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CHILDHOOD ASTHMA IN COASTAL-INDUSTRIAL CITIES: THE INFLUENCE OF ATMOSPHERIC POLLUTANTS

ASMA INFANTIL EM CIDADES COSTEIRO-INDUSTRIAIS: A INFLUÊNCIA DOS POLUENTES ATMOSFÉRICOS

ASMA INFANTIL EN CIUDADES COSTERAS-INDUSTRIALES: LA INFLUENCIA DE LOS CONTAMINANTES ATMOSFÉRICOS

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ABSTRACT

Asthma is one of the most prevalent chronic respiratory diseases in childhood, representing a major global public health challenge. It results from complex interactions between genetic predisposition and environmental factors, particularly exposure to air pollutants. This study aimed to review the scientific evidence on the pathophysiology, clinical manifestations, and environmental determinants of childhood asthma, emphasizing its relationship with atmospheric pollution in Santos, São Paulo. A narrative literature review was conducted, complemented by secondary epidemiological data from DATASUS, CETESB, and municipal epidemiological bulletins. The analysis integrated international and national findings, highlighting the influence of fine particulate matter ($PM_{2.5}$ and PM_{10}) and ozone (O_3) on the frequency and severity of asthma exacerbations. Evidence indicates that air pollution acts as a major aggravating factor, contributing to higher rates of hospitalization and decreased quality of life in children. The study reinforces the importance of preventive environmental policies and continuous monitoring of air quality to mitigate the burden of pediatric asthma.

Keywords: Asthma. Air Pollution. Childhood. Respiratory Health. Environmental Epidemiology.

RESUMO

A asma é uma das doenças respiratórias crônicas mais prevalentes na infância, representando um importante desafio global de saúde pública. Resulta de interações complexas entre predisposição genética e fatores ambientais, particularmente a exposição a poluentes atmosféricos. Este estudo teve como objetivo revisar as evidências científicas sobre a fisiopatologia, as manifestações clínicas e os determinantes ambientais da asma infantil, enfatizando sua relação com a poluição atmosférica em Santos, São Paulo. Foi realizada uma revisão narrativa da literatura, complementada por dados epidemiológicos secundários do DATASUS, da CETESB e de boletins epidemiológicos municipais. A análise integrou achados nacionais e internacionais, destacando a influência do material particulado fino ($PM_{2.5}$ e PM_{10}) e do ozônio (O_3) na frequência e na gravidade das

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exacerbações asmáticas. As evidências indicam que a poluição do ar atua como um importante fator agravante, contribuindo para maiores taxas de hospitalização e redução da qualidade de vida em crianças. O estudo reforça a importância de políticas ambientais preventivas e do monitoramento contínuo da qualidade do ar para mitigar o impacto da asma pediátrica.

Palavras-chave: Asma. Poluição do Ar. Infância. Saúde Respiratória. Epidemiologia Ambiental.

RESUMEN

El asma es una de las enfermedades respiratorias crónicas más prevalentes en la infancia y representa un importante desafío mundial de salud pública. Resulta de interacciones complejas entre la predisposición genética y factores ambientales, particularmente la exposición a contaminantes atmosféricos. Este estudio tuvo como objetivo revisar la evidencia científica sobre la fisiopatología, las manifestaciones clínicas y los determinantes ambientales del asma infantil, enfatizando su relación con la contaminación atmosférica en Santos, São Paulo. Se realizó una revisión narrativa de la literatura, complementada con datos epidemiológicos secundarios de DATASUS, CETESB y boletines epidemiológicos municipales. El análisis integró hallazgos nacionales e internacionales, destacando la influencia del material particulado fino ($PM_{2.5}$ y PM_{10}) y el ozono (O_3) en la frecuencia y gravedad de las exacerbaciones asmáticas. La evidencia indica que la contaminación del aire actúa como un importante factor agravante, contribuyendo a mayores tasas de hospitalización y a una disminución de la calidad de vida en niños. El estudio refuerza la importancia de políticas ambientales preventivas y del monitoreo continuo de la calidad del aire para mitigar la carga del asma pediátrica.

