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SPATIAL ANALYSIS OF PNEUMONIA DISTRIBUTION IN CHILDREN UNDER FIVE IN WEST JAVA: RELATIONSHIPS WITH INDIVIDUAL AND ENVIRONMENTAL DETERMINANTS

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ABSTRACT

Pneumonia is a major cause of mortality among children under five, especially in developing countries like Indonesia. In 2023, West Java recorded over 18,000 cases, making it one of the provinces with the highest burden. This study analyzes the spatial distribution of pneumonia in children under five across 27 districts/cities in West Java and examines its association with individual and environmental determinants. Data were obtained from the 2023 Indonesia Health Survey (Survei Kesehatan Indonesia or SKI), Statistics Indonesia (Badan Pusat Statistik or BPS), and the West Java Health Office. Descriptive analysis (mean, median, standard deviation) was conducted using SPSS, and geospatial mapping was performed using QGIS. The results revealed notable spatial clusters of pneumonia incidence among children under five in several districts. High-High clusters, indicating areas with high pneumonia rates surrounded by similarly high-risk districts, were prominently observed in regions with elevated prevalence of household tobacco smoking and use of wood fuel for cooking, such as Bogor, Sukabumi, Cianjur, and Garut. Conversely, Low-Low clusters, representing low pneumonia incidence surrounded by similarly low-risk districts, were identified in areas with better population density management and lower tobacco exposure, such as Majalengka, Cirebon, and Kuningan. Significant gaps in basic immunization coverage and exclusive breastfeeding practices were also spatially evident. Districts like Karawang and Purwakarta demonstrated Low-Low clusters for basic immunization, highlighting regional disparities potentially due to limited healthcare accessibility. Likewise, Majalengka and Indramayu showed Low-Low clusters for exclusive breastfeeding practices, signaling inadequate maternal and community support. This spatial epidemiological analysis highlights critical hotspots and underscores the importance of geographically targeted health policies, including intensified immunization campaigns, promotion of exclusive breastfeeding, and tobacco control initiatives, to effectively reduce pneumonia risks among vulnerable children in West Java.

Keywords: pneumonia, children under five, spatial analysis, West Java, environmental determinants

Introduction

Pneumonia is a leading cause of death among children under five, particularly in developing countries. According to the World Health Organization, pneumonia accounted for 14% of all deaths in children under five, with over 700,000 deaths annually worldwide.[1,2] In Indonesia, pneumonia remains a significant public health concern, with a prevalence of 3.8% among children under five, varying significantly across provinces.[3] In 2023 alone, Indonesia recorded 102,576 pneumonia cases in children under five, with West Java ranking second-highest after West Papua, reporting 18,000 cases.[4]

Efforts to control pneumonia in children rely heavily on preventive strategies, particularly basic immunization coverage.[5] Despite nationwide immunization programs, disparities in coverage persist. In 2020, West Java reported an immunization rate of 79.6%, which fell short of the national target of 93%.[6,7] This gap reflects regional inequalities in healthcare access and implementation of public health programs, potentially leaving many children vulnerable to preventable infections.[8,9]

In addition to immunization, household exposure to tobacco smoke is a critical yet often overlooked risk factor for childhood pneumonia. The 2023 Indonesia Health Survey (Survei Kesehatan Indonesia or SKI) reported that Indonesia has approximately 70 million active smokers, with 7.4% comprising children and adolescents aged 10–18 years.[4,10] Furthermore, the 2018 Basic Health Research (Riset Kesehatan Dasar or Riskesdas) indicated that household exposure to secondhand smoke in West Java (58.3%) was higher than the national average (57.8%), exacerbating respiratory infections in children. Previous studies have established a direct link between secondhand smoke exposure and increased pneumonia incidence in young children, making this a crucial public health concern.[11]

Beyond household risk factors, environmental determinants such as population density and inadequate sanitation contribute to pneumonia transmission. A study in rural Bangladesh demonstrated that poor access to clean Water, Sanitation, and Hygiene (WASH) significantly increased respiratory infections among young children.[12] In Indonesia, particularly in West Java, which has the highest population density in the country, urban overcrowding and poor air quality may further elevate pneumonia risks.[13]

Although national-level data on pneumonia burden is available, district-level spatial analyses are still limited in Indonesia. A recent study conducted in North Sumatra revealed significant disparities in pneumonia prevalence between rural and urban districts, with rural areas recording nearly six times the prevalence of community-acquired pneumonia (CAP) compared to urban regions (194.89 vs. 32.43 per 100,000 population, respectively).[14] These findings underscore the importance of sub-provincial analysis in identifying high-risk areas and tailoring interventions accordingly. However, to date, little is known about the spatial distribution of pneumonia incidence and its contextual determinants in West Java.

Understanding the spatial distribution of pneumonia cases and their associated risk factors is crucial for designing targeted interventions to reduce pneumonia incidence in children under five. Despite existing studies on pneumonia prevalence in Indonesia, limited research has examined its spatial patterns and environmental determinants at the district level, particularly in West Java. Identifying high-risk areas and analyzing their relationship with factors such as immunization coverage, household tobacco smoke exposure, and environmental conditions can help policymakers implement region-specific prevention strategies. To fill this gap, this study adopts an ecological design to examine the distribution of pneumonia across 27 districts and cities in West Java. Through spatial and statistical analyses, it aims to identify clustering patterns of pneumonia and evaluate their association with individual and environmental determinants.

