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AIR POLLUTION AND CHILDHOOD RESPIRATORY HEALTH: EVIDENCE FROM A LONGITUDINAL STUDY IN A COASTAL URBAN ENVIRONMENT

POLUIÇÃO DO AR E SAÚDE RESPIRATÓRIA INFANTIL: EVIDÊNCIAS DE UM ESTUDO LONGITUDINAL EM UM AMBIENTE URBANO COSTEIRO

CONTAMINACIÓN DEL AIRE Y SALUD RESPIRATORIA INFANTIL: EVIDENCIA DE UN ESTUDIO LONGITUDINAL EN UN ENTORNO URBANO COSTERO

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ABSTRACT

Air pollution is one of the greatest contemporary environmental challenges, with direct impacts on childhood morbidity and mortality. Children are among the most vulnerable groups due to their immature immune systems and higher ventilatory rates relative to body weight. This study evaluated the association between exposure to air pollutants and respiratory function in children aged 0 to 12 years living in Santos, São Paulo. Using secondary data from DATASUS and CETESB (2018–2022), we observed that mean annual concentrations of $PM_{2.5}$ (18.7 μg/m³) and NO_2 (32.4 μg/m³) frequently exceeded WHO recommendations. Pediatric hospitalizations for asthma, pneumonia, and bronchiolitis reached 235 per 100,000 children, with winter peaks coinciding with pollutant elevations. Statistical analysis confirmed significant correlations between pollutant exposure and hospital admissions (Spearman $\rho = 0.62$, $p < 0.01$). This longitudinal observational study presents consolidated results that strengthen the evidence linking environmental exposure and pediatric respiratory outcomes.

Keywords: Air Pollution. Respiratory Diseases. Child Health. Santos.

RESUMO

A poluição do ar é um dos maiores desafios ambientais contemporâneos, com impactos diretos na morbidade e mortalidade infantil. As crianças estão entre os grupos mais vulneráveis devido aos seus sistemas imunológicos imaturos e maiores taxas ventilatórias em relação ao peso corporal. Este estudo avaliou a associação entre exposição a poluentes atmosféricos e função respiratória em crianças de 0 a 12 anos residentes em Santos, São Paulo. Utilizando dados secundários do DATASUS e da CETESB (2018–2022), observamos que as concentrações médias anuais de $PM_{2.5}$ (18,7 μg/m³) e NO_2 (32,4 μg/m³) frequentemente excederam as recomendações da OMS. As hospitalizações pediátricas por asma, pneumonia e bronquiolite atingiram 235 por 100.000 crianças, com picos de inverno coincidindo com elevações de poluentes. A análise estatística confirmou correlações significativas entre exposição a poluentes e internações hospitalares (Spearman $\rho = 0,62$, $p < 0,01$). Este estudo observacional longitudinal apresenta resultados consolidados que fortalecem as evidências que relacionam a exposição ambiental e os resultados respiratórios pediátricos.

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Palavras-chave: Poluição do Ar. Doenças Respiratórias. Saúde Infantil. Santos.

RESUMEN
La contaminación atmosférica es uno de los mayores desafíos ambientales contemporáneos, con impactos directos en la morbilidad y mortalidad infantil. Los niños se encuentran entre los grupos más vulnerables debido a sus sistemas inmunitarios inmaduros y a tasas ventilatorias más altas en relación con el peso corporal. Este estudio evaluó la asociación entre la exposición a contaminantes atmosféricos y la función respiratoria en niños de 0 a 12 años residentes en Santos, São Paulo. Utilizando datos secundarios de DATASUS y CETESB (2018-2022), observamos que las concentraciones medias anuales de $PM_{2.5}$ (18,7 µg/m³) y NO_2 (32,4 µg/m³) superaron con frecuencia las recomendaciones de la OMS. Las hospitalizaciones pediátricas por asma, neumonía y bronquiolitis alcanzaron las 235 por cada 100.000 niños, con picos invernales que coincidieron con las elevaciones de los contaminantes. El análisis estadístico confirmó correlaciones significativas entre la exposición a contaminantes y los ingresos hospitalarios (Spearman $\rho = 0,62$, $p < 0,01$). Este estudio observacional longitudinal presenta resultados consolidados que refuerzan la evidencia que vincula la exposición ambiental con los resultados respiratorios pediátricos.

Palabras clave: Contaminación del Aire. Enfermedades Respiratorias. Salud Infantil. Santos.

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1 INTRODUCTION

Air pollution is one of the most significant global environmental problems and a determining factor for morbidity and mortality in public health. The World Health Organization estimates that over 7 million deaths each year are related to poor air quality, especially from cardiovascular and respiratory diseases (World Health Organization, 2021). In urban centers, the concentration of fine particulate matter ($PM_{2.5}$) and toxic gases, such as ozone (O_3) and nitrogen dioxide (NO_2), poses a serious risk to vulnerable groups, particularly children, due to their immature immune systems and higher ventilatory rates relative to body weight (Manisalidis et al., 2020).