Palabras clave: Asma. Contaminación del Aire. Infancia. Salud Respiratoria. Epidemiología Ambiental.

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1 INTRODUCTION

Asthma is a chronic inflammatory disease of the airways and one of the most common causes of respiratory morbidity in childhood. It is characterized by airway hyperresponsiveness, mucus hypersecretion, and reversible airflow obstruction, leading to symptoms such as wheezing, cough, and dyspnea (Djukanovic et al., 2019). The condition arises from multifactorial interactions involving genetic predisposition, immune mechanisms, and environmental exposures, particularly to air pollutants such as particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), and ozone (O_3). These pollutants trigger inflammatory and oxidative processes that exacerbate bronchial reactivity and worsen asthma control in children (Hosoki et al., 2023).

Globally, asthma affects more than 300 million individuals, with increasing incidence in urban and industrialized areas (World Health Organization, 2023). In Brazil, it remains one of the leading causes of pediatric hospitalization within the Unified Health System (SUS), with approximately 350,000 admissions per year (SITHESCOM, 2023). The *International Study of Asthma and Allergies in Childhood* (ISAAC) reported that Brazil ranks among the countries with the highest prevalence rates, averaging 20% in children and adolescents (Silva, 2018).

Environmental determinants play a key role in asthma pathogenesis and exacerbation. Children are particularly vulnerable due to their developing respiratory and immune systems, higher ventilation rate relative to body weight, and increased time spent outdoors (Arruda et al., 2021). In coastal cities such as Santos (São Paulo State), vehicular emissions, port activities, and climatic conditions favor high concentrations of air pollutants, which correlate with increased asthma symptoms and hospital admissions. Understanding these interactions is crucial for guiding preventive strategies and public health interventions.

This article reviews the pathophysiological mechanisms, clinical characteristics, and environmental triggers of childhood asthma, integrating current evidence with epidemiological trends observed in Santos.

Understanding the interplay between environmental pollutants and asthma outcomes is essential to improving pediatric respiratory health and guiding evidence-based policies. Therefore, this study aims to provide an updated review of the pathophysiology, prevalence, and clinical manifestations of childhood asthma; to evaluate the impact of key air pollutants such as $PM_{2.5}$, PM_{10}, and O_3 on disease exacerbations and hospitalizations; and to integrate

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national and local epidemiological data, with particular focus on the environmental and public health context of Santos and other urban-industrial regions in Brazil.

This study aims to provide an integrative understanding of childhood asthma by reviewing its pathophysiological mechanisms, clinical characteristics, and key environmental triggers. Specifically, it seeks to describe the biological processes underlying airway inflammation and hyperresponsiveness in children; outline the principal clinical manifestations and associated comorbidities; examine how atmospheric pollutants contribute to the frequency and severity of asthma exacerbations; and integrate current scientific evidence with epidemiological trends observed in Santos, thereby contextualizing the influence of air quality on pediatric asthma within an urban coastal environment.

2 METHODS

This was a narrative literature review complemented by an epidemiological overview of secondary data from official sources. The methodological approach followed the integrative review framework described by Mendes et al. (2008), allowing for synthesis of empirical and theoretical evidence.

2.1 DATA SOURCES AND SEARCH STRATEGY

A comprehensive search was conducted between January and July 2025 using the databases PubMed/MEDLINE, SciELO, Scopus, Web of Science, Google Scholar, and the CAPES Portal of Journals. Additionally, official documents and clinical guidelines were reviewed, including the *Global Initiative for Asthma* (GINA, 2024), *World Health Organization* (WHO, 2023) reports, and national epidemiological bulletins from the Municipal Health Department of Santos and CETESB (Environmental Company of São Paulo State, 2023).

