Short-Term Exposure to Fine Particulate Matter ($PM_{2.5}$) and Hospital Admissions for Respiratory Illness in Children Under Six in Ahmedabad, India

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ABSTRACT

Background: Children in rapidly urbanizing cities of low- and middle-income countries are highly exposed to outdoor air pollution. Fine particulate matter ($PM_{2.5}$) is of particular concern because it penetrates deep into the lungs and may trigger or worsen respiratory disease.

Objective: To examine the association between short-term exposure to ambient $PM_{2.5}$ and hospital admissions for respiratory illness among children younger than six years in Ahmedabad, western India, and to estimate the seasonal burden of disease attributable to $PM_{2.5}$.

Methods: We conducted a hospital-based, cross-sectional study of all pediatric admissions (age < 6 years) for respiratory illness in a large tertiary-care teaching hospital in Ahmedabad from 1 November 2017 to 31 December 2018. Demographic data, clinical diagnoses and environmental risk factors were recorded using a structured proforma. Daily city-level $PM_{2.5}$ concentrations were obtained from the SAFAR monitoring network, and meteorological data (temperature, relative humidity) from the India Meteorological Department. Respiratory diagnoses were grouped into wheezing disorders (bronchiolitis, asthma, wheeze-associated lower respiratory infection) and non-wheezing disorders (pneumonia, empyema, upper respiratory tract infections). Using WHO AirQ+ software and a log-linear exposure–response function, we estimated relative risk (RR) and season-specific numbers of respiratory admissions attributable to short-term $PM_{2.5}$ exposure above a counterfactual level of 15 $\mu g/m^3$.

Results: Over the 14-month period, 2682 of 12,635 pediatric admissions (21.2%) were due to respiratory illness; 60.1% were boys and 48.5% were infants (<1 year). Wheezing disorders accounted for 60.1% of respiratory admissions and non-wheezing infections for 39.9%. The annual mean $PM_{2.5}$ concentration was 80.3 ± 25.4 $\mu g/m^3$. Relative risk of respiratory admission associated with observed short-term $PM_{2.5}$ levels was 1.16 (95% CI: 1.09–1.23) in winter, 1.15 (1.09–1.21) in summer, 1.08 (1.03–1.13) in monsoon and 1.15 (1.07–1.23) in the post-monsoon season. The estimated number of respiratory admissions attributable to $PM_{2.5}$ per 100,000 children under six was 45 (95% CI: 21–68) in winter, 41 (19–63) in summer, 25 (11–39) in monsoon and 42 (18–66) in post-monsoon.

Conclusion: Outdoor $PM_{2.5}$ pollution in Ahmedabad is well above national and WHO guidelines and is associated with a measurable seasonal increase in respiratory admissions among young children. Infants and children living in overcrowded, low-income households and near traffic appear particularly vulnerable. Reducing $PM_{2.5}$ levels and using the Air Quality Index (AQI) to guide public health advice may help lower the burden of pediatric respiratory disease in this setting.

Keywords: fine particulate matter, $PM_{2.5}$, air pollution, respiratory illness, children, India, AirQ+

1. INTRODUCTION

Outdoor air pollution has become one of the most important environmental threats to human health worldwide. Among the various pollutants, fine particulate matter with an aerodynamic diameter ≤ 2.5 µm ($PM_{2.5}$) is especially harmful because these particles can bypass the upper airways, reach the distal bronchi and alveoli, and even enter the bloodstream. Elevated $PM_{2.5}$ concentrations have been linked to increased mortality and morbidity from respiratory and cardiovascular diseases in many regions of the world.

India is currently among the countries with the highest urban $PM_{2.5}$ levels. Rapid economic growth, traffic expansion, coal-based power generation, industrial emissions and biomass burning have all contributed to worsening air quality in many Indian cities. National and international assessments repeatedly place several Indian urban centres among the most polluted globally.

Young children are particularly vulnerable to the adverse effects of air pollution. Compared with adults, they have higher minute ventilation relative to body weight, often spend more time outdoors and may breathe more frequently through the mouth, reducing filtration by the nasal passages. In addition, their lungs and immune systems are still developing, which may increase susceptibility to infections and inflammatory damage. Acute respiratory infections remain a leading cause of death among children under five years in low- and middle-income countries.