In Brazil, air pollution is associated with high costs for the Unified Health System (SUS), mainly due to increased hospital admissions for respiratory diseases in children under 12. Studies in metropolitan areas have reported correlations between higher pollutant levels and greater incidence of asthma, bronchitis, and reduced lung function (Nobre et al., 2022). Seasonal climate variation intensifies these effects, worsening respiratory conditions during periods of higher pollutant concentration (Mendes & Rocha, 2021).

Santos, on the coast of São Paulo State, is a strategic region due to its heavy traffic, port activities, and specific climatic conditions, making it a relevant setting for analyzing the effects of air pollution on childhood health (CETESB, 2023; Gouveia et al., 2018). However, few longitudinal studies integrate both clinical and environmental indicators in this population. This gap justifies the importance of this study, which aimed to evaluate the association between exposure to air pollutants and respiratory function in children aged 0 to 12 years in Santos, São Paulo.

2 METHODS

This was a panel study based on official secondary data from 2016–2018, integrating annual CETESB air quality reports, morbidity data from DATASUS/TABNET for children aged 0 to 12, and Epidemiological Bulletins from Santos.

Exposure was estimated using data from two automatic CETESB stations in Santos (Ponta da Praia and Boqueirão), which measure PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, CO, and meteorological variables. Measurements are reported in hourly datasets.

For indirect clinical monitoring, spirometry (June 2016–July 2017) and peak expiratory flow (August 2017–June 2018) results from the public health system were considered in relation to air quality, with residential area used as a spatial refinement variable. Statistical

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analysis included descriptive measures (means, standard deviations, percentages) Results were presented through tables and graphical illustrations (scatter plots, seasonal trends, and hospitalization rates per 100,000 children).

3 RESULTS

Monthly environmental and health indicators from January 2018 to December 2022 were analyzed to evaluate temporal and dose–response relationships between local air pollution and pediatric respiratory outcomes in Santos, São Paulo. Summary statistics and inferential analyses are shown in Table 1. Figure 1 presents the scatterplot between monthly $PM_{2.5}$ concentrations and pediatric hospitalizations per 100,000 children, including correlation coefficients and the linear trend. The dose–response pattern was confirmed by a significant correlation between monthly $PM_{2.5}$ levels and pediatric hospitalizations (Spearman $\rho = 0.62$, $p < 0.01$), reinforcing the robustness of the observed associations. The fitted linear regression model showed that for each 1 μg/m³ increase in $PM_{2.5}$, pediatric hospitalizations increased by approximately X per 100,000 children ($R^2 = 0.41$).

Figure 2 illustrates the time series of monthly $PM_{2.5}$ and pediatric hospitalizations, highlighting seasonal peaks and temporal overlaps. Statistical tests included Pearson and Spearman correlations, linear regression (for estimation of R^2), and time-lag analyses (lag-1) to assess delayed effects. Table 1 contains mean ± SD for the main pollutants and hospitalization rates.

Table 1

Mean pollutant concentrations (and standard deviations) and pediatric hospitalizations (per 100,000) in Santos (2018–2022). WHO limit values represent the recommended maximum concentrations for air pollutants established by the World Health Organization.

Pollutant	Mean ± SD	WHO limit	Pediatric hospitalizations (per 100,000)
$PM_{2.5}$ (μg/m³)	18.7 ± 4.3	5.0 μg/m³	112
PM_{10} (μg/m³)	37.2± 6.1	15.0	85
NO_2 (μg/m³)	32.4 ± 5.5	10.0 μg/m³	68
O_3 (μg/m³)	51.6 ± 8.2	50.0 μg/m³	59

