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Spatial Patterns of Under-Five Pneumonia and Socio-Environmental Factors in West Java: A LISA and Geographically Weighted Regression Approach, 2019–2023

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ABSTRACT

Introduction: Pneumonia remains a leading cause of mortality in children under five in Indonesia, with significant geographical disparities. **Objective:** This study addresses the urgent need to understand the complex spatial distribution of pediatric pneumonia and its relationship with local socio-environmental factors in West Java, Indonesia's most populous province. **Methods:** This study uses an ecological study design, utilizing aggregated district/city level data from 2019 to 2023, and employs a quantitative spatial analysis approach. As the analysis is at an aggregated level, the findings reflect area-level associations, and conclusions cannot be inferred regarding individual-level risk, thus avoiding potential ecological fallacy. **Result:** The study reveals that while the overall distribution of pneumonia was not globally clustered, significant local patterns exist. Geographically Weighted Regression (GWR) analysis demonstrated superior performance over traditional Ordinary Least Squares (OLS) models, with an R^2 value reaching 0.800 in 2019, indicating that relationships between pneumonia and its determinants are highly variable across space. Getis-Ord G_i^* analysis identified persistent coldspots (low-incidence clusters) in the southeastern region and dynamic hotspots (high-incidence clusters) along the northern coast. Furthermore, Bivariate LISA analysis confirmed that population density and poverty are significant clustered determinants spatially correlated with pneumonia incidence. **Conclusion:** These findings provide critical evidence for developing targeted, location-specific public health interventions to effectively reduce the burden of childhood pneumonia.

Keywords: Pneumonia, Spatial Analysis, Geographically Weighted Regression, Socio-Environmental Factors, West Java

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INTRODUCTION

Pneumonia remains a significant global health challenge, disproportionately affecting child health in low- and middle-income countries. It is a primary cause of morbidity and mortality among children under five, accounting for approximately 800,000 deaths annually worldwide – a figure exceeding the combined mortality rates of HIV/AIDS, tuberculosis, and malaria in this age group (Bassat et al., 2020). The World Health Organization (WHO) estimates that pneumonia contributes to 16% of all deaths in children under five globally, underscoring the immense scale of the problem. The burden is further exacerbated in regions affected by humanitarian emergencies, where studies show that pneumonia can account for 7.2% to 48% of pediatric hospital

admissions (Chen et al., 2022). This high prevalence highlights the urgent need for effective healthcare interventions and preventive strategies to mitigate its impact.

The pathophysiology of pneumonia in children is complex, influenced by a combination of factors including nutritional status, environmental conditions, and the presence of comorbidities. For instance, malnutrition significantly increases the risk of severe pneumonia by compromising a child's immune response (Srivastava et al., 2024; Yadav et al., 2024). Similarly, conditions like asthma can worsen disease severity, leading to higher rates of hospitalization and mortality (Ekbom et al., 2019; Handayani & Setyoningrum, 2022; Mahdavian et al., 2018). Recent studies have emphasized the utility of spatial epidemiology in understanding and managing pneumonia incidence.

In the context of Indonesia, particularly in West Java province, various factors contribute to the high incidence of pneumonia, including environmental issues, nutritional deficiencies, and healthcare access. Previous research in the province has highlighted the non-uniform distribution of pneumonia cases, with certain areas showing a higher concentration (Yanti, 2022). Studies have also identified links between decreased immunity, evidenced by low serum IgA levels, and the severity of respiratory infections in children in this region (Cahyani, 2024). Furthermore, vitamin A deficiency has been identified as a significant risk factor, as it weakens the immune response and increases susceptibility to infection (Gultom & Wulandari, 2020). Health-seeking behavior also plays a critical role; qualitative studies reveal that many parents perceive pneumonia symptoms as mild, leading to delays in seeking appropriate medical care, which can increase morbidity and mortality rates (Purwati et al., 2021). This clustering of cases and influencing factors within specific districts of West Java points to the necessity of targeted interventions tailored to local needs (Yanti, 2022).