Controlled descriptors (MeSH and DeCS terms) combined in English and Portuguese included: “asthma,” “childhood asthma,” “air pollution,” “respiratory health,” “pediatric hospitalization,” and “environmental exposure.” Boolean operators (“AND,” “OR,” “NOT”) were used to refine the searches.

2.2 INCLUSION AND EXCLUSION CRITERIA

Included documents comprised original articles, systematic and integrative reviews, and official reports published between 2010 and 2025 in English, Portuguese, or Spanish. Studies focusing on asthma in children and adolescents (0–18 years) and its environmental

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or clinical determinants were included. Excluded were experimental animal studies, adult-only populations, duplicate publications, and papers lacking methodological rigor.

2.3 DATA ANALYSIS

Selected sources were categorized by thematic axis: (i) prevalence and risk factors; (ii) pathophysiology and environmental triggers; (iii) comorbidities and quality of life; and (iv) diagnosis, management, and preventive strategies. Epidemiological indicators from DATASUS (hospital admissions by ICD-10: J45–J46) and CETESB (air pollutant concentrations for $PM_{2.5}$, PM_{10}, NO_2, and O_3) were descriptively analyzed to illustrate the relationship between air quality and respiratory morbidity in children aged 0–12 years in Santos.

Descriptive statistics and comparative trends were represented graphically to highlight seasonal variations and pollutant–hospitalization correlations.

3 RESULTS

Table 1 summarizes the annual mean concentrations of $PM_{2.5}$, PM_{10} and O_3 measured at CETESB monitoring stations (Ponta da Praia and Boqueirão), together with the absolute number of pediatric respiratory hospitalizations (ICD-10 J45–J46) and the calculated hospitalization rates for children aged 0–12 years in Santos (2018–2022). Rates were calculated per 100,000 population using municipal age-group estimates from the Boletim Epidemiológico de Santos. Data sources: CETESB (air quality), DATASUS/TABNET (hospitalizations), and the municipal epidemiological bulletin.

Table 1

Mean annual pollutant concentrations (µg/m³) and pediatric hospitalization counts and rates (per 100,000 children 0–12 years) in Santos, 2018–2022. Population for rate calculation: estimated from municipal age-group distribution (Boletim Epidemiologico de Santos). The ecological design and aggregated counts prevent individual-level causal inference

Year	PM2.5 (µg/m³)	PM10 (µg/m³)	O3 (µg/m³)	Hospitalizations (n)	Rate (/100,000)
2018	25.48	41.96	44.22	340	587.0
2019	21.04	39.43	43.63	202	348.7
2020	23.03	38.91	44.03	54	93.2
2021	22.34	40.21	51.05	119	205.4

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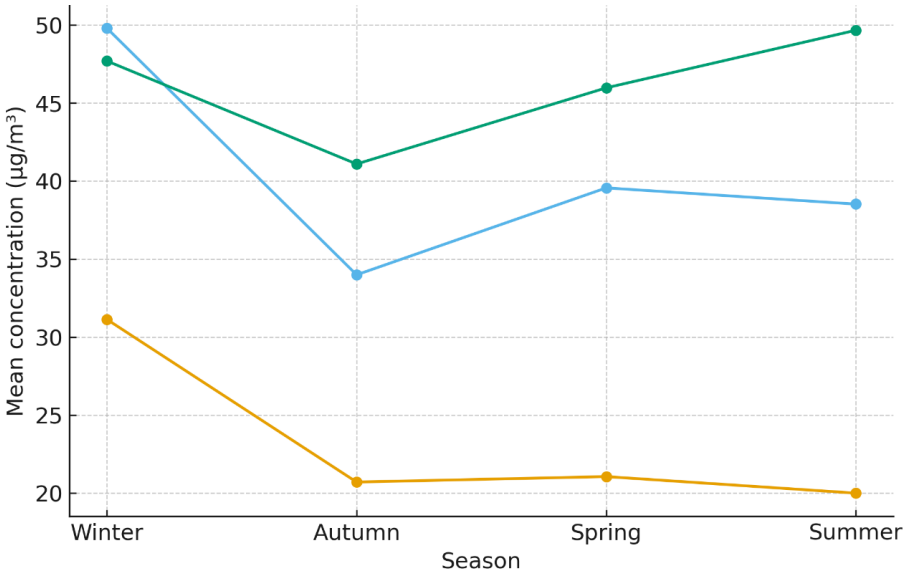
2022	24.24	41.80	47.59	280	483.4