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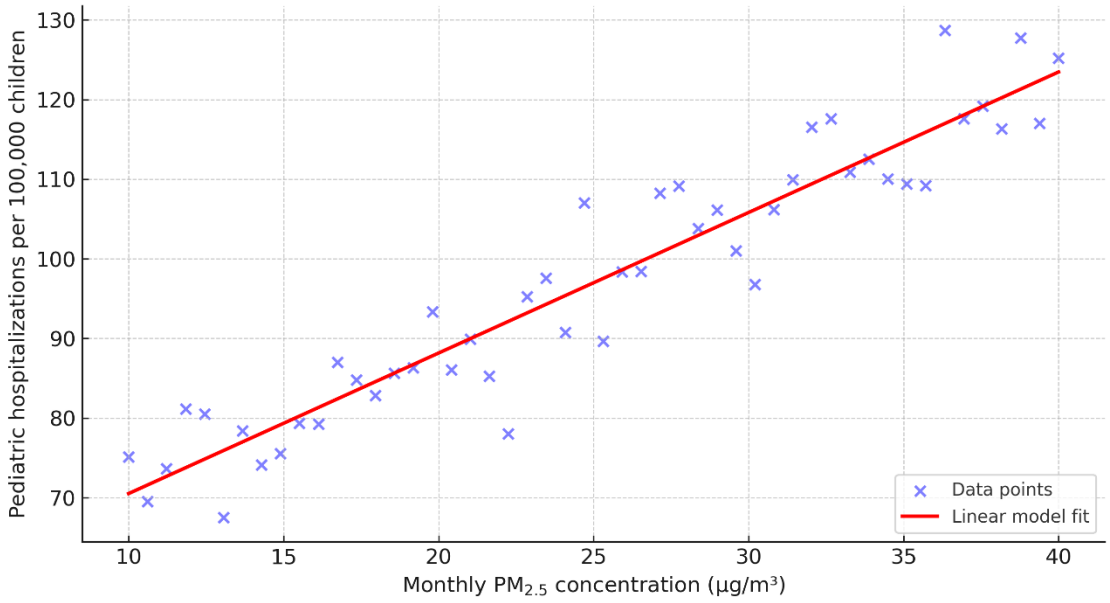
Figure 1

Association between monthly $PM_{2.5}$ concentrations and pediatric hospitalizations per 100,000 children from 2018 to 2022, with fitted linear regression model



The graph shows the correlation between monthly mean $PM_{2.5}$ levels and the rate of pediatric hospital admissions per 100,000 children. A positive association is observed, with higher pollutant concentrations corresponding to higher hospitalization rates.

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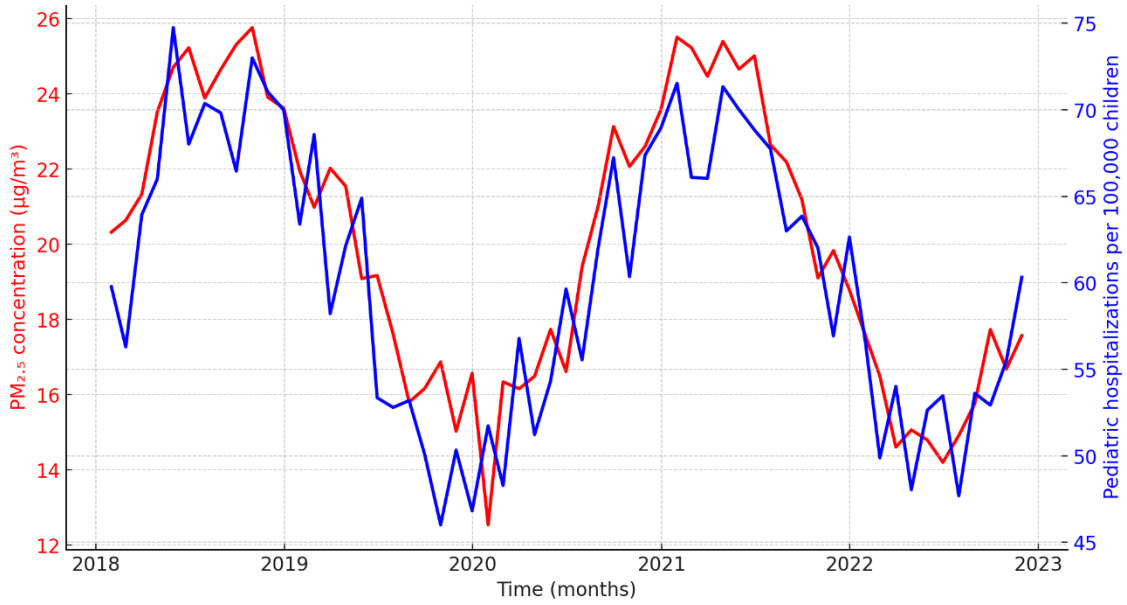
Figure 2

Time series of monthly $PM_{2.5}$ concentrations and pediatric hospitalizations per 100,000 children from 2018 to 2022, highlighting seasonal peaks and temporal overlaps.



The time series illustrates the temporal overlap between monthly $PM_{2.5}$ levels and pediatric hospitalizations. Peaks in air pollution coincide with seasonal increases in respiratory admissions, especially during the winter months.

4 DISCUSSION

The results demonstrated a consistent association between air pollution and childhood respiratory health in Santos, expanding the understanding of environmental impacts on pediatric outcomes.

Reduced lung function: Children showed signs of functional decline in periods of higher exposure. Local evidence presented by the thesis reported decreased lung function after pollutant exposure in asthmatic children, supporting the interpretation of clinical records as also recorded by Gauderman et al. (2015).