Method

This study employed an analytical ecological study design to examine the spatial distribution of pneumonia cases in children under five and its relationship with determinant factors, including individual and environmental characteristics. The unit of analysis consisted of 27 districts/cities in West Java Province, which included Bandung, Bandung Barat, Bekasi, Bogor, Ciamis, Cianjur, Cirebon, Garut, Indramayu, Karawang, Kota Bandung, Kota Banjar, Kota Bekasi, Kota Bogor, Kota Cimahi, Kota Cirebon, Kota Depok, Kota Sukabumi, Kota Tasikmalaya, Kuningan, Majalengka, Pangandaran, Purwakarta, Subang, Sukabumi, Sumedang, and Tasikmalaya. These regions were selected based on the availability of complete pneumonia case data, coverage in official health reports, and their administrative significance within West Java's public health framework. Data for this study were obtained from multiple official sources, including the 2023 Indonesia Health Survey (Survei Kesehatan Indonesia or SKI), the West Java Provincial Health Office, and Statistics Indonesia (Badan Pusat Statistik atau BPS).

The dependent variable in this study was the number of pneumonia cases in children under five, obtained from the West Java Provincial Health Office. The independent variables consisted of child health indicators, household risk factors, and environmental determinants. Child health indicators included complete basic immunization status, defined as the percentage of children who received all essential vaccines according to the national immunization schedule, exclusive breastfeeding rate, which referred to the proportion of infants exclusively breastfed for the first six months, and Low Birth Weight (LBW), representing the percentage of live births weighing less than 2500 grams. These variables were obtained from the 2023 Indonesia Health Survey (SKI). Household risk factors included household exposure to tobacco smoke, measured as the percentage of children living in households with at least one active smoker, also sourced from Indonesia Health Survey[4]. Meanwhile, environmental determinants were collected from Statistics Indonesia[6] and included population density (total population per square kilometer in each district/city), adequate housing access (percentage of households meeting government-defined housing standards such as proper ventilation, lighting, and space adequacy), and use of wood fuel for cooking (proportion of households relying on biomass fuel, which contributes to indoor air pollution and increased risk of respiratory infections).

To analyze whether pneumonia cases are spatially clustered, this study employed Global Moran's Index (I) to assess overall spatial autocorrelation. Moran's Index values range from -1 to 1, where values between -1 and 0 indicate negative spatial autocorrelation (dispersion), values between 0 and 1 indicate positive spatial autocorrelation (clustering), and a value of 0 suggests a random pattern. The null hypothesis (H_0) assumes no spatial autocorrelation among regions.

To explore localized spatial patterns, Local Indicators of Spatial Association (LISA) were applied to identify spatial clusters and potential outliers of pneumonia cases. The Moran Scatter Plot was used to visualize spatial autocorrelation and is divided into four quadrants, as shown in Table 1:

Table 1. Quadrants of Moran's Index for Spatial Autocorrelation Explanation

Quadrant	Explanation
Quadrant I (High-High - HH)	Regions with high observed values are surrounded by other regions with high observed values, also known as hotspots.
Quadrant II (Low-High - LH)	Regions with low observed values are surrounded by regions with high observed values, also referred to as outliers.
Quadrant III (Low-Low - LL)	Regions with low observed values are surrounded by other regions with low observed values, also known as cold spots.
Quadrant IV (High-Low - HL)	Regions with high observed values are surrounded by regions with low observed values, also referred to as outliers.

The spatial interpretation used in the map visualizations is represented through a standardized color scheme that indicates the type and significance of spatial clustering. Red represents High-High clusters, which are districts with high values of a particular independent variable (such as high smoking prevalence or high population density) that are surrounded by neighboring districts with similarly high values. These areas are identified as hotspots, where a specific risk factor is significantly concentrated. Blue indicates Low-Low clusters, where low values are surrounded by other districts with low values, signifying cold spots or areas with notably low levels of the observed factor. Light pink is used to identify High-Low outliers, referring to districts with high values that are surrounded by neighboring districts with low values, suggesting localized anomalies or extremes. Conversely, light blue shows Low-High outliers, where a district with a low value is surrounded by high-value neighbors, indicating an area that stands out for having relatively lower exposure compared to its surroundings. Finally, gray indicates districts that do not exhibit statistically significant spatial clustering, meaning their values are randomly distributed and do not show any meaningful geographic pattern.

Spatial analyses, including computation of Moran's Index and LISA, were conducted using GeoDa software. QGIS was used for geospatial mapping and visual interpretation of spatial patterns, including the color-coded cluster visualization described above. Descriptive statistics (mean, standard deviation, min-max) and bivariate analysis were conducted using SPSS. Spatial regression was used to explore the relationship between determinant factors and pneumonia distribution. This study was approved by the Health Research Ethics Committee of Universitas Airlangga (Code: 57/EA/KEPK/2025), dated February 24, 2025.

