Original Article

Spatial analysis of hospitalization and mortality rates due to pneumonia in children under one year of age

Análise espacial das taxas de internação e mortalidade por pneumonia em crianças menores de um ano

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ABSTRACT

Objective: to analyze the distribution and spatial autocorrelation of hospitalization and mortality rates due to pneumonia in children under one year of age. **Methods:** an ecological, population-based study with a geospatial approach, which analyzed hospitalizations and mortality due to pneumonia in children under one year of age between 2019 and 2023, using data from the Information Technology Department of the Unified Health System. Rates were calculated per 1,000 live births in the same period and location. Spatial autocorrelation was assessed using Moran's Global and Local Indices, using Microsoft Excel®, GeoDa®, and QGIS®. **Results:** 15,520 hospitalization cases and 91 deaths were analyzed. Hospitalization rates ranged from zero to 318.22, with High-High clusters in the Northwest, West, Midwest, Southwest, and South-Central regions. Mortality rates ranged from zero to 4.70, with High-High clusters in the West, Northwest, South-Central, and Southwest regions. The bivariate analysis did not show a significant spatial correlation between hospitalization and mortality rates. **Conclusion:** the spatial autocorrelation of hospitalizations and deaths from pneumonia in children under one year of age revealed disparities between municipalities. **Contributions to practice:** guiding public health policies, strengthening primary care, and the surveillance and monitoring of epidemiological data.

Descriptors: Spatial Analysis; Child; Hospitalization; Mortality; Pneumonia.

RESUMO

Objetivo: analisar a distribuição e a autocorrelação espacial das taxas de internação e mortalidade por pneumonia em crianças menores de um ano. **Métodos:** estudo ecológico, de base populacional e abordagem geoespacial, que analisou internações e mortalidade por pneumonia em crianças menores de um ano entre 2019 e 2023, com dados do Departamento de Informática do Sistema Único de Saúde. As taxas foram calculadas por 1.000 nascidos vivos no mesmo período e local. A autocorrelação espacial foi avaliada por meio dos Índices de Moran Global e Local, utilizando *Microsoft Excel*®, GeoDa® e QGIS®. **Resultados:** foram analisados 15.520 casos de internação e 91 óbitos. As taxas de internação variaram de zero a 318,22, com *clusters* Alto-Alto no Noroeste, Oeste, Centro-Oeste, Sudoeste e Centro-Sul. As taxas de mortalidade variaram de zero a 4,70, com *clusters* Alto-Alto no Oeste, Noroeste, Centro-Sul e Sudoeste. A análise bivariada não evidenciou correlação espacial significativa entre as taxas de internação e mortalidade. **Conclusão:** a autocorrelação espacial das internações e óbitos por pneumonia em crianças menores de um ano revelou disparidades entre os municípios. **Contribuições para a prática:** orientam políticas públicas em saúde, fortalecendo a atuação da atenção primária e a vigilância e monitoramento de dados epidemiológicos.

Descritores: Análise Espacial; Criança; Hospitalização; Mortalidade; Pneumonia.

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Introduction

Pneumonia is an acute respiratory infection that compromises the lungs, making breathing and gas exchange difficult, and can be caused by different etiological agents. It is a condition responsible for a large proportion of infant deaths worldwide, being strongly influenced by socioeconomic and health factors that affect children's living conditions[1].

In children under one year of age, the main etiology of pneumonia differs from that observed in other age groups, being predominantly viral, with respiratory syncytial virus as the most common pathogen. The circulation of this virus has shown significant seasonal changes in the post-pandemic period, with outbreaks occurring outside the usual period, reflecting shifts in epidemiological patterns[2].

Internationally, pneumonia is a significant cause of childhood morbidity. In the United States, it accounts for approximately 1.5 million pediatric visits annually. In Spain, the hospital incidence of community-acquired pneumonia increased from 126 to 131 cases per 100,000 children between 2016 and 2019[3].

