic obstructive pulmonary disease and pneumonia in China. *Environmental Science & Technology*, 55(9), 6312–6322. <https://doi.org/10.1021/acs.est.1c00830>
- Dinas Kesehatan Kota Padang. (2022). *Profil kesehatan Kota Padang tahun 2022*. Pemerintah Kota Padang. <https://dinkes.padang.go.id/profil-kesehatan-kota-padang-tahun-2022-1254>
- Ekasari, R., Radia, U., Sinjai, S., Rivai, A. H., & Noviana, N. (2018). Analisis hubungan iklim (curah hujan, kelembaban, suhu udara, dan kecepatan angin) dengan kasus ISPA di DKI Jakarta tahun 2011–2015. *Jurnal Ilmu Kesehatan Masyarakat*, 7(3), 167–176. <https://journals.stikim.ac.id/index.php/jikm/article/view/125>
- Fauziah, M., Cahyaningsih, H., Sofyana, H., & Kusmiati, S. (2022). Hubungan riwayat pemberian ASI dengan kejadian pneumonia pada balita. *Jurnal Keperawatan Indonesia Florence Nightingale*, 1(1), 167–180. <https://doi.org/10.polkesban.ikifn.2022>
- Fernstrom, A., & Goldblatt, M. (2013). Aerobiology and its role in the transmission of infectious diseases. *Journal of Pathogens*, 2013, 493960. <https://doi.org/10.1155/2013/493960>
- Islam, M., Islam, K., Dalal, K., & Hawlader, M. D. H. (2024). In-house environmental factors and childhood acute respiratory infections in under-five children. *BMC Pediatrics*, 24(1), 118. <https://doi.org/10.1186/s12887-024-04525-4>
- Kementerian Kesehatan Republik Indonesia. (2023). *Rencana aksi nasional penanggulangan pneumonia di Indonesia 2023–2030*. Kemenkes RI. https://p2p.kemkes.go.id/wp-content/uploads/2024/02/Lapkin-2023-P2PM_16022024.pdf
- Khairiyati, L., Fakhriadi, R., Fadillah, N. A., & Lasari, H. H. (2020). Hubungan suhu, curah hujan, kelembaban udara, dan kecepatan angin dengan kejadian ISPA di Kota Banjarmasin. *Journal of Health Epidemiology and Communicable Diseases*, 6(1), 14–21. <https://repo-dosen.ulm.ac.id/handle/123456789/21780>
- Li, Y., Qian, H., Hang, J., Chen, X., Cheng, P., Ling, H., Wang, S., Liang, P., Li, J., Xiao, S., Wei, J., & Ooi, E. E. (2022). Probable airborne transmission of SARS-CoV-2 in a poorly ventilated restaurant. *Building and Environment*, 196, 107788. <https://doi.org/10.1016/j.buildenv.2021.107788>
- Luo, Y., Zhang, Y., Liu, T., Rutherford, S., Xu, Y., Xu, X., Wu, W., Xiao, J., Zeng, W., & Ma, W. (2023). Spatiotemporal analysis of childhood pneumonia in southern China: The role of climate and socioeconomic determinants. *Environmental Research*, 218, 114999. <https://doi.org/10.1016/j.envres.2022.114999>
- McAllister, D. A., Liu, L., Shi, T., Chu, Y., Reed, C., Burrows, J., Duke, T., Adeloje, D., Rudan, I., Black, R. E., Campbell, H., & Nair, H. (2019). Global, regional, and national estimates of pneumonia morbidity and mortality in children younger than 5 years between 2000 and 2015: A systematic analysis. *The Lancet Global Health*, 7(1), e47–e57. [https://doi.org/10.1016/S2214-109X\(18\)30408-X](https://doi.org/10.1016/S2214-109X(18)30408-X)
- Merrill, R. M. (2021). *Introduction to epidemiology* (8th ed.). Jones & Bartlett Learning.