Results

The descriptive characteristics of pneumonia cases and their associated risk factors in West Java Province are presented in Table 2. The number of pneumonia cases among children under five varied widely, ranging from 953 (Kota Banjar) to 78,856 (Kabupaten Bandung Barat), with an average of 11,063 cases. Immunization coverage averaged 56.75%, far below the national target of 93%, with Kabupaten Garut showing the lowest (39.64%) and Kabupaten Sumedang the highest (76.29%). Exclusive breastfeeding showed relatively high and even coverage across the province, averaging 76.55%. Among environmental variables, the use of wood fuel for cooking averaged 6.86%, with some districts reaching over 20%. Household tobacco smoke exposure was highest in Kabupaten Cirebon (17.67%), while access to adequate housing ranged from 30.51% to 86.35%.

Table 2. Descriptive Analysis of Pneumonia Case Coverage, Child Characteristics, and Environmental Factors in West Java Province, 2023

Variable	Mean	Median	SD	Minimum	Maximum
Pneumonia Case Coverage	11,063.26	8267	14,803.06	953	78,856
Complete Basic Immunization (%)	56.75	55.75	9.50	39.64	76.29
Exclusive Breastfeeding (%)	76.55	76.13	5.32	66.39	87.84
Low Birth Weight (cases)	739.67	518	542.96	124	1967
Household Tobacco Smoking (%)	13.38	14.22	2.73	7.78	17.67
Population Density (people/km²)	3,910.93	1,468	4,668.12	385	15,176
Adequate Housing Access (%)	56.19	54.98	16.39	30.51	86.35
Cooking with Wood Fuel (%)	6.86	4.49	6.72	0.27	23.13

Notes: SD = Standard Deviation

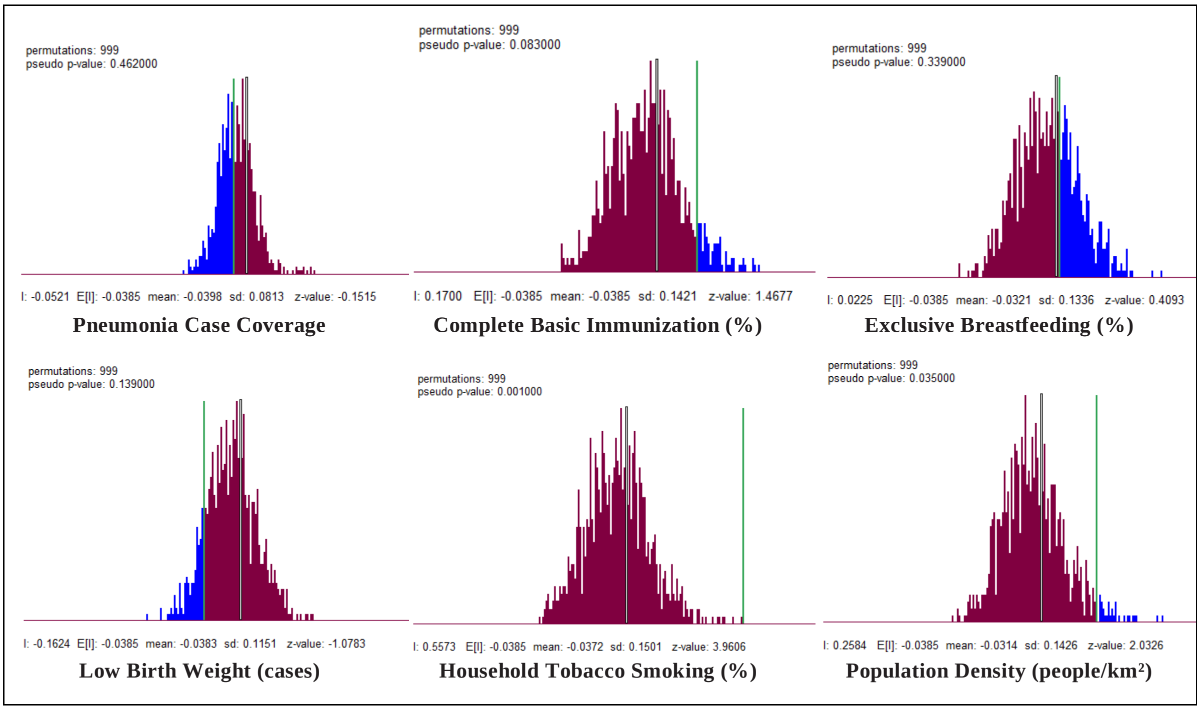
Table 3 presents the spatial autocorrelation analysis using Moran's Index to evaluate the distribution patterns of pneumonia case coverage and its determinant factors in West Java Province, 2023. A negative Moran's I for pneumonia (–0.0521) indicates a dispersed distribution, suggesting that pneumonia cases among children under five are spread across regions rather than forming geographic clusters. This pattern implies a stronger influence from individual-level factors (e.g., immunity, comorbidities, healthcare access) than spatially structured environmental conditions.