A considerable portion of these hospitalizations can be prevented through timely access to essential health care, such as vaccination and pediatric follow-up. However, challenges related to vaccine adherence and unequal access to health services persist, contributing to high morbidity and mortality rates[4-5]. The effectiveness of interventions depends on their adaptation to regional and social particularities.

In recent years, Brazil has experienced a significant drop in vaccination coverage, exacerbated by political crises and the COVID-19 pandemic. Between 2017 and 2021, this reduction was alarming and adversely affected protection against vaccine-preventable diseases, including pneumonia. Despite efforts to increase vaccination rates in 2023, rates remain suboptimal, particularly among the most vulnerable children[6].

The COVID-19 pandemic has also significantly altered the profile of respiratory infections in children. During periods of social distancing, there was a temporary reduction in cases and deaths from respiratory etiologies apart from COVID-19. However, with the resumption of social activities, there was a sharp increase in cases, including respiratory syncytial virus infections, resulting in hospital overcrowding across various Brazilian states[7].

Given this scenario, analyzing the spatial distribution of hospitalizations and pneumonia-related mortality enables the identification of regional inequalities and informs health policies aimed at reducing infant morbidity and mortality. Despite the relevance of the topic, there is a scarcity of studies that simultaneously investigate hospitalization and mortality rates due to pneumonia in infants in the state of Paraná, particularly using spatial autocorrelation methods, such as Bayesian methods and the bivariate Moran index.

Given this scenario, the question arises: how are hospitalization and mortality rates for pneumonia among children under one year of age spatially distributed in Paraná, and what spatial patterns can be identified? This study aims to analyze the distribution and spatial autocorrelation of hospitalization and mortality rates due to pneumonia in children under one year of age.

Methods

Type and period of study

Ecological, population-based study with a geospatial approach, conducted with cases of hospitalization and mortality due to pneumonia in children under one year of age in the state of Paraná, Brazil, referring to the period from 2019 to 2023.

The state of Paraná is in southern Brazil, comprises 399 municipalities, and is organized into 22 health regions. These health regions are grouped into four macro-regions, integrated into a healthcare network[8].

In 2023, the estimated population of Paraná was approximately 11.4 million inhabitants. Curiti-

ba, the capital, has about 1.8 million residents, and its metropolitan area has almost 3.7 million people. This population concentration highlights the importance of the state in the Brazilian context[9].

Source and collection of data

The data were extracted from the Hospital Information System of the Brazilian Unified Health System, the Mortality Information System, and the Live Birth Information System, all accessed through the SUS Information Technology Department (DATASUS) in September 2024. The code J18 was used: pneumonia caused by an unspecified microorganism, according to the International Classification of Diseases. It should be noted that only records of children under one year of age were considered[10].

Data analysis

Hospitalization and mortality rates were calculated by dividing the sum of events from 2019 to 2023 by the number of live births in the same period and location, then multiplying the result by 1,000. Given the presence of low-density municipalities, event occurrences cause distortion and variability. Thus, smoothing was performed using the local empirical Bayesian method, which is well suited to analyzing small populations and reducing random fluctuations, thereby reducing instability by generating rates weighted by boundaries (a first-order queen matrix) to constrain random fluctuations[11].

The spatial distribution was presented using thematic maps, classified using the natural breaks method, with a gradual color scale from light to dark. This procedure allowed the data to be grouped into classes with greater internal uniformity and greater differentiation between them, reducing intraclass variability and increasing interclass variability[10]. Using the neighborhood matrix, an average of 5.58 neighbors was defined for each municipality (minimum: 2;

maximum: 12; median: 5).

The Moran index was applied to the smoothed rates, yielding Global and Local Moran Indices. The univariate Global Moran Index was calculated using a pseudo-significance test with 999 permutations (p >0.050). The Global Moran Index tests the hypothesis of spatial dependence, with values close to zero indicating randomness and values close to one indicating direct (+) or inverse (-) spatial autocorrelation[12]. Next, the univariate Local Moran Index was calculated to identify clusters that influence the Global Moran Index, namely: high-high, areas and neighbors with high rates; low-low, areas and neighbors with low rates; low-high, areas with low rates and neighbors with high rates; high-low, areas with high rates and neighbors with low rates; not significant, areas without spatial trend[13].