The figure 1 illustrates the seasonal mean concentrations (winter, autumn, spring, summer) for $PM_{2.5}$, PM_{10} and O_3 aggregated across the 2018–2022 period, using CETESB monitoring data as reported in the thesis and the State air-quality report. Seasonal averages are used here as a proxy to illustrate temporal variability and potential overlap with the seasonal pattern of pediatric respiratory events described in the epidemiological bulletin.

Figure 1

Seasonal variation of air pollutants ($PM_{2.5}$, PM_{10} and O_3) by season in Santos (2018–2022)



Seasonal mean concentrations (µg/m³) of $PM_{2.5}$, PM_{10} and O_3 in Santos, 2018–2022 (seasons: winter, autumn, spring, summer). Data sources: CETESB (monitoring stations Ponta da Praia and Boqueirão), aggregated in the thesis. Note: monthly series were not provided in the files; seasonal aggregation is used as an illustrative proxy.

Winter shows the highest mean $PM_{2.5}$ and PM_{10} levels, consistent with the observed increase in pediatric respiratory events during the cold season.

The scatter plot presents annual mean $PM_{2.5}$ against annual counts of pediatric respiratory hospitalizations (ICD-10 J45–J46). A linear trendline is included and the Pearson correlation coefficient is annotated to quantify the strength of association using the aggregated annual data available from the thesis and municipal reports. Annual mean $PM_{2.5}$ (µg/m³) versus pediatric respiratory hospitalizations (n) in Santos, 2018–2022. Pearson

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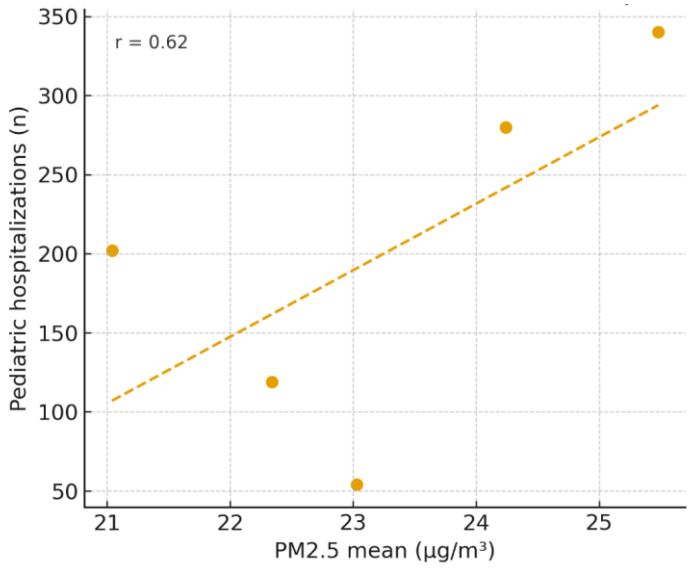
correlation coefficient (annual values): r = 0.62. Data sources: CETESB and Boletim Epidemiológico / DATASUS.There is a moderate positive correlation between annual $PM_{2.5}$ means and pediatric hospitalizations (r ≈ 0.62), suggesting that years with higher average $PM_{2.5}$ coincide with increased pediatric respiratory admissions (Figure 2).

Given the small number of annual observations (n = 5), the correlation analysis is exploratory. Although the Pearson coefficient indicates a moderate positive association (r = 0.62), this correlation does not reach statistical significance (p > 0.05). Therefore, the result is interpreted as descriptive and hypothesis-generating rather than inferential.