Table 3. Spatial Autocorrelation Analysis of Pneumonia Case Coverage and Determinant Factors in West Java Province, 2023

Variable	Moran's Index	E[I]	Pattern
Pneumonia Case Coverage	-0.0521	-0.0385	Negative
Complete Basic Immunization (%)	1.180556	-0.0385	Positive
Exclusive Breastfeeding (%)	0.15625	-0.0385	Positive
Low Birth Weight (cases)	-0.1624	-0.0385	Negative
Household Tobacco Smoking (%)	3.870139	-0.0385	Positive
Population Density (people/km²)	1.791667	-0.0385	Positive
Adequate Housing Access (%)	4.216667	-0.0385	Positive
Cooking with Wood Fuel (%)	2.84375	-0.0385	Positive

Notes: E[I] = Expected Value of Moran's Index.

Conversely, several risk factors showed positive spatial autocorrelation, indicating geographic clustering. The strongest clustering was observed in adequate housing access (Moran's I = 4.22), household tobacco smoking (Moran's I = 3.87), and wood fuel use (Moran's I = 2.84). This suggests that districts with poor housing and environmental risks tend to be concentrated in specific areas. In addition, population density (Moran's I = 1.79) and immunization coverage (Moran's I = 1.18) also clustered spatially, though less intensely. On the other hand, low birth weight exhibited a dispersed pattern (Moran's I = –0.1624), like pneumonia, reinforcing that not all health indicators are driven by geographic clustering. These findings highlight the need for geographically targeted interventions to address clustered environmental risks, while emphasizing broader strategies to tackle individual-level vulnerabilities associated with pneumonia burden.



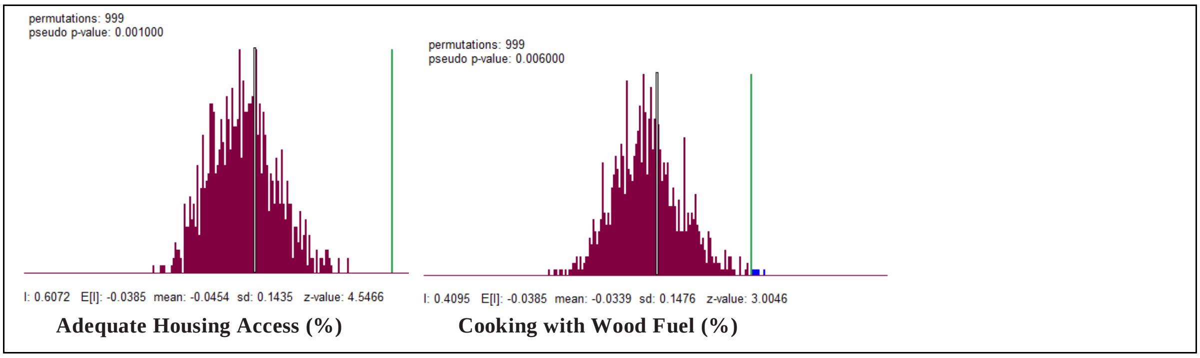


Figure 1. Moran's Index Histograms for Pneumonia Case Coverage, Child Characteristics, and Environmental Factors in West Java, 2023

Figure 1. Moran's Index histograms illustrating the spatial autocorrelation of pneumonia case coverage and its determinant factors across 27 districts/cities in West Java Province, 2023. Each histogram is based on 999 permutations under the null hypothesis of spatial randomness. The green vertical line represents the observed Moran's I value, while the distribution shows simulated values. Pseudo p-values indicate the statistical significance of spatial clustering. Significant clustering is observed for household tobacco smoking, adequate housing access, and cooking with wood fuel ($p < 0.01$), while pneumonia case coverage and low birth weight show non-significant or dispersed patterns ($p > 0.05$).

Figure 1 demonstrates that pneumonia case coverage exhibits a dispersed spatial pattern (Moran's I = –0.0521, p = 0.4620), indicating no significant geographic clustering. Similarly, low birth weight also shows a dispersed distribution (Moran's I = –0.1624, p = 0.1390), suggesting that both outcomes are likely influenced by individual-level rather than spatial factors. In contrast, household tobacco smoking shows strong spatial clustering (Moran's I = 0.5573, p = 0.0010), indicating that areas with high smoking prevalence are geographically concentrated. Adequate housing access (Moran's I = 0.6072, p = 0.0010) and cooking with wood fuel (Moran's I = 0.4095, p = 0.0060) also exhibit significant clustering, highlighting specific regions with high environmental risks.

Population density (Moran's I = 0.2584, p = 0.0350) shows moderate clustering. Meanwhile, complete basic immunization (Moran's I = 0.1700, p = 0.0830) and exclusive breastfeeding (Moran's I = 0.0225, p = 0.3390) show weak or non-significant spatial patterns, indicating a relatively even distribution across districts. These results emphasize that while pneumonia cases themselves do not cluster spatially, environmental risk factors do, underscoring the need for geographically targeted interventions to reduce exposure to tobacco smoke, poor housing, and indoor air pollution in high-risk areas.

Table 4 presents the results of the bivariate spatial autocorrelation analysis, examining the relationship between pneumonia case detection coverage and its determinant factors. The results show that pneumonia coverage exhibits a dispersed spatial pattern (Moran's I = –0.0732, p = 0.1694), indicating an absence of geographic clustering and suggesting that pneumonia incidence is more likely influenced by non-spatial factors such as healthcare access, individual immunity, or comorbidities.