The use of the Local Moran Index is warranted even when the Global Moran Index is not statistically significant. The Global Moran Index provides a broad view of spatial autocorrelation in an area but may not reveal patterns that manifest at local scales. The Local Moran Index, in turn, is crucial for identifying specific areas with high autocorrelation, known as hotspots, and those with low autocorrelation, called coldspots. In addition, it allows the identification of clusters and outliers that are not evident in the global analysis. Therefore, even when global spatial autocorrelation is considered weak or irrelevant, there may be relevant local clusters that the Global Moran Index does not detect[14].

Assuming that the hospitalization rate is correlated with the mortality rate, a bivariate Moran's I test was applied to examine the spatial association between the two variables, using values from neighboring municipalities. In this analysis, spatial clusters were classified as: areas and neighbors with high rates; areas and neighbors with low rates; areas with low rates and neighbors with high rates; areas with high rates and neighbors with low rates; and areas without spatial trends[14].

The territorial boundaries of the municipalities

were obtained from the Brazilian Institute of Geography and Statistics by downloading the 2022 municipal grid data. Statistical and spatial analyses were performed using Microsoft Excel® 2016, GeoDa® software (version 1.20.0), and QGIS® (version 2.36.3).

Ethical aspects

Finally, it should be noted that this study was exempt from evaluation by the Human Research Ethics Committee, as it used publicly available, aggregated, and anonymized data.

Results

A total of 15,520 cases of hospitalization for pneumonia distributed across 208 municipalities and 91 cases of mortality from the same infection in 61 municipalities were analyzed between 2019 and 2023 in the state of Paraná. The smoothed hospitalization rates ranged from zero to 318.22 cases per thousand live births (Figure 1A), while the smoothed mortality rates ranged from zero to 4.70 cases per thousand live births (Figure 1B).
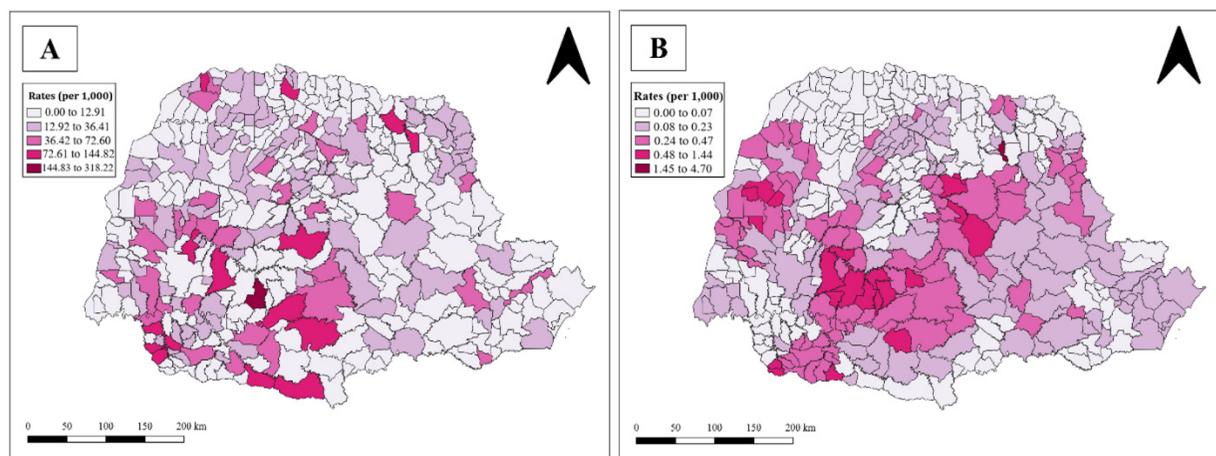

