

Environmental determinants of pneumonia in children: A literature review

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ABSTRAK

Pneumonia masih menjadi salah satu penyebab utama kematian pada anak balita, terutama di negara berpendapatan rendah dan menengah seperti Indonesia. Paparan lingkungan, termasuk polusi udara di dalam dan di luar ruangan, merupakan faktor penting yang berkontribusi terhadap kejadian pneumonia pada anak. Penelitian ini bertujuan untuk mengkaji faktor risiko lingkungan yang berhubungan dengan pneumonia pada anak serta mengidentifikasi variabel yang memiliki dampak terbesar terhadap risiko penyakit tersebut. Penelitian ini menggunakan metode *systematic literature review* dengan mengikuti pedoman PRISMA. Studi yang relevan dari PubMed, Scopus, dan Google Scholar yang dipublikasikan pada tahun 2020–2025 diseleksi menggunakan kata kunci yang berkaitan dengan pneumonia pada anak dan determinan lingkungan. Dari 599 studi yang awalnya teridentifikasi, sebanyak 12 studi memenuhi kriteria inklusi setelah melalui proses penyaringan dan penilaian kualitas menggunakan *Newcastle-Ottawa Scale* dan *AXIS tools*. Hasil penelitian menunjukkan bahwa 75% studi melaporkan adanya determinan lingkungan yang signifikan terhadap kejadian pneumonia. Konsentrasi PM2.5 yang tinggi, partikel ultrahalus, asap biomassa, paparan asap rokok lingkungan, kelembapan rumah tangga, serta ventilasi yang buruk secara konsisten dikaitkan dengan peningkatan risiko pneumonia pada anak. Faktor sosial ekonomi seperti pendapatan rendah, kepadatan hunian, imunisasi yang tidak lengkap, serta tidak diberikannya ASI eksklusif juga meningkatkan kerentanan terhadap penyakit ini. Sebaliknya, ventilasi yang memadai, penggunaan bahan bakar bersih, dan filtrasi udara merupakan faktor protektif. Temuan ini menekankan pentingnya intervensi terpadu antara kesehatan lingkungan dan kesehatan anak. Kebijakan yang mendorong udara bersih, perbaikan kondisi perumahan, serta program kesehatan yang terarah sangat diperlukan untuk menurunkan insiden pneumonia dan meningkatkan derajat kesehatan anak.

Kata kunci: faktor lingkungan, kesehatan masyarakat, kondisi rumah tangga, pneumonia pada anak, polusi udara

ABSTRACT

Pneumonia remains a leading cause of mortality in children under five, especially in low- and middle-income countries such as Indonesia. Environmental exposures, including indoor and outdoor air pollution, are key contributors to childhood pneumonia. This study aims to examine environmental risk factors associated with pneumonia in children and identify the variables with the greatest impact on disease risk. A systematic literature review was conducted following the PRISMA guidelines. Relevant studies from PubMed, Scopus, and Google Scholar published between 2020 and 2025 were screened using keywords related to pediatric pneumonia and environmental determinants. Of 599 studies initially identified, 12 met the inclusion criteria after screening and quality assessment the Newcastle-Ottawa Scale and AXIS tool. Findings indicated that 75% of studies reported significant environmental determinants of pneumonia. Higher concentrations of PM2.5, ultrafine particles, biomass smoke, secondhand tobacco smoke, household humidity, and poor ventilation were consistently linked to increased risk. Socioeconomic factors such as low income, overcrowding, incomplete immunization, and non-exclusive breastfeeding further heightened vulnerability. Protective factors included adequate ventilation, clean fuel use, and air filtration. These results highlight the importance of integrated environmental and child health interventions. Policies promoting clean air, improved housing, and targeted health programs are essential to reduce

pneumonia incidence and improve child health outcomes.