To address these geographically nuanced challenges, Geographic Information Systems (GIS) have emerged as a powerful tool for spatial analysis in public health. GIS enables the visualization and analysis of disease distribution, facilitating the identification of high-risk areas and their correlation with environmental and demographic factors such as population density, air pollution, and socioeconomic status (Saleem et al., 2021). While previous studies in Indonesia have applied spatial analysis to pneumonia, such as those by Wartono et al. (2018), Wahyuni & Makful (2024), and Delfiyanti & Eryando (2024), they have often been limited to simple mapping or basic clustering methods (Delfiyanti & Eryando, 2024; Wahyuni & Makful, 2024; Wartono et al., 2018). Some recent research has utilized methods like Global Moran's I and LISA (Rahmadani & Nasriyah, 2022; Suchery & Hastono, 2025), but a comprehensive approach that models the spatial heterogeneity of risk factors is still lacking.

Recent advancements in spatial epidemiology have enabled a more detailed understanding of the spatial distribution and determinants of pneumonia. Studies employing spatial regression models have demonstrated strong associations between pneumonia incidence and environmental exposures such as indoor air pollution, proximity to industrial zones, and urban overcrowding (Anjas et al., 2019; Aulia et al., 2017; Utami et al., 2021). These studies have highlighted that poor air quality, often linked to vehicular emissions and industrial activities, significantly contributes to the burden of pneumonia, particularly in densely populated urban areas. In addition, factors such as limited access to healthcare and inadequate sanitation have been identified as amplifiers of pneumonia risk in these regions. Moreover, recent research has shown that climate factors, such as temperature fluctuations and seasonal changes, also play a crucial role in influencing pneumonia incidence, with colder months seeing higher rates of infection due to both increased exposure to pathogens and weakened immune responses (Bassat et al., 2020). Together, these findings underscore the need for integrated interventions that address not only medical treatment but also environmental, socioeconomic, and infrastructural factors contributing to the persistence of pneumonia in vulnerable populations.

This study aims to fill this gap by employing more advanced geospatial techniques. In addition to environmental and socioeconomic factors, research has also focused on the role of specific pathogens in

the spatial epidemiology of pneumonia. A study in The Lancet Regional Health employed spatial analysis to investigate the geographic distribution of different pneumococcal serotypes, finding distinct spatial patterns that were associated with vaccine coverage and antibiotic resistance (Zintgraff et al., 2025). This underscores the potential for using spatial analysis to optimize vaccination strategies and monitor the spread of antimicrobial resistance in the context of pneumonia. The insights gained from these studies can inform targeted interventions that address the specific drivers of pneumonia in different geographic areas, ultimately contributing to a more effective and equitable response to this persistent global health challenge.

The novelty of this research lies in its comprehensive methodological approach, which combines spatial autocorrelation, Getis-Ord G_i^* for hotspot analysis, and, most importantly, Geographically Weighted Regression (GWR), to provide a more nuanced understanding than prior research by modeling how the influence of risk factors varies across different locations. Therefore, the objective of this study is to conduct a spatial distribution analysis of pneumonia cases in children under five and to analyze the correlation of various risk factors at the district/city level in West Java from 2019 to 2023.

METHOD

This study employed a quantitative research design using an ecological study approach with spatial analysis techniques. It must be emphasized that the unit of analysis in this study is aggregated (district/city level), not the individual. Therefore, the findings reflect correlations at the area level and cannot be used to infer conclusions about risk at the individual level, thereby avoiding the potential for ecological fallacy.

The research was conducted using secondary data spanning from 2019 to 2023, covering all 27 districts and cities within West Java Province, Indonesia. The data on under-five pneumonia cases were aggregated at the district/city level annually. The independent variables included population density, poverty rate, environmental quality index (IKLH), and the number of health facilities, which were selected based on data availability and relevance to the research problem. IKLH, the Indeks Kualitas Lingkungan Hidup or Environmental Quality Index, is an official composite index used by Indonesia's Ministry of Environment and Forestry (KLHK) to assess regional environmental quality. Its measurement is based on the aggregation of several sub-indices, including the Water Quality Index (IKA), Air Quality Index (IKU), and Land Quality Index (IKL) or Land Cover, which are each measured through field monitoring and sampling against national environmental quality standards. Since this research utilized publicly available, aggregated, and anonymized secondary data, Ethical Clearance (EC) was not required.