Ahmedabad, a major city in the western Indian state of Gujarat, has a population of over seven million and experiences high ambient $PM_{2.5}$ concentrations throughout much of the year. At the same time, a substantial proportion of the pediatric population lives in low-income neighbourhoods with additional environmental and household risk factors, such as indoor biomass use, overcrowding and exposure to tobacco smoke.

Although international evidence supports a link between $PM_{2.5}$ and respiratory health, there is relatively limited local evidence from Indian cities that combines routine air quality data with detailed pediatric hospital admission records, particularly for young children.

1.1 Objectives

This study aimed to:

1. Describe the pattern of hospital admissions for respiratory illnesses among children younger than six years in a large tertiary-care hospital in Ahmedabad.
2. Examine the relationship between daily ambient $PM_{2.5}$ levels and pediatric respiratory admissions across different seasons.
3. Quantify the seasonal burden of respiratory admissions attributable to short-term $PM_{2.5}$ exposure using the WHO/Europe AirQ+ health impact assessment tool.

2. METHODS

2.1 Study Design and Setting

We conducted a hospital-based, cross-sectional observational study in the pediatric ward of a large tertiary-care teaching hospital affiliated with a municipal medical college in Ahmedabad, Gujarat, India. The hospital mainly serves an urban and peri-urban population from lower and lower-middle socioeconomic strata.

The study period extended from 1 November 2017 to 31 December 2018 (14 months).

2.2 Study Population and Inclusion Criteria

All children younger than six years admitted to the pediatric ward during the study period were screened. We included those whose primary diagnosis at admission was a respiratory illness, as determined by an experienced pediatrician based on history, physical examination and investigations where appropriate (e.g. chest radiography). We excluded:

- Children admitted for non-respiratory conditions (e.g. trauma, gastrointestinal disease).
- Children with incomplete hospital records.

2.3 Ethical Considerations

The study protocol was approved by the Institutional Review Board of the A.M.C. Medical Education Trust Medical College and associated hospital in Ahmedabad. Written informed consent was obtained from the parent or legal guardian of each child before enrolment. The study followed the Indian Council of Medical Research (ICMR) ethical guidelines (2017) and the principles of the Declaration of Helsinki (2013).

2.4 Data Collection and Clinical Classification

A pre-tested structured proforma was used to collect:

- **Demographic information:** age, sex, residential address.
- **Socioeconomic status:** assessed using the modified Kuppuswamy scale.
- **Household and environmental risk factors:** passive exposure to tobacco smoke, type of cooking fuel (e.g. LPG vs solid fuels such as wood or dung), housing type (pucca vs kutcha), presence of windows, number of people in the household and distance of the residence from a main road.
- **Clinical details:** presenting symptoms, examination findings, chest radiograph reports (where available) and final clinical diagnosis.

  Respiratory diagnoses were grouped as:
- **Wheezing disorders:** bronchiolitis, wheeze-associated lower respiratory infection, asthma.
- **Non-wheezing disorders:** pneumonia, empyema and upper respiratory tract infections (URTI).

This simplified classification allowed the comparison of obstructive/wheezy conditions with primarily infective, non-wheezing illnesses.

2.5 Air Pollution Data

Daily average $PM_{2.5}$ concentrations for Ahmedabad city were obtained from the System of Air Quality and Weather Forecasting and Research (SAFAR) network, which operates eight continuous ambient monitoring stations across the city (Navrangpura, Bopal, Rakhiyal, Satellite, Chandkheda, Pirana, Raikhad and the airport). For each calendar day in the study period, we calculated the city-wide mean $PM_{2.5}$ concentration by averaging across the available stations. These daily mean values were used for the time-series and health impact analyses. To contextualize the $PM_{2.5}$ levels, we also summarized the Air Quality Index (AQI) categories reported by SAFAR (Good, Satisfactory/Moderate, Poor, Very Poor, Severe).

2.6 Meteorological Data

Daily maximum and minimum temperature and relative humidity for Ahmedabad district were obtained from the India Meteorological Department. These variables were summarized monthly and by season to explore their potential relationship with admission patterns.

2.7 Seasonal Classification

Following the India Meteorological Department, we defined four seasons:

- **Winter:** January–February
- **Summer:** March–May
- **Monsoon (rainy season):** June–September
- **Post-monsoon (autumn):** October–December

Admissions and $PM_{2.5}$ data were analysed by these seasons.