Keywords: *Air pollution, childhood pneumonia, environmental factor, household conditions, public health*

INTRODUCTION

Air pollution is increasingly recognized as a major global environmental health issue that threatens both ecosystems and human well-being. It refers to the accumulation of chemical, physical, or biological agents in indoor or outdoor air that alters the atmosphere's normal composition (World Health Organization [WHO], 2025). Major pollutants such as particulate matter (PM_{2.5}), ozone, nitrogen dioxide, carbon monoxide, and sulfur dioxide are produced by motor vehicles, industrial operations, household fuel use, and forest fires. These pollutants contribute substantially to the global burden of disease and are strongly associated with respiratory and cardiovascular disorders, as well as other adverse health outcomes (WHO, 2025). Each year, indoor and outdoor air pollution are responsible for approximately seven million preventable deaths worldwide, illustrating the urgent need for effective interventions. Approximately 99% of people globally are exposed to air pollution concentrations that exceed the limits set by the World Health Organization, and the heaviest burden occurs in low- and middle- income countries where exposure levels are most severe (WHO, 2025). Because many pollution sources, including fossil fuel combustion, also emit greenhouse gases, air pollution is closely linked to climate change, presenting a dual opportunity to improve public health and mitigate climate impacts concurrently.

Previous studies have consistently demonstrated that exposure to air pollution adversely affects respiratory health. Fine particulate matter has been consistently associated with increased risks of respiratory infections, stroke, cardiovascular disease, and lung cancer. In addition, the continued reliance on solid fuels such as coal, kerosene, and biomass for cooking and heating in open fires or traditional stoves still exposes an estimated 2.4 billion people worldwide to household air pollution (WHO, 2025). Children are among the groups most susceptible to the health impacts of pollution because their bodies are still developing, their immune systems are not yet fully mature, and their longer remaining lifespan raises their overall cumulative exposure risk (Sly & Flack, 2008, as cited in Cortes-Ramirez *et al.*, 2021). Ananda and Budyanra (2024) emphasized that the under-five age range represents a period of rapid growth and immune development that makes young children particularly prone to respiratory infections such as pneumonia.

Several recent studies have demonstrated an association between environmental exposure and pediatric pneumonia. For example, Harnani *et al.* (2020) found that household factors such as poor ventilation, overcrowding, and the use of biomass fuel significantly increase pneumonia incidence among Indonesian children. Consistent with previous evidence, the studies of Bergmann *et al.* (2025) and He *et al.* (2022) demonstrated that transient exposure to ultrafine particles (UFP) and PM_{2.5} markedly increases pediatric hospital admissions due to respiratory infections in both high- and low-income countries. However, despite the abundance of research on environmental pollution and respiratory health, the integration of findings across diverse contexts and methodological approaches remains limited. Most studies focus on isolated environmental exposures rather than evaluating how multiple environmental, social, and behavioral determinants interact to influence childhood pneumonia.

The novelty of this article lies in its comprehensive synthesis of recent global evidence (2020-2025) that examines environmental determinants influencing pneumonia in children under five years of age. Unlike prior studies that examined single variables or localized populations, this literature review integrates findings from various study designs, including cross-sectional, case-control, cohort, and spatial analyses to provide a multidimensional understanding of both outdoor and indoor environmental risk factors. This integrative approach fills the existing research gap by highlighting not only pollutant exposure but also socioeconomic and housing conditions as interacting drivers of pneumonia risk.

In light of the aforementioned factors, the study seeks to address the following research question: Which environmental and socioeconomic factors are most strongly associated with pneumonia cases in children under five years old? The study assumes that exposure to outdoor air pollutants such as PM_{2.5} and ultrafine particles, along with indoor conditions including ventilation quality, humidity levels, and household fuel type, plays a substantial role in shaping pneumonia risk, with socioeconomic inequalities influencing the extent of these effects. The objective of this literature review is to analyze and integrate current research on environmental and socioeconomic contributors to pneumonia in young children, while highlighting the importance of environmental health strategies in reducing child mortality and supporting sustainable health improvements in low- and middle-income countries.

METHODS

This study adopts a systematic literature review approach and was developed in alignment with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Searching for articles was done using three electronic databases: PubMed, Scopus, and Google Scholar. The articles were published between 2020 and 2025. Using Boolean operators, the keywords used combine terms related to pneumonia in children with environmental factors. The keywords are ("pneumonia" OR "lower respiratory infection" OR "LRTI") AND ("children" OR "child" OR "under-five" OR "pediatric") AND ("environmental factors" OR "air pollution" OR "household air pollution" OR "indoor air" OR "ventilation" OR "overcrowding" OR "climate"). The selected articles are limited to the English language and are open access.