In contrast, household tobacco smoking prevalence demonstrates significant spatial clustering (Moran's I = 1.4111, p = 0.031), indicating that regions with high smoking prevalence tend to be near other high-prevalence areas. This suggests that certain areas have consistently high levels of secondhand smoke exposure, which could contribute to increased pneumonia risk among children. Similarly, low birth weight cases also exhibit a clustered distribution (Moran's I = 1.4312, p = 0.036), reinforcing the notion that neonatal health risks are geographically structured, with certain regions having consistently higher numbers of Low Birth Weight (LBW) cases.

Table 4. Moran's Index, Z-scores, and p-values of Independent Variables' Relationship to Pneumonia Case Detection Coverage Among Children Under Five in West Java Province, 2023

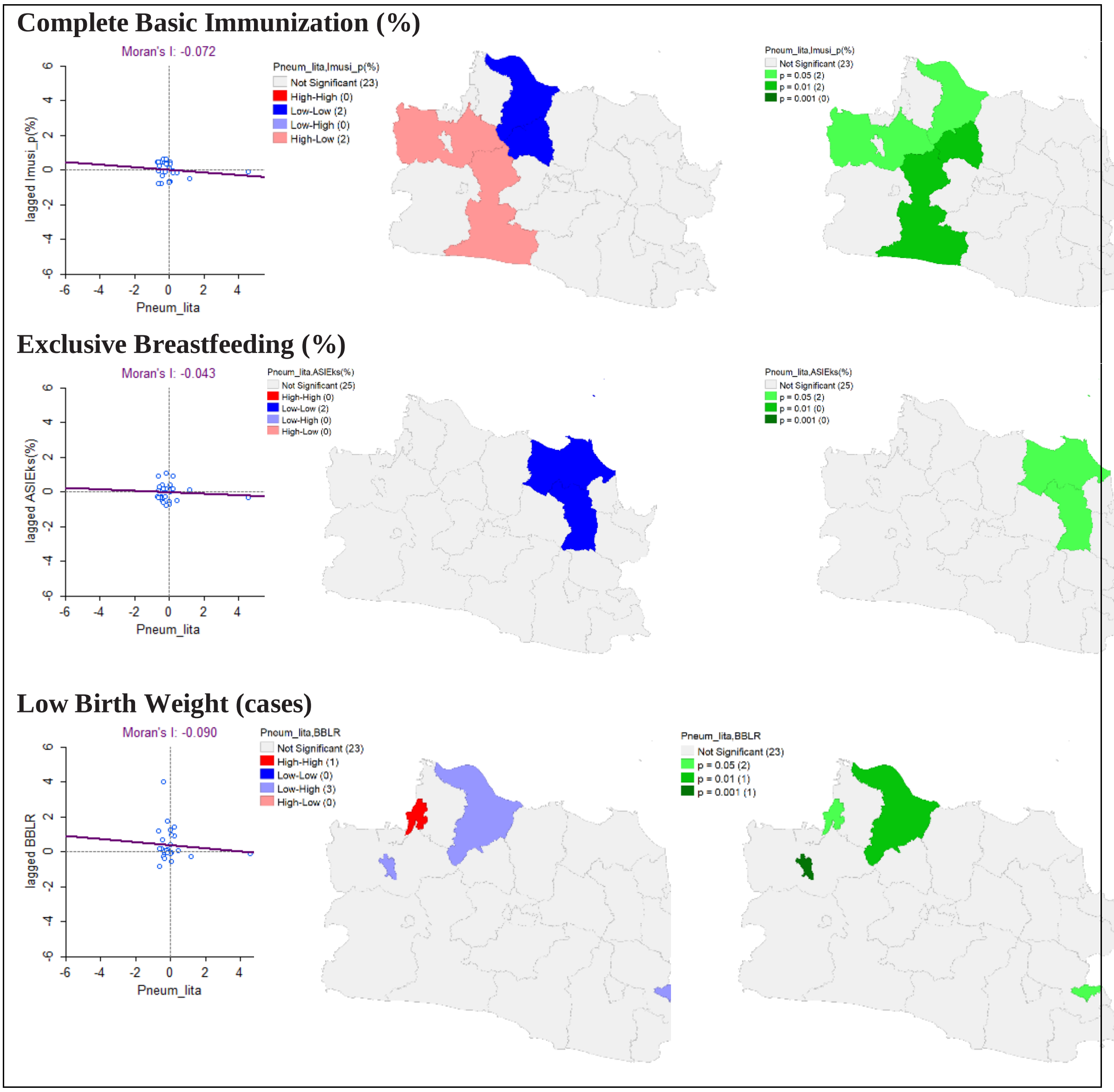
Variable	Moran's Index	E[I]	Pattern
Pneumonia Case Coverage	-0.0732	-0.6664	0.169444
Complete Basic Immunization (%)	-0.0435	-0.3571	0.24375
Exclusive Breastfeeding (%)	-0.0901	-0.6779	0.14375
Low Birth Weight (cases)	1.43125	18.617	0.036
Household Tobacco Smoking (%)	1.411111	20.197	0.031
Population Density (people/km²)	-0.0514	-0.6100	0.179861
Adequate Housing Access (%)	-0.1950	-17.340	0.022
Cooking with Wood Fuel (%)	-0.0732	-0.6664	0.169444

Population density shows moderate but non-significant spatial clustering (Moran's I = -0.0514, p = 0.1799), indicating that densely populated areas do not strongly correlate with pneumonia case detection. Likewise, cooking with wood fuel follows a dispersed pattern (Moran's I = -0.0732, p = 0.1694), suggesting that household air pollution does not cluster geographically in a way that influences pneumonia incidence. Adequate housing access exhibits a weak spatial correlation (Moran's I = -0.1950, p = 0.022), showing marginal statistical significance, but the relationship is not strong enough to confirm a definitive spatial association with pneumonia cases.