Figure 1 – Spatial distribution of smoothed rates, using the empirical Bayesian method, of hospitalization (A) and mortality (B) due to pneumonia, per 1,000 live births, among children under one year of age, according to municipalities in Paraná, Brazil, 2019 to 2023. Maringá, PR, Brazil, 2025

According to the smoothed rates, the least pigmented regions correspond to the lowest rates, whereas the most pigmented regions correspond to the highest rates. Thus, the lowest hospitalization rates occurred in the Metropolitan, North, Southeast, and Central-East regions, ranging from 12.92 to 36.41. In contrast, the Northwest, West, Midwest, Southwest, and South-Central regions showed high rates, ranging from 72.61 to 144.82, with some points reaching 318.22 per thousand live births (Figure 1A).

Pneumonia mortality rates varied greatly across different regions of the state of Paraná. The lowest rates were identified in the Metropolitan, North, Northwest, West, and Southeast regions of the state,

ranging from zero to 0.23. Higher rates, ranging from 0.24 to 1.44, were observed in the West, Northwest, Center-South, Southwest, and Center-East regions. The highest rate was observed in a point in the North region, ranging from 1.45 to 4.70 per thousand live births (Figure 1B).

The Global Moran Index for hospitalizations indicated a positive/direct autocorrelation, with a value of 0.05 (p = 0.040), suggesting a slight spatial autocorrelation and indicating tha presence of a weak geographical pattern, albeit weak, in the distribution of hospitalization rates for pneumonia. For mortality cases, the Global Moran Index was 0.20 (p = 0.010), indicating more substantial positive spatial autocor-

relation and suggesting that pneumonia mortality rates are clustered in certain regions.

High-high hospitalization clusters were observed in 11 municipalities distributed across the Central-South, Southwest, and West regions of the state. Low-low clusters were concentrated in 15 municipalities located in the Metropolitan and Northwest regions. The distribution pattern also showed Low-high clusters in 20 municipalities located in the Northwest, North, Central-South, and Southwest regions (Figure 2A).
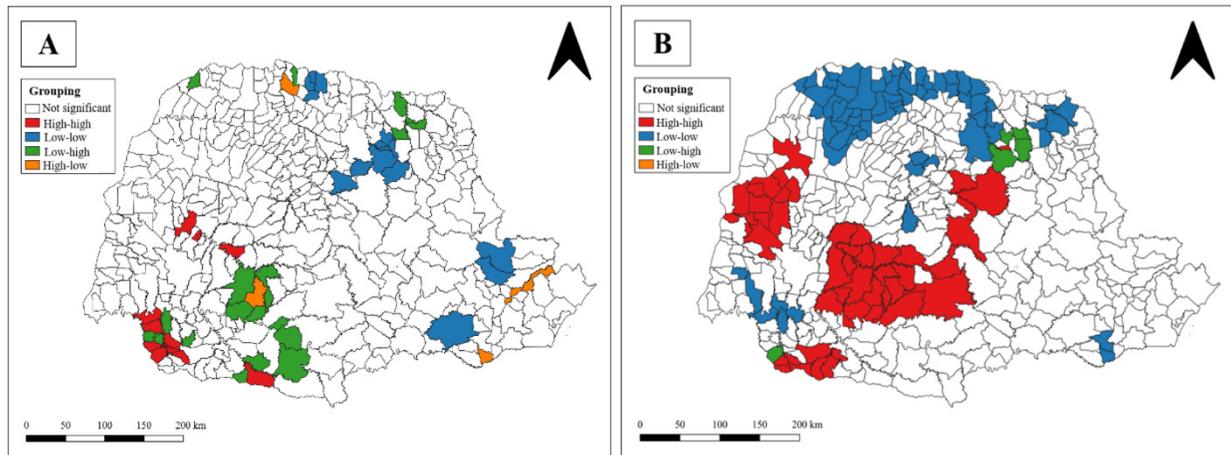

Figure 2 – Spatial autocorrelation of smoothed rates, using the empirical Bayesian method, of hospitalization (A) and mortality (B) due to pneumonia, per 1,000 live births, among children under one year of age, according to municipalities in Paraná, Brazil, 2019 to 2023. Maringá, PR, Brazil, 2025

Regarding mortality clusters, a significant pattern in the distribution of High-high and Low-low clusters was observed. High-high clusters were present in 49 municipalities located in the Northwest, West, Southwest, South Central, and East Central regions. Low-low clusters are distributed across 68 municipalities located in the Northwest, North, West, Southwest, and Metropolitan regions (Figure 2B).