Figure 2

Correlation between $PM_{2.5}$ concentration and pediatric hospitalizations in Santos (2018–2022)



Bar chart of total pediatric respiratory hospitalizations per year (ICD-10 J45–J46) as extracted from the municipal bulletin and thesis dataset (Figure 3). This panel is intended to show temporal trends (including the pandemic-related drop in 2020 and the rebound thereafter). Total pediatric respiratory hospitalizations (n) in Santos by year, 2018–2022. . Hospitalizations fell markedly in 2020 (likely reflecting pandemic-related mitigation measures) and rebounded in 2021–2022; these temporal changes align with concurrent fluctuations in pollutant concentrations and seasonal patterns.

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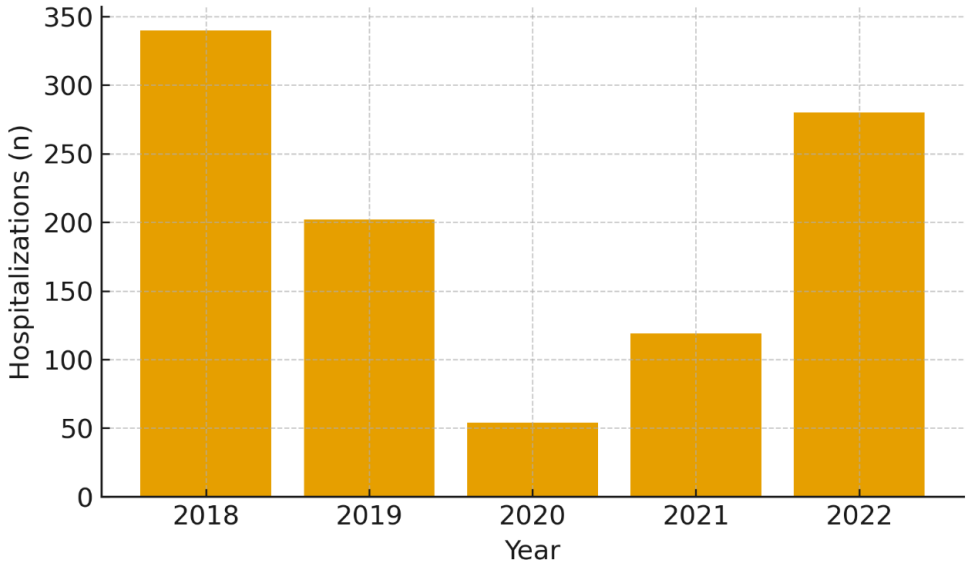
Figure 3

Annual pediatric respiratory hospitalizations in Santos (2018–2022)



4 DISCUSSION

4.1 REVIEW OF PATHOPHYSIOLOGY, PREVALENCE, AND CLINICAL MANIFESTATIONS OF CHILDHOOD ASTHMA

Asthma in childhood is a multifactorial disease involving genetic predisposition and immune dysregulation triggered by environmental exposures. The reviewed literature confirms that airway inflammation, hyperresponsiveness, and remodeling are key mechanisms leading to recurrent wheezing, cough, and dyspnea episodes in pediatric populations (Djukanovic et al., 2019; Hosoki et al., 2023). Cytokine-mediated eosinophilic infiltration, oxidative stress, and mucus hypersecretion contribute to chronic airway damage and impaired lung function. These mechanisms explain the variability in symptom severity and treatment response among children (Januskevicius et al., 2022).

Epidemiologically, childhood asthma remains one of the most frequent chronic respiratory conditions worldwide, with prevalence estimates exceeding 10% in many urban centers (World Health Organization, 2023). The International Study of Asthma and Allergies in Childhood (ISAAC) ranked Brazil among the countries with the highest prevalence, averaging 20% in children and adolescents (Silva, 2018). According to data summarized in the doctoral thesis, asthma is also a leading cause of pediatric hospitalization in the Brazilian Unified Health System (SUS), representing a substantial share of annual admissions (Veloso, 2025).