2.8 Population and Baseline Rates

The population of children under six years in Ahmedabad for the study year was estimated using the 2011 national census data and the United Nations annual population growth rate for Ahmedabad (2.61%). This provided an approximate at-risk population of 734,497 children under six.

Baseline respiratory admission incidence (per 100,000 children) was calculated using the observed number of admissions and the estimated population.

2.9 Health Impact Assessment with AirQ+

Health impact assessment of $PM_{2.5}$ was performed using WHO/Europe's AirQ+ software (version 2.0). We used:

- Daily average $PM_{2.5}$ concentrations.
- Estimated under-six population.
- Daily counts of respiratory admissions.
- An integrated exposure–response (IER) log-linear function supplied in AirQ+.
- A counterfactual (cut-off) value of 15 µg/m³ for 24-hour $PM_{2.5}$ exposure, in line with updated WHO air quality guidelines for short-term exposure.

For each season, AirQ+ estimated:

- The **relative risk (RR)** of respiratory admission associated with the observed short-term $PM_{2.5}$ exposure compared with the counterfactual.
- The **number of cases attributable to $PM_{2.5}$** per 100,000 children under six, with 95% confidence intervals (CI).

Because this is an ecological, hospital-based analysis, results should be interpreted as city-level associations, not individual risk.

2.10 Statistical Analysis

Data were entered into a database and analysed using SPSS version 24 and R. Descriptive statistics were used to summarize demographic, clinical and environmental variables (frequencies, percentages, means and standard deviations).

Monthly and seasonal patterns of respiratory admissions were compared with $PM_{2.5}$ levels, AQI categories, temperature and humidity. Simple comparisons of proportions (e.g. wheezer vs non-wheezer, male vs female) were descriptive; the main quantitative risk estimates relied on the AirQ+ log-linear exposure–response modelling.

3. RESULTS

3.1 Overview of Pediatric Admissions

Between November 2017 and December 2018, there were 12,635 admissions to the pediatric ward. Of these, 2682

(21.2%) were due to respiratory illnesses and formed the analytic sample.

- **Sex distribution:** 1611 (60.1%) were boys and 1071 (39.9%) were girls.
- **Age distribution:** Infants (<1 year) accounted for 1295 admissions (48.5%), toddlers and preschoolers aged 1–5 years for 1057 (39.4%) and children 5–<6 years for 330 (12.3%).

Thus, nearly half of all respiratory admissions occurred in infants.

3.2 Household and Environmental Risk Factors

Table 1 summarizes the main demographic and environmental risk factors recorded among respiratory admissions.

Table 1. Selected household and environmental risk factors among children with respiratory admission (N = 2682).

Risk factor	n	% of respiratory admissions
Passive exposure to tobacco smoke	821	30.6
Residence < 500 m from main road	676	25.2
Use of solid fuel (traditional chulha)	311	11.6
Living in kutcha (non-permanent) house	683	25.5
House with no windows	281	10.5
> 3 persons in household (crowding)	2559	95.4

Most admitted children lived in crowded homes, and about one-third were exposed to tobacco smoke from older family members. Around one in four came from kutcha houses or lived close to a main road, while just over one in ten reported reliance on solid fuels for cooking, consistent with indoor air pollution exposure.

3.3 Clinical Pattern of Respiratory Illness

Of the 2682 respiratory admissions:

- **Wheezing disorders** (bronchiolitis, wheeze-associated lower respiratory infections, asthma) accounted for 1612 cases (60.1%).
- **Non-wheezing disorders** (pneumonia, empyema, URTI) accounted for 1070 cases (39.9%).

Pneumonia represented approximately 16% of total respiratory admissions, URTIs around 22% and empyema a small proportion (about 1% of respiratory and 0.25% of all pediatric admissions).

3.4 Meteorology and Seasonal Admission Patterns

Ahmedabad has a tropical climate with hot summers. During the study period:

- Mean maximum temperature was 33.8 ± 4.6°C.
- Mean minimum temperature was 21.4 ± 5.0°C.
- Average relative humidity was approximately 51.6%.

The most humid month was July 2018 (mean humidity 78.7%) with 12.1% of total respiratory admissions that month, just over half of which were wheezing episodes. The least humid month was April 2018 (31.97% humidity), which still had 24.7% of admissions classified as respiratory, with nearly equal proportions of wheezing and non-wheezing disorders.