Moran's bivariate analysis of hospitalization and mortality rates for pneumonia in children under one year of age yielded a Moran's I statistic of 0.01 (p = 0.160), suggesting no discernible spatial pattern or correlation. In general, areas with high or low hospitalization rates are not strongly associated with areas with high or low mortality rates.

The analysis of the association between hospitalization and mortality rates identified 13 high-high clusters distributed in the North, Central-South, and Southwest regions of the state, indicating that municipalities with high hospitalization and mortality rates due to pneumonia are surrounded by neigh boring municipalities that also have high rates. Fifteen low-low clusters were identified in the Metropolitan, Northwest, and North regions (Figure 3).
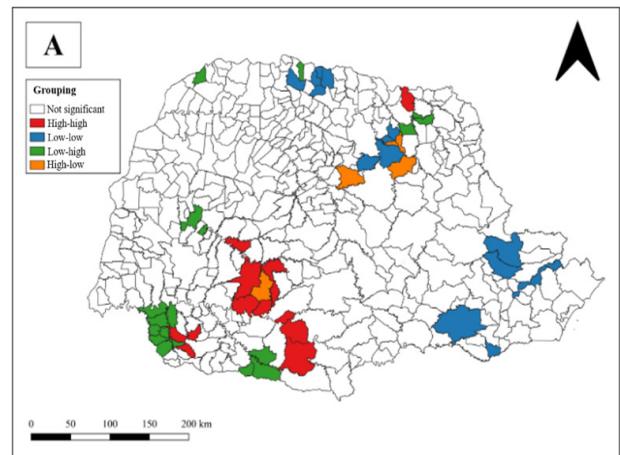

Figure 3 – Spatial correlation between hospitalization and mortality rates for pneumonia, smoothed using the empirical Bayesian method, per 1,000 live births, among children under one year of age, according to municipalities in Paraná, Brazil, from 2019 to 2023. Maringá, PR, Brazil, 2025

Discussion

This study identified municipalities and regions with the highest vulnerability to hospitalization and death from pneumonia in children under one year of age in Paraná, advancing knowledge by demonstrating that, although hospitalization rates show weak spatial autocorrelation, mortality is significantly concentrated in specific territorial clusters. This finding indicates that the determinants associated with death go beyond hospitalization, suggesting inequalities in timely access to services, case severity, and the effectiveness of child health care.

The absence of a significant spatial correlation between hospitalization and mortality reinforces that municipalities with higher hospitalization rates are not necessarily those with the highest risk of death. This pattern suggests that factors related to the quality of care, the speed of access to services, and clinical conditions at the time of admission may play a more decisive role in infant mortality from pneumonia, highlighting weaknesses that are not captured by hospitalization alone.

The findings show significant variation in hospitalization rates for pneumonia among municipalities and regions in Paraná, possibly associated with the availability of health resources and local environmental conditions[15]. Factors such as health service infrastructure and access to care directly influence hospitalization and mortality rates, contributing to the maintenance of regional inequalities[16].

The results of this study are corroborated by evidence of a reduction in pneumonia hospitalization rates, from 25 to 13.83 hospitalizations per thousand children between 2000 and 2019, respectively. However, despite the overall decline, regions with high hospitalization rates were identified in the South, and clusters with low rates in the Northeast, indicating that better socioeconomic indicators do not eliminate unequal spatial patterns[17]. These findings reinforce the importance of geospatial analysis to identify priority areas for intervention.