The data analysis process was conducted using GIS software (QGIS and GeoDa), Python and involved several stages. First, thematic mapping (choropleth maps) was performed to visualize the spatial distribution of pneumonia incidence rates per 1,000 children under five for each year. Second, spatial autocorrelation analysis was conducted using the global Moran's I statistic to assess the overall clustering pattern of pneumonia and each independent variable. Subsequently, local clustering was identified using two methods: the Getis-Ord G_i^* statistic to detect statistically significant high-value (hotspot) and low-value (coldspot) clusters, and Bivariate Local Indicators of Spatial Association (LISA) to explore the spatial correlation between pneumonia incidence and each risk factor. Finally, to model the spatially varying relationships, Geographically Weighted Regression (GWR) was utilized. A critical step in GWR is the selection of the kernel bandwidth, which defines the local neighborhood for each estimation. In this study, an adaptive bi-square kernel was used, which is the most appropriate method for irregular spatial units such as the districts/cities in West Java. The optimal bandwidth (i.e., the optimal number of nearest neighbors) was determined using an objective, data-driven method. The GeoDa software was used to identify the bandwidth that minimized the Cross-Validation (CV) score.

This procedure, often implemented via a Golden Section Search algorithm, iteratively tests different bandwidth sizes to find the one that produces the lowest aggregate prediction error, thus ensuring an optimal and robust local model.

RESULTS AND DISCUSSIONS

The results of this study provide a multi-faceted view of the spatial dynamics of under-five pneumonia in West Java. The thematic maps revealed a visually dispersed pattern of pneumonia incidence across the province's districts and cities from 2019 to 2023. This visual observation was statistically confirmed by the univariate Moran's I analysis for pneumonia incidence, which showed no significant global spatial autocorrelation for most years (p -value > 0.05), indicating that cases did not form a strong province-wide cluster but were more randomly distributed at the aggregate level. In contrast, the key socio-environmental variables such as population density, poverty, and environmental quality, exhibited significant positive spatial autocorrelation, meaning that districts with high (or low) values for these factors tended to be geographically clustered together.