There were 599 records found at first, including 199 from PubMed, 200 from Scopus, and 200 from Google Scholar. After removing duplicates with Mendeley, 13 duplicates were removed, leaving 586 records to be screened. During the title and abstract screening stage, 549 articles were not included because they were not relevant (for example, they were not focused on the environment, they were not about childhood pneumonia, or they were not in the right range of publication).

A total of 37 full-text articles were assessed for eligibility. Twenty-one of these were excluded for several reasons: participants were not pertinent (e.g., adult or elderly populations), outcomes did not evaluate the relationship between environmental factors and pneumonia, the study type was inappropriate (e.g., protocol or review), or the full text was inaccessible. This screening process resulted in 15 articles being selected for quality evaluation. The assessment method depended on the study design. Cohort and case-control studies were reviewed using the Newcastle-Ottawa Scale (NOS), while cross-sectional studies were appraised with the AXIS tool. At this stage, three articles were excluded

because of poor methodological quality or a high likelihood of bias. Ultimately, 12 studies met the inclusion standards and were incorporated into the systematic review.

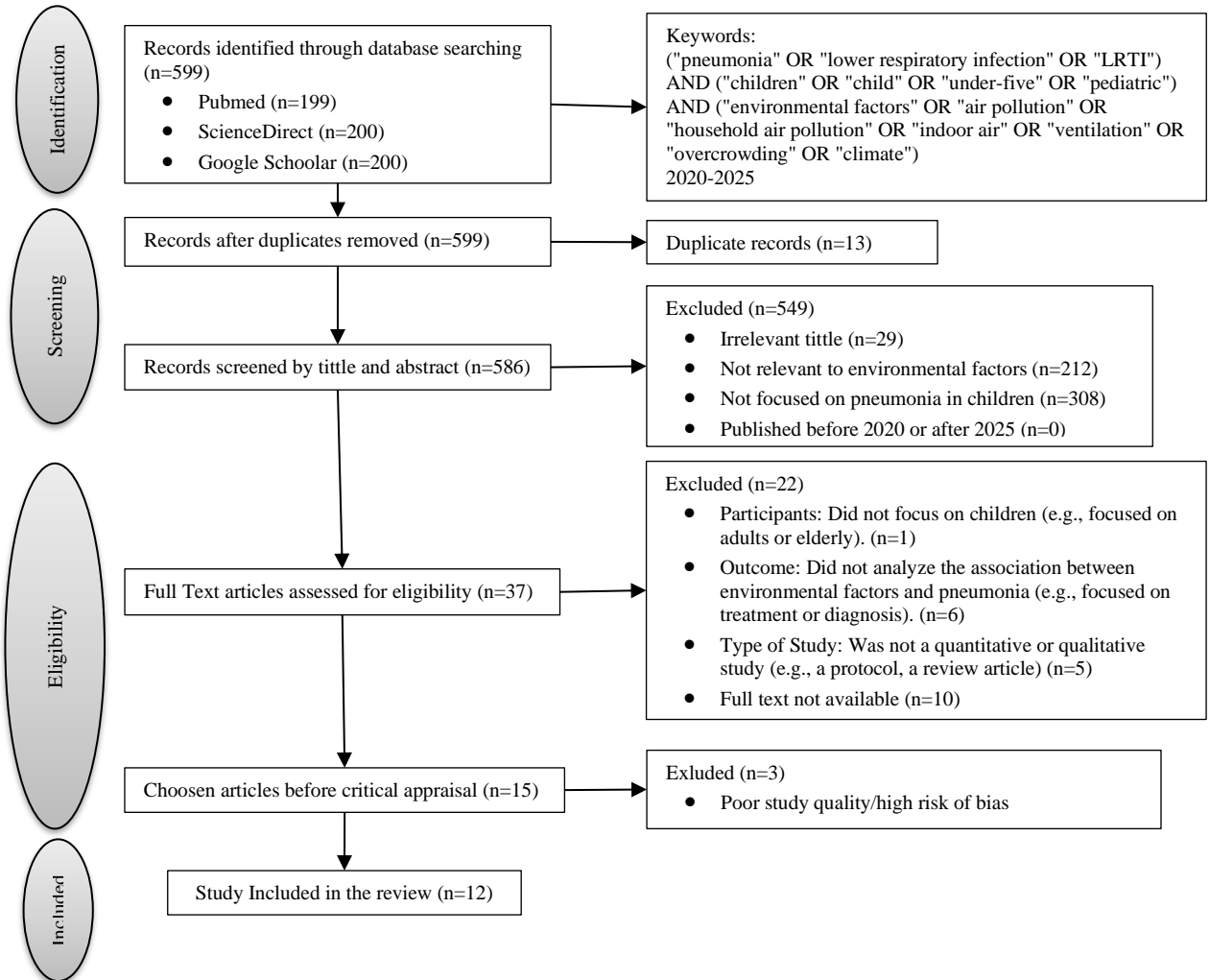


Figure 1. PRISMA Flow Diagram Illustrating the Literature Search and Selection Process

RESULTS

The review findings are presented in Table 1. Furthermore, Table 2 provides a summary of the literature review.

Table 1. Detailed Literature Review Matrix

No.	Authors	Title	Research Method	Sample Amount	Results	Conclusion
1	Sumariyah, Sutinin Gsiah & Adi (2024)	Risk Factors for Pneumonia in Toddlers at a Regional General Hospital of Mappi Regency, South Papua Province	Case-control study; chi-square & logistic regression	72 cases, 72 controls	1. History of asthma significantly increases the risk of pneumonia (OR=20.3). 2. Comorbidities are associated with an elevated risk (OR=4.7). 3. Poor nutritional status	The main risk factors for pneumonia among children under five include a history of asthma, comorbidities,