In this context, investigations into COVID-19 hospitalizations in children and adolescents also pointed to higher death rates in more vulnerable populations, such as indigenous children, children under two years of age, and residents of geopolitically disadvantaged regions, highlighting the influence of unequal access to health services on the severity of outcomes[18]. Thus, the identification of spatial clusters is a strategic tool for targeting interventions to reduce infant mortality[19].

The Northwest, West, and Midwest regions had higher concentrations of cases, possibly associated with restricted access to health services and socioeconomic inequalities[20]. Rural areas and areas far from urban centers tend to face greater barriers to care, which may partly explain the high hospitalization rates observed in these regions, ranging from 72.61 to 144.82 per thousand live births, with peaks reaching 318.22. In contrast, the Metropolitan, North, Southeast, and Central-East regions, with lower rates (ranging from 12.92 to 36.41), may be in contexts with higher primary care coverage, better hospital infrastructure, and a greater presence of trained professionals.

In addition to these factors, environmental and seasonal conditions significantly affect the incidence of respiratory diseases in children. A national study reported an increase in pneumonia cases during winter and a decrease in summer, associated with climatic conditions that compromise airway defenses. In Paraná, where the climate is variable, practices such as the use of wood-burning stoves, influenced by cultural and economic factors, are still common. In addition to the large number of fires, carbon monoxide emissions pose a risk to respiratory health[21].

In northern Brazil, a distinct seasonal pattern was observed, with less influence of winter on hospitalization rates, in contrast to the present study, which reports a stronger association with cold and dry weather[22].

That said, domestic air pollution from solid fuels and climate-related particulate matter are predisposing factors for hospitalization and mortality from respiratory infections. Respiratory infections remain an important global health problem, especially in certain vulnerable areas[23].

Study limitations

Among the study's limitations, we note the use of secondary data, which are subject to underreporting and incompleteness and may affect the accuracy of the rates analyzed. In addition, because this is an ecological study, it is not possible to establish causal relationships or individual-level inferences. Furthermore, more detailed socioeconomic indicators, such as per capita income, maternal education, and access to basic sanitation, could enrich the analysis, offering a deeper understanding of health inequalities. The absence of similar studies limits comparisons with other Brazilian contexts but highlights the study's innovative nature.

Contributions to practice

Despite the limitations, the findings offer relevant insights into public policy formulation and health management. The evidence can inform targeted actions in priority regions, such as strengthening primary care, intensifying vaccination strategies, training health care teams, and actively monitoring cases. In this context, spatial analysis can inform the territorialized planning of prevention, control, and rapid response actions. Thus, the study contributes significantly to the understanding of regional inequalities in hospitalization and mortality from pneumonia and can assist health managers in developing more effective strategies to improve access to health services.

In addition, the results indicate the need to integrate epidemiological, environmental, and social data in future investigations, incorporating climatic and virological variables, to elucidate the multiple determinants of child morbidity and mortality from pneumonia in the state.

Conclusion

The study highlighted the uneven spatial distribution of hospitalization and mortality rates due to pneumonia in children under one year of age in the state of Paraná. A slight spatial autocorrelation was observed in hospitalization rates, whereas a more pronounced spatial autocorrelation was observed in mortality rates, indicating distinct territorial clusters among municipalities. No significant spatial correlation was identified between hospitalization and mortality rates, indicating that areas with higher hospitalization rates do not necessarily correspond to higher mortality risks. The identification of spatial clusters contributes to the understanding of the territorial patterns of this child health condition.

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Authors' contribution

Conception and design of the study or analysis and interpretation of data**: Oliveira LM, Piran CMG, Mori MM.** Writing of the manuscript or critical revision of intellectual content**;** Final approval of the version to be published; Responsibility for all aspects of the text, ensuring the accuracy and integrity of any part of the manuscript**: Oliveira LM, Piran CMG, Mori MM, Moraes LFS, Cargnin AVE, Sanches RCN, Furtado MD**.

Data availability

The authors declare that the data used in this study are in the public domain and are available in the Live Birth Information System. The processed data and maps produced can be requested from the corresponding author.

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