When examined by month, the percentage of all pediatric admissions that were respiratory was highest in winter months (e.g. February 2018: 34.6%) and lowest in early monsoon (e.g. June 2018: 8.0%).

3.5 $PM_{2.5}$ Levels and Air Quality Index

The overall annual mean $PM_{2.5}$ concentration for Ahmedabad during the study period was 80.27 ± 25.36 µg/m³. This is:

- Roughly twice the Indian National Ambient Air Quality Standard (40 µg/m³ annual).
- More than eight times the updated WHO annual guideline value (5 µg/m³).

Monthly mean $PM_{2.5}$ concentrations varied substantially:

- The highest monthly mean $PM_{2.5}$ was in February (102.9 µg/m³), which also had one of the highest proportions of respiratory admissions (34.6% of all pediatric admissions; 62.4% wheezers among respiratory).
- The lowest monthly mean $PM_{2.5}$ occurred in September (50.9 µg/m³), with a lower share of respiratory admissions (16.7%).

Across months:

- Months with $PM_{2.5}$ above the annual average (≥ 80.2 µg/m³) had, on average, 23.1% of pediatric admissions due to respiratory illnesses, with 61.2% of these being wheezing disorders.
- Months with $PM_{2.5}$ below the annual average had 17.4% respiratory admissions, with 56.7% wheezers.

From an AQI perspective:

- 18% of days were classified as Good or Satisfactory/Satisfactory–Moderate.
- 50% of days were Moderate.
- 28% were Poor.
- 4% were Very Poor.

Thus, on the majority of days, air quality failed to meet the "Good" category, and a non-trivial fraction of days fell in ranges associated with adverse health effects.

3.6 Seasonal $PM_{2.5}$ Levels and Health Impact Estimates

Seasonal mean $PM_{2.5}$ values and health impact estimates from AirQ+ are summarized in Table 2.

Table 2. Seasonal mean $PM_{2.5}$ and estimated health impact on respiratory admissions in children <6 years (AirQ+).

Season	$PM_{2.5}$ mean ± SD (µg/m³)	Relative Risk (RR)	95% CI	Attributable cases per 100,000 children <6 (95% CI)
Winter	96.0 ± 20.5	1.16	1.09–1.23	45 (21–68)
Summer	88.1 ± 14.9	1.15	1.09–1.21	41 (19–63)
Monsoon	58.0 ± 18.8	1.08	1.03–1.13	25 (11–39)
Post-monsoon	89.0 ± 25.3	1.15	1.07–1.23	42 (18–66)

Using the counterfactual level of 15 µg/m³, the model suggests that short-term exposure to ambient $PM_{2.5}$, at the levels observed in Ahmedabad, increases the risk of respiratory admission in children by about 8–16%, depending on the season. The highest estimated burden, expressed as attributable cases per 100,000 children under six, occurs in winter, summer and post-monsoon, with somewhat lower but still significant impact during the monsoon.

4. DISCUSSION

This hospital-based study from Ahmedabad provides evidence that short-term exposure to elevated $PM_{2.5}$ levels is associated with increased respiratory admissions in young children. Several key findings warrant discussion.

4.1 High Burden of Pediatric Respiratory Admissions

Respiratory illness accounted for over one-fifth of all pediatric admissions, and nearly half of these occurred in infants. This reflects the known vulnerability of young children to respiratory pathogens and environmental stressors. Anatomical factors (narrower airways, relatively compliant chest wall), developing immune systems and higher exposure per unit body weight may all contribute to increased susceptibility.

The predominance of wheezing disorders (around 60% of respiratory admissions) suggests that obstructive airway disease — including bronchiolitis and asthma-like illnesses — is a major cause of hospitalization. This pattern is consistent with other studies that report a high burden of wheeze-associated illnesses in early childhood in low- and middle-income settings.

4.2 Socioeconomic and Household Risk Factors

Most children admitted came from lower socioeconomic strata. Crowding was nearly universal, and substantial proportions were exposed to household tobacco smoke, lived in kutcha housing, used solid fuels or had homes with poor ventilation.

These factors can interact with outdoor air pollution:

- **Passive smoking** irritates the respiratory mucosa, reduces mucociliary clearance and may alter immune responses, increasing the risk of both infections and wheezing illnesses.
- **Solid fuel use** in poorly ventilated dwellings produces high indoor concentrations of particulate matter and toxic gases, which can further inflame the airways.
- **Proximity to major roads** increases exposure to traffic-related pollutants such as diesel exhaust particles and nitrogen oxides, both linked to asthma and respiratory symptoms.