No.	Author s	Tittle	Research Method	Sample Amount	Results	Conclusion
					increases the risk (OR=2.9). 4. Use of firewood for cooking increases the risk (OR=3.8).	poor nutritional status, and exposure to firewood smoke.
2	Ratnani ngsih & Lusiana (2020)	Relationship Between Cleanliness of the Home Environment with Incidence of Acute Respiratory Infections among Children Under Five Years	Cross-sectional; Spearman Rho test	66 children under five years old	1. Most respondent households were categorized as healthy (55%). 2. Children living in healthy houses had fewer ARI cases (53%). 3. Spearman's test showed a significant correlation between house cleanliness and ARI incidence (p<0.005).	Proper household hygiene practices are essential for reducing the occurrence of acute respiratory infections (ARI) in children under the age of five years old.
3	Davila Cordova <i>et al.</i> (2020)	Association of PM2.5 concentration with health center outpatient visits for respiratory diseases of children under 5 years old in Lima, Peru	Time-series analysis; negative binomial model	3,099,438 outpatient visits (2011–2015)	1. An elevation in PM _{2.5} levels corresponded to a 6% uptick in hospital visits related to acute lower respiratory infections (ALRI). 2. A 16–19% rise in pneumonia visits. 3. A 10% increase in bronchiolitis/asthma visits.	PM2.5 exposure significantly increases clinic visits of children under five with respiratory diseases.
4	Bergmann <i>et al.</i> (2025)	Short-term exposure to ultrafine particles and respiratory infection hospital admissions in children in Copenhagen, Denmark	Case-crossover study; RR estimated per IQR increase in UFP	109,585 hospital admissions (2002–2018)	1. UFP exposure was associated with higher total respiratory hospitalization (RR=1.04). 2. Significant increases were observed for URTI (RR=1.04) and pneumonia (RR=1.06). 3. Stronger effects were found in children <15 years and boys.	Short-term exposure to ultrafine particles greatly raises the likelihood of hospital admission for pneumonia and other respiratory infections in children, and this association remains strong even after controlling for other pollutants such as PM _{2.5} and nitrogen dioxide (NO ₂).