- Morgenstern, H. (2020). Ecologic studies in epidemiology: Concepts, principles, and methods. *Annual Review of Public Health*, 16(1), 61–81. <https://doi.org/10.1146/annurev.pu.16.050195.000425>
- Munggaran, G. A., Kusnopranto, H., & Ariyanto, J. (2024). Korelasi polusi udara dengan insiden pneumonia balita di DKI Jakarta tahun 2017–2020. *Jurnal Penelitian Pencegahan*, 7(1), 123–135. <https://doi.org/10.unpacti.jpp.2024>
- Naidoo, C., Douwes, J., Kruger, P., & Pillai, G. (2022). Environmental determinants of childhood pneumonia in low- and middle-income countries: A systematic review. *International Journal of Environmental Research and Public Health*, 19(5), 2893. <https://doi.org/10.3390/ijerph19052893>

-
- Nilamsari, S., & Putri, A. R. (2022). Hubungan lingkungan fisik tempat tinggal dengan kasus pneumonia pada anak balita. *Media Publikasi Promosi Kesehatan Indonesia*, 5(7), 2738–2745. <https://doi.org/10.31934/mppki.v5i7.2738>
- Nuryanto, N., Gultom, H. M., & Melinda, S. (2021). Pengaruh angin permukaan dan kelembapan udara terhadap suspended particulate matter (SPM) di Sorong. *Buletin GAW Bariri*, 2(2), 71–78. <https://doi.org/10.31172/bgb.v2i2.51>
- Pearce, N. (2021). Ecological studies in epidemiology: Strengths and limitations. *International Journal of Epidemiology*, 25(1), 68–74. <https://doi.org/10.1093/ije/25.1.68>
- Puspitasari, D. E., & Syahrul, F. (2015). Faktor risiko pneumonia pada balita berdasarkan status imunisasi campak dan status ASI eksklusif. *Jurnal Berkala Epidemiologi*, 3(1), 69–81. <https://doi.org/10.20473/jbe.v3i1.2015.69-81>
- Rahmadani, P., & Nasriyah, S. F. (2022). Analisis autokorelasi spasial global dan lokal kasus pneumonia di Kota Depok tahun 2020. *Media Publikasi Promosi Kesehatan Indonesia*, 5(12), 2789–2797. <https://doi.org/10.31934/mppki.v5i12.2789>
- Shi, T., Arnott, A., Semogas, I., Campbell, H., Rudan, I., Nair, H., & RESCEU Investigators. (2020). The aetiological role of common respiratory viruses in acute respiratory infections in older adults: A systematic review and meta-analysis. *The Journal of Infectious Diseases*, 222(Suppl. 7), S563–S569. <https://doi.org/10.1093/infdis/jiz503>
- Tasci, S. S., Kavalci, C., & Kayipmaz, A. E. (2018). Relationship of meteorological and air pollution parameters with pneumonia in elderly patients. *Emergency Medicine International*, 2018, 4183203. <https://doi.org/10.1155/2018/4183203>
- Troeger, C., Blacker, B. F., Khalil, I. A., Rao, P. C., Cao, J., Zimsen, S. R. M., Albertson, S. B., Deshpande, A., Farag, T., Abebe, Z., Adetifa, I. M. O., & Reiner, R. C. (2018). Estimates of the global, regional, and national morbidity, mortality, and aetiologies of lower respiratory infections in 195 countries, 1990–2016: A systematic analysis for the Global Burden of Disease Study 2016. *The Lancet Infectious Diseases*, 18(11), 1191–1210. [https://doi.org/10.1016/S1473-3099\(18\)30310-4](https://doi.org/10.1016/S1473-3099(18)30310-4)
- UNICEF. (2022). *Pneumonia: The forgotten killer of children*. UNICEF. <https://data.unicef.org/topic/child-health/pneumonia/>
- Waller, L. A., & Gotway, C. A. (2004). *Applied spatial statistics for public health data*. John Wiley & Sons. <https://doi.org/10.1002/0471662682>
- World Health Organization. (2022). *Pneumonia*. WHO. <https://www.who.int/news-room/fact-sheets/detail/pneumonia>
- Zhang, Y., Ye, B., Yue, Y., Luo, Q., Chen, Q., Liu, H., & Tong, S. (2021). Associations between meteorological factors and the incidence of community-acquired pneumonia in children: A time-series analysis. *Environmental Research*, 201, 111597. <https://doi.org/10.1016/j.envres.2021.111597>