Complete basic immunization (Moran's I = –0.0435, p = 0.2438) and exclusive breastfeeding (Moran's I = –0.0901, p = 0.1438) showed no significant spatial autocorrelation, indicating that these indicators are evenly distributed across regions and not strongly influenced by geographic location.

These results emphasize the need for targeted interventions in areas where risk factors—such as household tobacco smoking and low birth weight show significant clustering. High-risk districts should be prioritized for smoking cessation programs and neonatal health services. Meanwhile, the dispersed pattern of pneumonia cases suggests the importance of addressing individual-level factors, including healthcare access, nutrition, and comorbidities. Environmental risks like poor housing and wood fuel use may contribute to pneumonia but require broader public health strategies beyond spatial targeting.

Figure 2 presents the spatial cluster analysis using Local Indicators of Spatial Association (LISA) to assess the relationship between pneumonia case detection in children under five and various determinant factors across districts in West Java Province. The maps show statistically significant spatial associations between pneumonia cases and each determinant, with specific cluster types observed in several districts.



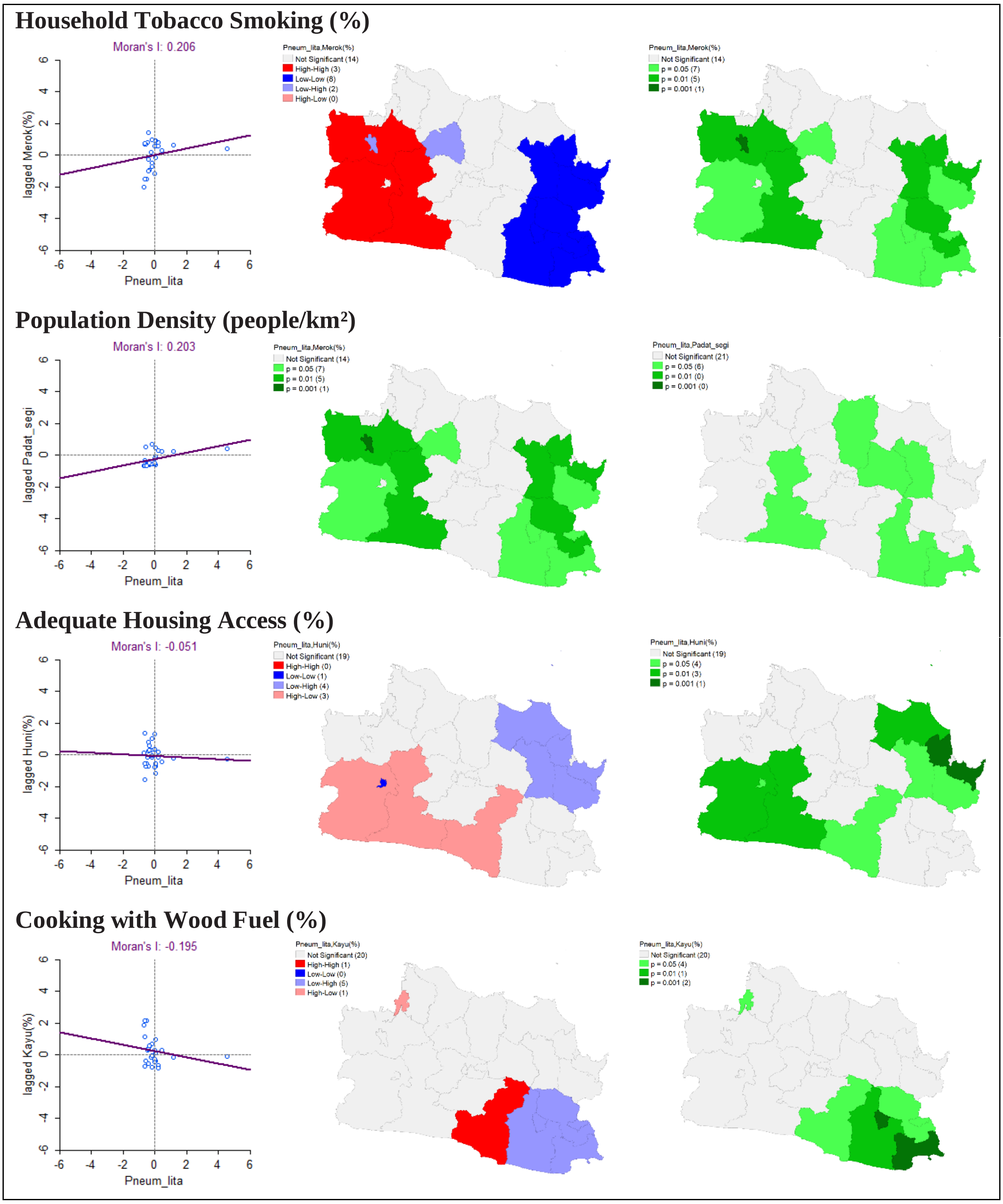


Figure 2. Cluster Map of the Relationship Between Pneumonia Case Detection Coverage in Children Under Five and Child Characteristics and Environmental Factors in West Java Province, 2023