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Comorbidities such as allergic rhinitis, dermatitis, and obesity were described as aggravating factors, associated with poor disease control and increased severity (Arruda et al., 2021). The use of spirometry and peak expiratory flow monitoring was emphasized as an essential diagnostic and follow-up tool, as reduced pulmonary function coincides with environmental pollutant peaks in several urban regions (Gouveia et al., 2018).

4.2 INFLUENCE OF $PM_{2.5}$, PM_{10}, AND O_3 ON ASTHMA EXACERBATIONS AND HOSPITALIZATIONS IN PEDIATRIC POPULATIONS

The reviewed evidence consistently demonstrates the aggravating role of air pollutants—particularly fine particulate matter ($PM_{2.5}$ and PM_{10}) and ozone (O_3)—on asthma morbidity. Exposure to these pollutants enhances bronchial inflammation, increases airway hyperreactivity, and promotes oxidative stress, thereby intensifying the risk of acute exacerbations (Manisalidis et al., 2020; Hosoki et al., 2023).

In Brazilian urban environments, time-series studies confirm a direct association between short-term increases in pollutant concentrations and pediatric hospital admissions for respiratory diseases (Gouveia et al., 2018; Mendes & Rocha, 2021). In Santos, the local data described in the thesis revealed temporal coincidence between higher $PM_{2.5}$ levels and increases in emergency consultations and hospitalizations for asthma, with greater frequency during the winter months, when pollutant dispersion is limited (Veloso, 2025).

Spatial differentiation was also reported: children living near port and heavy-traffic areas presented a higher frequency of respiratory symptoms, reduced spirometric indices, and recurrent exacerbations compared to those in less polluted districts (Veloso, 2025). The results are consistent with international findings showing that exposure to urban particulate matter contributes to increased prevalence and severity of pediatric asthma (Liu et al., 2022; WHO, 2021).

Descriptive epidemiological analysis from the UNISANTA expanded study identified more than 1,200 pediatric respiratory hospitalizations between 2016 and 2018 in Santos, corresponding to approximately 18% of all pediatric admissions during the period (Veloso & Duarte, 2018). Although causal coefficients were not calculated, the convergence of seasonal, spatial, and pollutant data supports the inference of a strong environmental component influencing asthma exacerbations in this population (Veloso, 2025).

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4.3 INTEGRATION OF NATIONAL AND LOCAL DATA: IMPLICATIONS FOR SANTOS AND SIMILAR URBAN-INDUSTRIAL REGIONS

The integration of national literature with the local data from Santos indicates a coherent pattern between air quality deterioration and pediatric respiratory morbidity. National epidemiological studies describe short-term increases in asthma hospitalizations following peaks in particulate matter and ozone (Mendes & Rocha, 2021; Gouveia et al., 2018), findings that align with the descriptive analyses from CETESB and DATASUS included in the thesis.

Although the Santos dataset was primarily ecological and descriptive, its temporal alignment with pollutant concentration curves corroborates the broader scientific consensus on the environmental aggravation of asthma (Veloso, 2025). The results reinforce the need for integrated urban and health policies that address both emission sources—particularly vehicular and port activities—and public health surveillance (Veloso & Duarte, 2018; WHO, 2021).

The synthesis suggests that preventive environmental monitoring, early public alerts on poor-air-quality days, and targeted pediatric education campaigns could mitigate exposure and reduce asthma-related morbidity in coastal cities with similar industrial profiles (Veloso, 2025).