No.	Author s	Tittle	Research Method	Sample Amount	Results	Conclusion
5	Shi <i>et al.</i> (2021)	Ambient PM _{2.5} and its chemical constituents on lifetime-ever pneumonia in Chinese children: A multi-center study	Cross-sectional; multi-level logistic regression	30,315 children from 205 preschools across 6 cities in China	1. PM _{2.5} (per 10 µg/m ³) increases pneumonia risk (OR=1.12). 2. Significant constituents: NH ₄ ⁺ (OR=1.06), NO ₃ ⁻ (OR=1.05), OM (OR=1.09). 3. Higher risk in children <5 years and those breastfed <6 months.	Prolonged exposure to PM _{2.5} and its chemical constituents substantially elevates the likelihood of pneumonia in children.
6	Harnani <i>et al.</i> (2020)	Spatial Analysis of Pneumonia in Toddlers Based on Environmental, Individual, and Behavior Factors in Pelalawan Regency, Riau Province	Survey research with quantitative analytic methods; Geographically Weighted Logistic Regression (GWLR)	394 households with toddlers	1. Environmental factors: forest fire smoke, poor ventilation, crowded housing, mosquito coil use, household smoking. 2. Individual factors: malnutrition, lack of exclusive breastfeeding, lack of immunization. 3. Socioeconomic factors: low income, working mothers.	Environmental, socioeconomic, and behavioral factors significantly influence the distribution of childhood pneumonia in Pelalawan.
7	He, C., Liu, C., Chen, R., <i>et al.</i> (2022)	Fine particulate matter air pollution and under-5 children mortality in China: A national time-stratified case-crossover study	Time-stratified case-crossover design with individual-level conditional logistic regression	A total of 61,464 under-five mortality cases were paired with 208,109 corresponding control days.	1. A rise of 10 µg/m ³ in PM _{2.5} concentrations with a lag of zero to one day is associated with a 1.15 percent increase in mortality among children under five (95% CI: 0.65 to 1.65 percent). 2. For pneumonia, a 10 µg/m ³ increase in PM _{2.5} with a lag of zero to one day is linked to a 1.25 percent rise in mortality (95% CI: 0.01 to 2.51 percent). 3. Stronger effects were observed among neonates (<28 days), girls, and during warm seasons; associations were also noted for other causes (preterm/LBW, diarrhea, etc.).	Short periods of exposure to PM _{2.5} elevate the risk of death in children under five, including fatalities caused by pneumonia. Particular attention is needed for neonates, females, and warm seasons; stronger air pollution control policies are essential.

No.	Author s	Tittle	Research Method	Sample Amount	Results	Conclusion
8	Zhuge, Y., Qian, H., Zheng, X., <i>et al.</i> (2020)	Effects of parental smoking and indoor tobacco smoke exposure on respiratory outcomes in children	Cross-sectional survey + multilevel logistic regression (CCHH study, China)	A total of 41,176 children between the ages of 3 and 8 were sampled across eight cities	1. Lifetime prevalence of pneumonia: 32.3%. 2. Exposure to environmental tobacco smoke (ETS) odor at home was more consistently associated with pneumonia, dry night cough, croup, and common cold than parental smoking status (OR 1.06–1.95). 3. Exposure during infancy posed higher risks than during childhood.	Indoor tobacco smoke odor is a strong predictor of respiratory problems, including pneumonia; preventing household exposure to tobacco smoke is crucial.
9	Dai, Z., Woolley, K. E., Dickins, Craig, E., <i>et al.</i> (2025)	Assessing the association between household air pollution exposure and child health in Mongolia: a birth-cohort study	Birth cohort, longitudinal follow-up (7, 13, 36 bulan) dengan a Cox regression & linear regression	1,266 children from Ulaanbaatar	1. Higher household air pollution (HAP) scores increased pneumonia risk at 7 months (HR: 1.02 [1.01–1.04]). 2. HAP decreased BSID mental scores (13 months) and psychomotor scores (36 months). 3. HAP was associated with lower HAZ & WAZ (child growth indicators).	Household air pollution from coal combustion in Mongolia negatively impacts pneumonia incidence and child development up to 3 years; household pollution mitigation policies are required.
10	Haryanto, B., Jalaludin, B., Asyary, A., <i>et al.</i> (2025)	Associations Between Ambient PM2.5 Levels and Children's Pneumonia and Asthma During the COVID-19 Pandemic in Greater Jakarta (Jabodetabek)	Ecological study (2020–2022), korelasi & regresi	73,694 pediatric pneumonia cases and 15,825 asthma cases	1. Mean PM2.5 concentration: 42.5 µg/m ³ (highest in Bekasi, lowest in North Jakarta). 2. Strongest correlation between PM2.5 & pneumonia observed in Depok (r=0.61, p=0.004). 3. Asthma showed weak to moderate, mostly non-significant correlations.	PM2.5 contributes significantly to pediatric pneumonia cases in Jakarta; air quality interventions are urgently needed to improve child health.