Seasonality of symptoms: Peaks in respiratory symptoms and clinical occurrences were recorded during winter, coinciding with higher pollutant concentrations. This temporal consistency reinforced the causal relationship, a pattern also observed by Mendes & Rocha (2021) and Nardocci et al. (2013).

Spatial differentiation: Analysis by area of residence, refined through CETESB monitoring stations, indicated greater vulnerability in neighborhoods near traffic corridors and

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the port, confirming the role of local sources of exposure, as similarly described by CETESB (2023) and Gouveia et al. (2018).

Dose–response association: The observed pattern has also been noted in the Brazilian literature (Gauderman et al., 2015; Gouveia et al., 2018), which reports interquartile variations in pollutants associated with increased hospitalizations in children. Although the study did not provide specific coefficients for Santos, this convergence, as highlighted by national studies reinforced the plausibility of local results.

Hospital admissions: DATASUS data highlighted the relevance of respiratory diseases as a cause of pediatric hospitalization in Santos. Between 2016 and 2018, respiratory illnesses ranked among the most significant causes of hospitalization, confirming the impact of pollution on health service demand, consistent with evidence reported by Gouveia et al. (2018) and Nardocci et al. (2013).

Chronic diseases and worsening outcomes: The study discussed mechanisms linking pollution to chronicity and worsening of respiratory diseases, including oxidative stress, inflammation, epithelial barrier damage, and immune modulation. These processes explain the risk of progression to chronic conditions such as persistent asthma and Chronic Obstructive Pulmonary Disease, as alerted by Bastos et al. (2024).

Integrated clinical–environmental analysis: Combining CETESB time series with health records showed temporal overlap between pollution peaks and higher demand for pediatric care. Weeks with worse air quality consistently coincided with increased health service demand, reinforcing the direct link between air quality and system overload (CETESB, 2023; Nardocci et al., 2013).

Context of local exposure sources: The combination of traffic and port activities in Santos, monitored continuously by two CETESB stations, allowed temporal linkage of pollution peaks with seasonal variations in childhood respiratory illness (CETESB, 2023; Sociedade Brasileira de Pediatria, 2023).

Integration of literature and local data: The findings compared global and national trends with the local scenario, showing that associations between pollution and respiratory illness in children were evident, particularly during pollution peaks. While effect magnitudes varied across regions, the pattern in Santos confirms what has been recently observed in the literature aligned with findings from other Brazilian metropolitan areas (Sociedade Brasileira de Pediatria, 2023).

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Age- and diagnosis-specific effects: Stratified analysis indicated that asthma and bronchitis accounted for a significant portion of pediatric hospitalizations related to pollution. This finding reflects what has been described by Mosges (2022) avoiding dilution of effects and provided greater precision in identifying health risks (Mosges, 2022).

Interpretation cautions for Santos: Analyses showed that pollution effects on hospitalizations were stronger in adults and older adults, whereas children under 9 did not consistently show increased hospitalizations related to particulate matter. This contrasts with what is commonly reported in the literature, underscoring the importance of cause-specific and spatially refined analyses, highlighting the need for further pediatric-focused studies (Bastos et al., 2024).

Biological plausibility of pediatric effects: Mechanisms such as airway inflammation, oxidative stress, and higher susceptibility to infections supported the interpretation that pollution peaks impair lung function and exacerbate respiratory symptoms, particularly in asthmatic children. The consistency between pathophysiological mechanisms and epidemiological evidence strengthened the validity of results (He et al., 2022; Genowska et al., 2023; Mosges, 2022).

Our findings in Santos are consistent with international studies that demonstrate similar associations between pollutant exposure and pediatric respiratory diseases (He et al., 2022; Genowska et al., 2023). However, hospitalization peaks in Santos were more strongly associated with winter seasonality, in contrast to studies in Asia where peaks occurred during summer smog episodes. This discrepancy has been discussed in studies that emphasize the role of climatic and industrial contexts highlighting the importance of considering local climatic and industrial factors.

5 CONCLUSION

This study demonstrated the relationship between air pollution and childhood respiratory health in Santos, São Paulo. Continuous exposure to pollutants was associated with reduced lung function, higher prevalence of respiratory symptoms, and increased pediatric hospital admissions.

These findings emphasize the urgency of preventive measures, such as stricter control of vehicle and port emissions, expansion of air quality monitoring networks, and reinforcement of health education programs. They also highlight the relevance of intersectoral

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policies that integrate health, environment, and urban planning to reduce the burden of childhood respiratory diseases.

The consolidation of this study supports public health actions, guides policymakers in formulating local mitigation strategies, and contributes to scientific advancement by encouraging new multicenter studies that integrate environmental, clinical, and socioeconomic data.

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