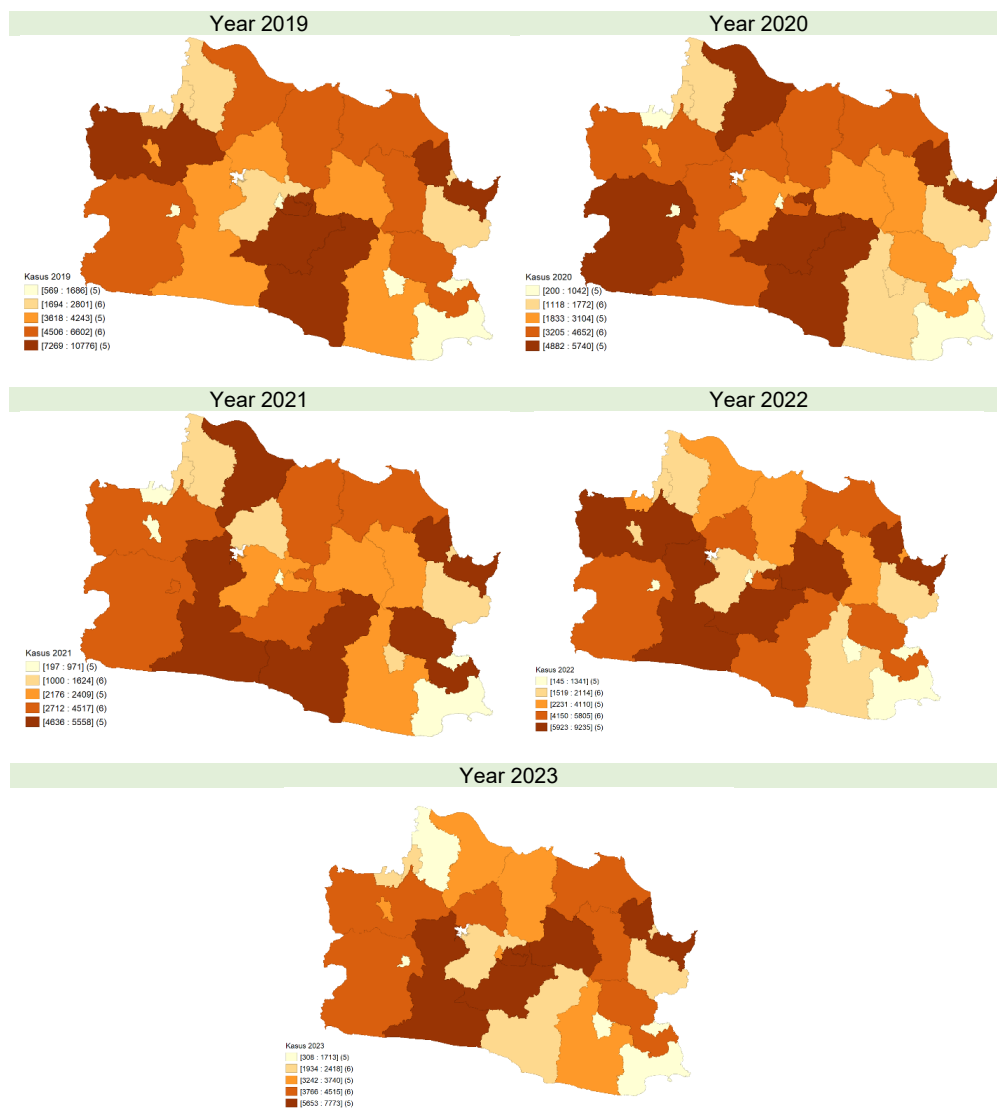


Figure 1. Thematic Map of Pneumonia Incidence in West Java Province, 2019 - 2023

Figure 1 aims to interpret the Thematic Map of pneumonia incidence distribution in West Java Province from 2019-2023. The focus of the analysis is to identify the geographical distribution patterns of cases, visually recognize areas with high (hotspots) and low (cold spots) case burdens, as well as to observe the trends of change that occurred during this five-year period.

A study by Yusdiana et al. (2025) in Rokan Hilir, Riau, affirms that the distribution of pneumonia in children under five is strongly influenced by environmental dynamics and does not always form fixed spatial clusters (Yusdiana et al., 2025). This condition is similar to the findings of Chekol et al (2024), who reported that a non-significant global autocorrelation in infectious diseases among children under five can occur in regions with a diverse mix of social and geographical conditions (Chekol et al., 2024)c.

Table 1. Univariate Analysis of the Spatial Distribution of Pneumonia using Moran's I

Year	Moran's I	E(I)	Z-Score	p-value	Pattern
2019	-0.1839		-1.0550	0.145000	Dispersed
2020	-0.0221		0.1449	0.439000	Gathered
2021	-0.2351	-0.0385	-1.3675	0.082000	Dispersed
2022	-0.2295		-1.3708	0.092000	Dispersed
2023	-0.0469		-0.0744	0.496000	Dispersed

Based on the results of the univariate analysis, it can be concluded that the distribution pattern of pneumonia in children under five across the Districts/Cities of West Java from 2019-2023 was generally dispersed, with the exception of a clustered pattern in 2020; however, overall, these patterns were not statistically significant. Thus, no statistically significant geographical pattern can be identified from the distribution of pneumonia cases at the district/city level in West Java, despite its visually dispersed appearance on the map.