No.	Author s	Tittle	Research Method	Sample Amount	Results	Conclusion
11	Zhao, C., Wang, L., Xi, X., <i>et al.</i> (2024)	Association between indoor environmental risk factors and pneumonia among preschool children in Urumqi: A case-control study	Case-control study, logistic regression	3,044 children (1,522 pneumonia cases vs 1,522 controls, aged 2-7 years)	1. Significant risk factors: cesarean delivery (OR 1.27), only child (OR 1.32), antibiotic use in the first year (OR 2.51), passive smoke exposure during pregnancy (OR 1.62). 2. Home factors: living in multi-family apartments (OR 1.64), laminated/ceramic flooring (OR ~1.31), indoor humidity (OR 1.30). 3. Protective factor: use of air filtration systems (OR 0.66).	Indoor environmental conditions play a critical role in childhood pneumonia; prevention should include controlling secondhand smoke, reducing humidity, and improving indoor air quality.
12	Syakbanah, N. L., Nabilah, S., Hanif, M., Putri, M. S. A., Arisma ya, A. R. P. A., Nafisah, E. L., & Mirasa, Y. A. (2025)	Impact of Unqualified Housing on Childhood Pneumonia: A Spatial Study in Urban and Rural of Bojonegoro, Indonesia	Cross-sectional with spatial analysis (GIS mapping, chi-square)	60 mothers of under-five children (urban and rural areas, 1:1 ratio)	1. Humidity significantly correlated with pneumonia in both urban (PR 16.50, p=0.03) and rural (PR 12.60, p=0.04) areas. 2. Lighting significantly correlated in urban (PR 23.00, p=0.01) and rural (PR 12.60, p=0.04) settings. 3. Occupancy density was significant in both settings (PR 12.60, p=0.04). 4. Ventilation area was significant in rural areas (PR 25.00, p=0.03). 5. Other factors (floor type, wall type, fuel, mosquito coil) were not significant.	Poor housing conditions such as high humidity, inadequate lighting, overcrowding, and limited ventilation heighten the risk of childhood pneumonia in Bojonegoro; improving healthy housing standards and ventilation is highly recommended.

Table 2. Article’s Result Summary

Category	Frequency	Conclusion
Environmental factors	9/12 (75%)	1. PM _{2.5} , ultrafine particles, and related chemical components such as NH ₄ ⁺ , NO ₃ ⁻ , and organic matter contribute to a higher likelihood of pneumonia in children.
		2. Exposure to smoke from firewood, secondhand tobacco smoke, and household humidity significantly elevate the risk.
		3. Poor housing conditions such as inadequate lighting, overcrowding, and limited ventilation are consistently associated with pneumonia.

4. The implementation of air filtration systems has demonstrated protective effects against air pollution-related health risks.
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Socioeconomic factors & protective behaviors

1. Low household income, high occupancy density, and residence in multi-family apartments increase vulnerability.
2. Lack of exclusive breastfeeding and incomplete immunization further elevate the risk.
3. Protective interventions include adequate ventilation, air filtration systems, household cleanliness, and the use of clean fuels.

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- Vulnerable population 3/12 (25%) 5/12 (41.7%) 1. The health effects of air pollution are stronger during winter (China multi-city) and warm seasons (He, 2022). Children under the age of five, particularly newborns, are especially vulnerable to pneumonia.
2. Spatial variation shows higher risks in areas with elevated PM2.5 concentrations (Depok, Bekasi, East Jakarta).
3. The COVID-19 pandemic influenced pneumonia case trends in Jakarta.
2. Malnutrition, low birth weight, and comorbid conditions increase susceptibility.
 3. Female children show higher mortality risk associated with PM2.5 exposure (He, 2022).
 4. Children with a history of asthma are at greater risk (Sumariyah, 2024).
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- Climate/seasonal & al factor