Based on Figure 2, two significant Low-Low clusters were identified for complete basic immunization in Karawang and Purwakarta, indicating that these districts and their neighbors exhibited both low immunization coverage and low pneumonia detection rates. Conversely, High-Low outlier clusters were observed in Bogor and Cianjur, suggesting districts with higher pneumonia detection surrounded by areas with lower immunization coverage—highlighting a potential mismatch in service reach or uptake.

Regarding exclusive breastfeeding, Low-Low clusters appeared in Indramayu and Majalengka, indicating lower breastfeeding rates and lower pneumonia case detection in spatially connected districts. This may reflect underlying socioeconomic or cultural patterns affecting child health practices and healthcare access.

The analysis of low birth weight (LBW) revealed a High-High cluster in Kota Bekasi, where high pneumonia case detection coincided with high LBW prevalence in surrounding areas. Additionally, Low-High outliers were detected in Karawang, Kota Bogor, and Kota Banjar, suggesting these districts had relatively low LBW rates yet were surrounded by areas with higher LBW prevalence.

Household tobacco smoke exposure exhibited a pronounced spatial pattern. High-High clusters were found in Bogor, Sukabumi, and Cianjur—districts with both high smoking prevalence and high pneumonia detection. In contrast, a widespread Low-Low cluster was identified in Majalengka, Cirebon, Kuningan, Ciamis, Pangandaran, Kota Tasikmalaya, Tasikmalaya, and Kota Banjar. Notably, Low-High outliers emerged in Kota Bogor and Purwakarta, which had lower smoking prevalence despite being surrounded by districts with higher levels.

For population density, Low-Low clusters were observed in Subang, Sumedang, Majalengka, Tasikmalaya, and Pangandaran, indicating both low population density and low pneumonia detection. Cianjur appeared as a High-Low outlier, suggesting high pneumonia cases despite being surrounded by less densely populated areas.

In terms of adequate housing access, High-Low outliers were identified in Sukabumi, Cianjur, and Garut—districts with better housing conditions located near areas with poorer housing quality. A Low-Low cluster was detected in Kota Sukabumi, and Low-High outliers were observed in Indramayu, Majalengka, Cirebon, and Kuningan.

Finally, spatial clustering of biomass fuel use for cooking (wood fuel) revealed a High-High cluster in Garut, suggesting a localized area with both high use of wood fuel and elevated pneumonia detection. Meanwhile, Low-High outliers were identified in Kota Tasikmalaya, Tasikmalaya, Ciamis, Kota Banjar, and Pangandaran, and a High-Low outlier in Kota Bekasi, potentially reflecting contrasting environmental exposure profiles.

These results reinforce the presence of geographic disparities in environmental and perinatal risk factors for pneumonia. Identifying these spatial clusters allows policymakers to implement targeted interventions in districts most affected by specific risk factors, such as smoking prevalence, inadequate housing, or reliance on wood fuel, while also ensuring universal coverage of preventive services like immunization and breastfeeding support.

Discussion

This study highlights significant spatial disparities in pneumonia case detection among children under five in West Java, revealing how both individual and environmental factors contribute to region-specific vulnerabilities. While pneumonia cases overall followed a dispersed pattern, several key determinants—including household tobacco smoking, use of wood fuel, low birth weight (LBW), and high population density—showed statistically significant spatial clustering, indicating the presence of localized health risks.

These findings aligned with previous studies highlight the protective role of complete basic immunization in reducing pneumonia risk in children. Vaccination against Haemophilus influenzae type b (Hib) and Streptococcus pneumoniae has been shown to significantly reduce the burden of invasive infections, including pneumonia, and prevent thousands of child deaths annually.[15] Studies confirm that adherence to the Expanded Programme on Immunization (EPI) schedule significantly lowers the incidence of severe pneumonia in children.[16] Furthermore, research from low- and middle-income countries suggests that disparities in immunization coverage contribute to clusters of increased pneumonia risk, particularly in underserved areas.[17] Similar findings have been reported by GAVI, who also noted the need for improved outreach in rural and underserved districts to ensure vaccine equity.[17]

In line with previous research, our study found that districts with Low-Low clusters of complete basic immunization (Karawang and Purwakarta) require prioritized interventions to increase vaccine coverage and prevent regional disease clusters. Additionally, districts like Cianjur and Bogor, where high pneumonia detection coincides with neighboring areas of low immunization coverage, highlight the importance of extending vaccine outreach to low-coverage neighboring areas to maximize herd immunity. This finding is consistent with reports emphasizing that comprehensive vaccine programs must include outreach strategies to neighboring low-coverage areas to maximize herd immunity.[11]

Regarding exclusive breastfeeding, while the results showed no widespread clustering of exclusive breastfeeding rates, significant Low-Low clustering was observed in Majalengka and Indramayu. These districts displayed lower breastfeeding rates, which are essential for reducing pneumonia risk. A recent study published in the International Breastfeeding Journal in March 2025 found that non-exclusive breastfeeding is associated with a 2.34-fold higher risk of developing pneumonia in children under five.[2] Similarly, research by Victora et al. showed that exclusive breastfeeding can reduce pneumonia risk by up to 23%, particularly in infants under six months.[18] Given these findings targeted breastfeeding promotion programs are needed in Majalengka and Indramayu. Expanding community-based lactation support, implementing workplace breastfeeding policies, and providing maternal education could significantly improve breastfeeding rates in these high-risk areas.