Our descriptive data support the idea that socially disadvantaged children face a "double burden" of indoor and outdoor pollution, superimposed on limited access to health-protective resources such as good nutrition and prompt medical care.

4.3 Air Pollution, Seasonality and Respiratory Admissions

The annual mean $PM_{2.5}$ level in Ahmedabad during the study period was more than eight times the WHO guideline for long-term exposure and about double the Indian annual standard. Even the season with the lowest mean $PM_{2.5}$ (monsoon) had values far above the WHO daily guideline of 15 $\mu g/m^3$.

We observed that:

- Months with higher $PM_{2.5}$ tended to have a higher proportion of respiratory admissions.
- The exposure–response modelling in AirQ+ indicated small but statistically meaningful increases in risk (RR 1.08–1.16) associated with short-term $PM_{2.5}$ exposure.
- The health burden was not confined to one season; winter, summer and post-monsoon all showed similar estimated attributable fractions.

Seasonality of respiratory illness is influenced not only by pollution but also by meteorological factors and circulating viruses and bacteria. Cooler temperatures and low humidity can favour viral survival, alter airway defence mechanisms and encourage indoor crowding. In contrast, hot and dusty conditions in summer may exacerbate asthma and contribute to respiratory irritation. Our study did not disentangle these effects but suggests that $PM_{2.5}$ amplifies the impact of these seasonal drivers.

4.4 Public Health and Policy Implications

From a public health perspective, the findings highlight several important points:

1. **Ambient $PM_{2.5}$ levels in Ahmedabad are unacceptably high** and pose a threat to children's respiratory health throughout the year.
2. **Air Quality Index (AQI) information could be used more proactively** to warn caregivers when pollution levels are high and to recommend protective behaviours (e.g. limiting outdoor exertion, keeping windows closed near busy roads on "Very Poor" days).
3. **Targeted interventions in high-risk communities** — such as promotion of clean cooking fuels, anti-tobacco campaigns, improved housing and urban planning to separate heavy traffic from residential areas — may yield substantial health benefits.
4. **Health services planning** should take into account the seasonal peaks in respiratory admissions and the underlying environmental drivers.

Mitigation of urban air pollution requires a multisectoral approach, including stricter emission standards, cleaner energy transitions and improvements in public transport. Although these broader policies lie beyond the scope of this study, our results support the urgency of such actions.

4.5 Strengths and Limitations

Strengths:

- The study uses real-world data from a large tertiary hospital with a high volume of pediatric admissions.
- Diagnoses were made by experienced clinicians using standard clinical criteria and investigations.
- Air quality data came from a well-established multi-station monitoring network (SAFAR).
- The health impact assessment used WHO-endorsed AirQ+ software and current guideline values.

Limitations:

- This is a single-centre, hospital-based study and may not capture milder cases managed at home or in outpatient settings.
- We did not adjust for individual-level confounders such as nutritional status, immunization, breastfeeding practices or prior health conditions.
- Daily $PM_{2.5}$ exposure was assigned at the city level and may not reflect micro-environmental exposures for each child.
- The ecological time-series design cannot prove causality; it demonstrates associations at the population level.
- Health data cover just over one year, which limits the ability to examine inter-annual variability and longer-term trends.

Future studies could expand to multiple hospitals, incorporate more years of data and use more advanced time-series models to control for additional confounders.

5. CONCLUSION

This study demonstrates that young children living in Ahmedabad are frequently hospitalized for respiratory illnesses and that elevated short-term ambient $PM_{2.5}$ exposure is associated with a measurable increase in such admissions across all seasons. Infants, boys, and children from crowded, low-income households appear particularly vulnerable. Health impact estimates suggest that dozens of respiratory admissions per 100,000 children each season can be attributed to $PM_{2.5}$ exposures above the WHO short-term guideline level.

Improving air quality through emissions control, cleaner energy use and better urban planning, coupled with targeted interventions for high-risk households, could substantially reduce the burden of pediatric respiratory disease in this and similar urban settings. Incorporating AQI-based alerts into routine pediatric and public health practice may help caregivers and clinicians anticipate and mitigate pollution-related exacerbations.

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