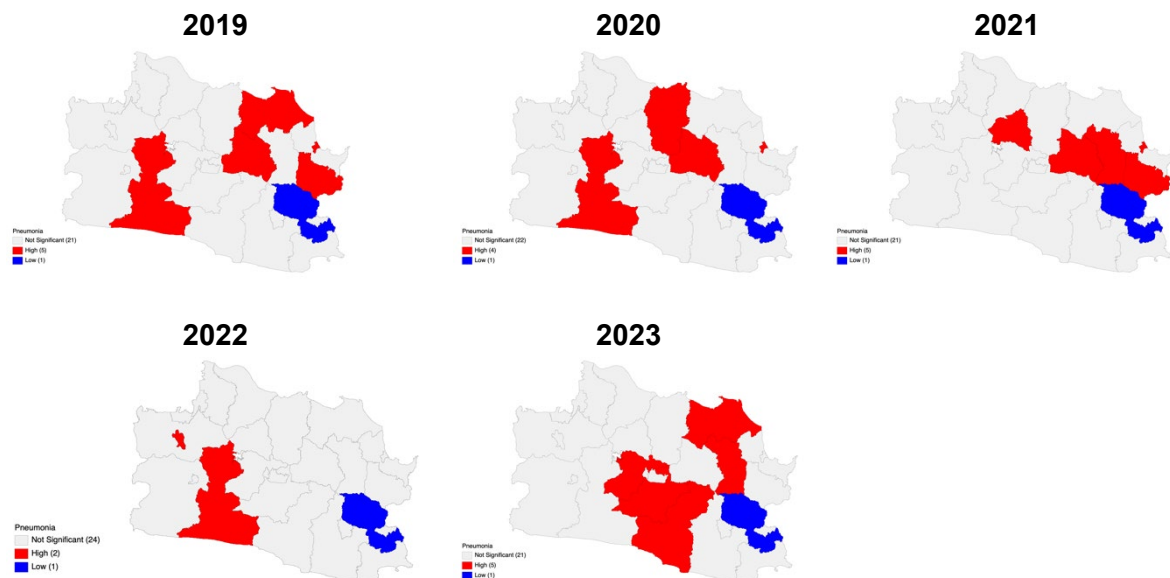


Figure 2. GI* Analysis (Getis-Ord Hotspot)

From the provided maps (Figure 2), a dynamic year-to-year pattern can be observed: **Cold spot (Low-Case Cluster - Blue):** A highly stable and persistent cold spot exists in the south-eastern region of West Java (potentially including Pangandaran Regency, Ciamis, and their surrounding areas). This

cluster appears consistently in almost every year of the analysis. It represents an area with a significantly lower pneumonia incidence compared to its neighbouring regions. **Hotspot (High-Case Cluster - Red):** The hotspot pattern is far more dynamic and fluctuating: **2019-2021:** Hotspots consistently appeared in the northern coastal region (Pantura) and in several pockets in the central-western part. The number of hotspot areas was relatively high (4-5 clusters). **2022:** There was a drastic decrease in the number of hotspots, leaving only 2 significant clusters. The hotspots in the Pantura region appeared to have disappeared this year. **2023:** A significant re-emergence of hotspots occurred. Not only did they reappear in the Pantura region, but a large new hotspot cluster also formed in the central part of West Java.

The Getis-Ord G_i^* hotspot analysis provided more localized insights, identifying clear and persistent spatial patterns. A stable and significant coldspot (a cluster of low pneumonia incidence) was consistently observed in the southeastern region of West Java, potentially covering areas like Pangandaran and Ciamis, throughout the study period. Conversely, hotspots (clusters of high pneumonia incidence) were far more dynamic. They consistently appeared in the northern coastal region (Pantura) and parts of the central-west from 2019-2021, diminished drastically in 2022, and then re-emerged significantly in 2023, indicating a fluctuating but recurring vulnerability in these areas. This finding is supported by Zhan et al. (2025) and Syukrilla (2023), who emphasize that infectious disease hotspots tend to shift over time and are strongly influenced by the role of health facilities, environmental management, and public awareness (Syukrilla et al., 2023; Zhan et al., 2025).