Environmental Risk Factors for Childhood Pneumonia

The scientific evidence from multiple reviewed studies confirms that both outdoor and indoor environmental exposures act as primary determinants of childhood pneumonia. The consistent association between PM_{2.5} and ultrafine particles (UFP) concentrations and respiratory morbidity reflects the biological plausibility that fine particulates penetrate deep into the alveoli, triggering oxidative stress, airway inflammation, and immune dysregulation (Bergmann *et al.*, 2025; He *et al.*, 2022). These mechanisms explain why elevated particulate levels correspond to increased hospitalization and mortality rates in children. Furthermore, chemical constituents such as ammonium (NH₄⁺), nitrate (NO₃⁻), and organic matter (OM) intensify toxic effects by generating reactive oxygen species, which damage epithelial cells and impair macrophage function (Shi *et al.*, 2021).

Indoor environmental exposures further heighten the risk, especially in low-income households where biomass fuel use, tobacco smoke, and damp living conditions are common (Sumariyah *et al.*, 2024; Zhao *et al.*, 2024). The combustion of solid fuels releases carbon monoxide, polycyclic aromatic hydrocarbons, and nitrogen oxides, which all contribute to chronic airway irritation and reduced lung defense. Poor ventilation and high humidity promote microbial growth, while inadequate lighting often reflects poor housing quality and socioeconomic deprivation. These environmental pathways collectively explain the epidemiological trend of high pneumonia incidence in both urban and rural development.

Socioeconomic Determinants and Protective Behaviors

The reviewed literature indicates that socioeconomic status operates as a structural determinant that mediates environmental risk. Children from low-income households experience cumulative exposure to pollutants due to overcrowding, unqualified housing, and limited access to the clean energy. Poverty also restricts healthcare utilization and immunization coverage, compounding vulnerability to infection (Harnani *et al.*, 2020; Syakbanah *et al.*, 2025). Parental education and caregiving behaviors play equally critical roles such as exposure to secondhand smoke, nonexclusive breastfeeding, and incomplete vaccination directly increase susceptibility (Zhuge *et al.*, 2020; Sumariyah *et al.*, 2024). This pattern supports the social-ecological model of disease causation, where environmental hazards and social behaviors interact to shape child health outcomes.

Vulnerable Populations

Age, nutrition, and comorbidities constitute intrinsic biological modifiers of pneumonia risk. Infants and neonates are more sensitive to pollutant exposure because of smaller airway diameters, higher respiratory rates, and immature immune defenses (He *et al.*, 2022). Malnutrition and low birth weight weaken mucosal immunity and lung function, predisposing children to infection (Dai *et al.*, 2025). Moreover, pre-existing conditions such as asthma further exacerbate inflammatory responses upon exposure to airborne particulates (Sumariyah *et al.*, 2024). Gender-specific findings, with girls showing higher PM_{2.5}-related mortality, may reflect hormonal and immunological differences affecting inflammatory susceptibility. These findings substantiate the hypothesis that pneumonia risk is not only environmentally induced but also biologically mediated.

Climate, Seasonal, and Contextual Variations

Temporal and geographic heterogeneity strongly influence the magnitude of environmental effects. During cold seasons, reduced ventilation and increased indoor

combustion elevate indoor pollutant concentrations, explaining the higher pneumonia incidence observed in winter in China (Li *et al.*, 2021). Conversely, in tropical countries like Indonesia, heat and humidity intensify pollutant chemical reactions, producing secondary aerosols that aggravate respiratory distress (Haryanto *et al.*, 2025). Spatial analyses reveal clustering of cases in areas with persistent high PM_{2.5} exposure, such as Depok and Bekasi, demonstrating the localized nature of environmental risk. This spatial dependency underscores the importance of site-specific interventions and real-time air quality monitoring in urban health planning.

Implications for Policy and Public Health Interventions

Synthesizing all findings, childhood pneumonia emerges as a multifactorial disease shaped by environmental, socioeconomic, and biological interactions. The evidence confirms the initial hypothesis that poor air quality and unhealthy housing conditions significantly increase pneumonia risk among children under five. For Indonesia and similar low- to middle-income countries, integrated interventions are essential: stricter air quality standards, urban ventilation planning, cleaner household energy, and social protection for vulnerable families. Nevertheless, methodological limitations remain. Most studies are cross-sectional, limiting causal inference, and few assess the long-term effects of environmental interventions. Future research should focus on longitudinal designs and intervention-based studies to quantify the health gains of pollution control and healthy housing initiatives.