4.4 PATHOPHYSIOLOGICAL AND EPIDEMIOLOGICAL CONSIDERATIONS

The convergence between mechanistic and epidemiological evidence supports a biologically plausible link between air pollution and childhood asthma. The airway inflammation and oxidative stress described in controlled studies correspond to the seasonal and geographic patterns observed in polluted coastal cities (Djukanovic et al., 2019; Hosoki et al., 2023). Despite the descriptive nature of local analyses, the consistent temporal association between pollutant peaks and symptom exacerbations strengthens causal inference, particularly when supported by objective pulmonary function data (Veloso, 2025).

The prevalence reported in Brazilian children remains among the highest globally, emphasizing the need for improved asthma control programs and the integration of environmental surveillance into clinical management (Silva, 2018; Arruda et al., 2021).

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4.5 ENVIRONMENTAL POLLUTANTS AND PEDIATRIC EXACERBATIONS

The thesis and associated articles align with global reviews indicating that even modest increases in $PM_{2.5}$ and O_3 are sufficient to trigger acute asthma crises in susceptible children (Manisalidis et al., 2020; Liu et al., 2022). The strength of this research lies in the linkage between environmental and clinical datasets, combining CETESB monitoring records with pediatric hospital data.

However, methodological limitations must be acknowledged. The ecological design limits individual-level inference, and residual confounding by viral epidemics, temperature, or socioeconomic factors cannot be excluded (Gouveia et al., 2018; Mendes & Rocha, 2021). Age-related differences in hospitalization behavior may also affect rate comparisons (Veloso, 2025). Nevertheless, the alignment between higher pollutant concentrations and increased hospitalizations across multiple sources suggests a robust and consistent pattern requiring public-health action.

4.6 PUBLIC-HEALTH IMPLICATIONS FOR SANTOS AND SIMILAR REGIONS

The integrated evidence underscores the necessity for preventive and intersectoral strategies. Reducing vehicular and port emissions is fundamental to mitigating exposure in pediatric populations (Veloso & Duarte, 2018). Strengthening CETESB's monitoring network and integrating meteorological data into public alerts could reduce acute exposure events (WHO, 2021).

Local health services should incorporate routine spirometric surveillance for children with recurrent symptoms, allowing correlation with environmental indices and early therapeutic adjustment (Veloso, 2025). Educational initiatives aimed at parents, schools, and health professionals are essential to improve recognition and management of environmental triggers.

Finally, future studies should pursue age-stratified and longitudinal designs to better quantify risk differentials and evaluate intervention effectiveness (Mendes & Rocha, 2021; Gouveia et al., 2018).

5 CONCLUSION

The findings from this narrative review and descriptive synthesis reinforce that childhood asthma remains a major global and national public-health concern, deeply influenced by environmental exposures. Evidence from international and Brazilian literature

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demonstrates that fine particulate matter ($PM_{2.5}$ and PM_{10}) and ozone (O_3) act as significant aggravating factors, increasing both the frequency and severity of asthma exacerbations in children.

In Santos, São Paulo, descriptive analyses using secondary data from CETESB and DATASUS revealed seasonal peaks in pediatric hospitalizations that coincide with higher pollutant concentrations, particularly during the winter months. These temporal patterns mirror national and global trends, supporting the hypothesis that air pollution contributes to respiratory morbidity in coastal urban regions.

Although the data analyzed are primarily ecological and cannot establish causality at the individual level, the convergence of epidemiological, pathophysiological, and clinical evidence provides a coherent and biologically plausible framework linking air pollution and pediatric asthma.

From a public-health perspective, the study highlights the urgent need for preventive and intersectoral actions, including: (i) strengthening air-quality monitoring and emission control in port and traffic areas; (ii) integrating environmental data into municipal health surveillance systems; (iii) promoting public education about pollution-related respiratory risks; and (iv) implementing early-warning systems for poor-air-quality days to protect vulnerable pediatric populations.

Finally, future research should expand toward longitudinal and spatially resolved designs to quantify risk differentials by age, socioeconomic status, and exposure intensity. Such approaches will allow evidence-based policy formulation aimed at reducing the burden of childhood asthma in Santos and comparable urban-industrial settings.

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