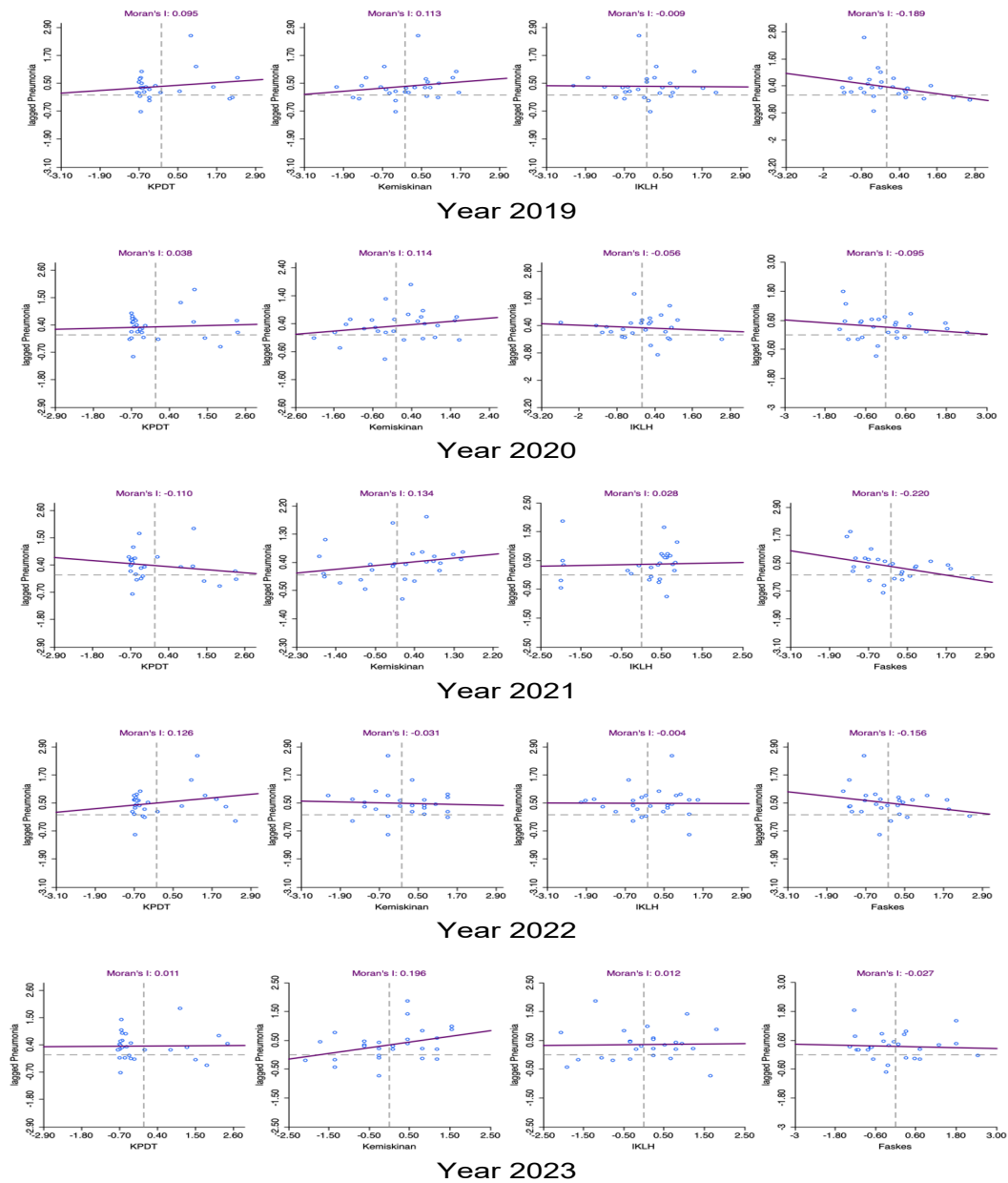


Figure 3. Bivariate LISA

The Bivariate LISA analysis further clarified these relationships, showing that areas with high pneumonia incidence were often spatially correlated with areas of high population density and high poverty rates (Musdalifah et al., 2023; Syani et al., 2017). An interesting finding from the LISA analysis was the complete disappearance of High-High clusters (high pneumonia, high risk) in 2021, a period marked by social restrictions during the COVID-19 pandemic, which may have temporarily altered transmission dynamics.