Despite the importance of exclusive breastfeeding, rates in Indonesia have declined from 64.5% in 2018 to 52.5% in 2021.[19] The Low-Low clustering observed in Majalengka and Indramayu suggests that insufficient breastfeeding education, limited maternal support, and socio-economic barriers may contribute to these lower breastfeeding rates. Studies have shown that early initiation of breastfeeding can significantly improve exclusive breastfeeding rates, particularly among working mothers in resource-limited settings.[20] Given this, it's crucial to implement targeted breastfeeding promotion initiatives in these areas, such as enhancing community-based lactation support, improving workplace breastfeeding policies, and expanding maternal education campaigns to improve breastfeeding rates in these high-risk districts.[21]

Regarding low birth weight (LBW), our study found that regions like Bekasi City exhibited High-High clustering, where high LBW prevalence coincided with high pneumonia case detection. LBW is a well-established risk factor for pneumonia, primarily due to the underdeveloped immune systems of newborns. Consistent with previous research, our findings show that areas with both high LBW and pneumonia clustering, such as Bekasi, require targeted neonatal care interventions to reduce pneumonia morbidity and mortality. LBW has long been linked to higher pneumonia risk, especially due to immature immune development.[22] A study further confirmed that preterm birth significantly increases the likelihood of bacterial pneumonia infections, particularly in low-resource settings.[22,23] In Bekasi, where both LBW and pneumonia cases are concentrated, it is critical to prioritize neonatal care interventions. This aligns with global recommendations, which emphasize improving maternal nutrition, enhancing antenatal care services, and strengthening neonatal follow-up programs in high-risk areas.[24,25]

In the case of household tobacco smoking, our analysis revealed strong spatial clustering in Bogor, Sukabumi, and Cianjur, with high smoking prevalence correlating with high pneumonia incidence. The relationship between secondhand smoke exposure and childhood respiratory diseases, including pneumonia, is well-established.[1] Children exposed to secondhand smoke are at an increased risk of developing pneumonia, asthma, and other respiratory conditions due to impaired lung development. A meta-analysis of case-control studies found that children exposed to secondhand smoke had a 2.15 times greater risk of developing pneumonia compared to those not exposed.[26] This underscores the urgent need for more aggressive tobacco control measures, including smoking cessation programs and stricter regulations to reduce secondhand smoke exposure in high-risk areas.

Population density was moderately clustered but showed no significant correlation with pneumonia detection. Previous studies have found that densely populated areas, such as those in Sidoarjo Regency, Indonesia, consistently report high pneumonia cases due to increased person-to-person transmission and limited healthcare access.[27] This suggests the importance of urban planning and infrastructure development to reduce overcrowding and improve healthcare access in densely populated districts.

The implications are clear, pneumonia prevention in West Java requires a two-pronged strategy. First, geographically targeted interventions must be prioritized in districts with spatial clustering of modifiable risks, including stricter tobacco control, clean cooking initiatives, and improved neonatal care. Second, systemic health policy efforts are needed to ensure equitable access to immunization and breastfeeding support, especially in underserved communities.

Nevertheless, the study has several limitations. First, as an ecological study, it is prone to the ecological fallacy, where associations observed at the district level may not apply to individuals. Second, the cross-sectional nature of the data precludes causal inference. Third, potential confounders such as indoor ventilation quality, actual air pollutant levels, and healthcare service availability were not included due to data constraints. Lastly, reliance on secondary data from surveys and administrative sources introduces the possibility of measurement bias or underreporting.

Despite these limitations, this study provides novel insights into how pneumonia risk factors are distributed across space, allowing policymakers to move beyond generalized interventions and adopt data-driven, location-specific strategies. The findings emphasize that to effectively reduce pneumonia morbidity and mortality among children under five, interventions must simultaneously target environmental exposures, maternal and child health services, and community-level health behaviors. Future research should consider longitudinal and multilevel modeling to validate these spatial associations and inform more precise policy actions.

Conclusion

This study found that pneumonia among children under five in West Java is influenced by both individual and environmental factors, with significant spatial clustering observed for household tobacco smoking, low birth weight, wood fuel usage, and population density. In contrast, complete basic immunization and exclusive breastfeeding showed no clear spatial patterns, suggesting systemic rather than geographic barriers. These findings highlight the need for spatially targeted public health interventions, alongside broader efforts to improve maternal and child health services and environmental conditions to effectively reduce the burden of pneumonia.

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Conflict of Interest

The authors declare no competing interests regarding the publication of this research.

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