DISCUSSION

The findings of this systematic review indicate that childhood pneumonia is influenced by the interaction of environmental, socioeconomic, and biological factors. Although individual studies highlight different determinants, the overall evidence shows that environmental exposure remains a central pathway contributing to respiratory infections in children. The consistency of findings across studies conducted in different countries suggests that environmental determinants of pneumonia represent a widespread public health concern affecting both developed and developing regions. An important insight from the reviewed literature is the strong interaction between environmental exposure and social vulnerability. Environmental risks are often concentrated among populations with lower socioeconomic status. Children living in low-income households are more likely to experience poor housing conditions, inadequate ventilation, and exposure to indoor pollutants such as biomass smoke or tobacco smoke. These environmental conditions often coexist with other structural disadvantages, including overcrowding and limited access to healthcare services. As a result, environmental exposure and socioeconomic inequality work together to increase children's susceptibility to respiratory infections.

Another key pattern observed across the literature is the importance of the household environment as a determinant of child respiratory health. Young children spend most of their time indoors, making the home environment a critical setting for exposure to pollutants and infectious agents. Poor ventilation can allow indoor pollutants to accumulate, while high humidity and damp conditions may facilitate the growth of microorganisms that contribute to respiratory illness. These findings suggest that improving the quality of the household environment may be an effective strategy for reducing pneumonia risk among children.

Preventive health behaviors also play an important role in moderating the impact of environmental risks. Several studies emphasize that protective practices such as exclusive

breastfeeding, complete immunization, and maintaining smoke-free homes can reduce children's vulnerability to respiratory infections. These behaviors help strengthen immune function and reduce exposure to harmful pollutants within the household environment. Therefore, environmental improvements should be supported by community-based health promotion programs that encourage protective caregiving practices. Despite the relatively consistent evidence linking environmental exposure to childhood pneumonia, several limitations within the existing literature should be considered. Many studies rely on cross-sectional research designs, which limit the ability to determine causal relationships between environmental factors and pneumonia incidence. Differences in study populations, sample sizes, and exposure measurement methods may also influence the comparability of findings. In addition, some studies were conducted under specific contextual conditions, such as seasonal variations or pandemic-related changes in human mobility, which may affect environmental exposure patterns.

Another limitation identified in the reviewed literature is the limited number of studies that evaluate the long-term effectiveness of environmental interventions. While many studies successfully identify environmental risk factors, fewer studies assess whether improvements in air quality, housing conditions, or household energy use lead to measurable reductions in pneumonia incidence. Future research should therefore focus on longitudinal study designs and intervention-based approaches that can better evaluate the health benefits of environmental improvement strategies.

Overall, the evidence synthesized in this review supports the understanding that childhood pneumonia is a multifactorial disease shaped by environmental exposure, socioeconomic conditions, and biological vulnerability. Addressing this burden requires integrated public health strategies that simultaneously improve environmental quality, reduce social inequalities, and strengthen preventive child health programs. Policies aimed at improving air quality, promoting clean household energy, and enhancing housing conditions are essential components of comprehensive pneumonia prevention efforts, particularly in low and middle income countries.

CONCLUSION

This review confirms that childhood pneumonia arises from the dynamic interaction between environmental, socioeconomic, and biological determinants. The synthesis of current evidence supports the hypothesis that poor air quality and inadequate housing conditions play a significant role in raising pneumonia risk in children under five years old. Environmental pollutants such as PM_{2.5}, UFP, and household smoke directly impair respiratory function, while social and economic disparities amplify children's exposure and reduce their resilience. The findings demonstrate that improving environmental quality and living conditions can significantly reduce pneumonia incidence. Strengthening air pollution control, promoting the use of clean household energy, and designing healthier housing environments represent actionable solutions for child health protection, particularly in low- and middle- income countries such as Indonesia. Moving forward, researchers and policymakers need to integrate environmental health perspectives into national child health strategies. Future studies should adopt longitudinal and intervention- based approaches to evaluate the long-term benefits of clean air initiatives and healthy housing programs. By aligning environmental management with public health action, societies can create healthier, more equitable environments where every child has the opportunity to grow and thrive.

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