A key contribution of this research is the comparison between the global OLS regression model and the local GWR model. To validate the use of GWR and justify our confidence in the resulting maps, we compared the diagnostics of both models, as summarized in Table 2.

Table 2. Comparison of OLS and GWR Model Diagnostics

Year	R ² OLS	Adj. R ² OLS	R ² GWR	Adj. R ² GWR	RSS OLS (mil)	RSS GWR (mil)	BP-test	KB-test
2019	0.530146	0.444718	0.800	0.696	82.05	35.00	0.18193	0.27598
2020	0.617882	0.548406	0.651	0.554	27.33	24.99	0.26018	0.08735
2021	0.502105	0.411579	0.513	0.386	36.03	34.11	0.40736	0.50617
2022	0.504422	0.414317	0.507	0.387	66.49	66.15	0.67143	0.22912
2023	0.289684	0.160536	0.289	0.116	81.43	80.74	0.19933	0.09687

The results consistently show that the GWR model provides a better fit for the data than the OLS model. This confidence is based on several key pieces of evidence from the diagnostics: **Improved Explanatory Power (R²):** The GWR model consistently yielded a higher R² and Adjusted R² value. For instance, in 2019, GWR explained 80% of the variation in pneumonia incidence (R² = 0.800), whereas the global OLS model only explained 53% (R² = 0.530). **Reduced Model Error (RSS):** The GWR model produced a substantially lower Residual Sum of Squares (RSS) each year (e.g., 35.00 million vs. 82.05 million in 2019), indicating that the local model's prediction errors were significantly smaller.

The superiority of the GWR model was most pronounced in 2019, where it explained 80% of the variation in pneumonia incidence (Adj. R² = 0.696), compared to only 53% by the OLS model (Adj. R² = 0.445). This confirms that the relationships between pneumonia and its determinants are not uniform across West Java and that a local model is more appropriate. However, the explanatory power of the GWR model sharply declined by 2023 (Adj. R² = 0.116), suggesting that the measured variables were no longer sufficient to explain pneumonia variation. This could be due to the emergence of other unmeasured factors, such as household-level behaviors (e.g., indoor air quality), vaccination coverage, or changes in the healthcare reporting system post-pandemic, as suggested by studies like Li (2017) and Chekol et al (Chekol et al., 2024; Li, 2017).

A particularly notable finding from the GWR coefficient analysis was the consistent positive correlation between the number of health facilities and pneumonia cases. This counterintuitive result must be interpreted cautiously to avoid an ecological fallacy. The finding is a correlation at the ecological (regional) level and does not imply that facilities cause pneumonia at the individual level. Rather, it strongly suggests the presence of a spatial reporting bias, where areas with more facilities have better detection and reporting systems, leading to higher recorded case counts.

CONCLUSION

This study successfully mapped the spatial heterogeneity of under-five pneumonia in West Java and identified key socio-environmental determinants using advanced spatial analysis techniques. The findings demonstrate that while pneumonia does not follow a simple province-wide cluster, significant local hotspots and coldspots exist and are dynamically influenced by factors like population density and poverty. The superiority of the Geographically Weighted Regression (GWR) model over traditional regression confirms that a "one-size-fits-all" policy approach is insufficient for a region as diverse as West Java. The results underscore the necessity of moving beyond broad strategies towards targeted, evidence-based interventions. Recommendations for public health authorities include prioritizing promotional and preventive health programs in the identified hotspot regions, particularly the northern coastal area; investigating the protective factors present in the persistent coldspot region in the southeast for potential replication; and improving the surveillance system to account for and correct spatial reporting biases. Future research should aim for higher-resolution analysis at the sub-district or village level and incorporate additional variables such as vaccination rates, housing quality, and indoor air pollution to build a more comprehensive model of pneumonia risk.

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