Linking PM Pollution to the Respiratory Health of Children: A Cross-sectional Study from Ahmedabad City in Western India

Khyati M. Kakkad¹, Chirantap Oza¹*, Priya Dutta², Varsha Chorsiya³, Prashant Rajput 4*

¹A.M.C Medical Education Trust Medical College and LG hospital, Ahmedabad 380008, India
²Indian Institute of Public Health Gandhinagar 382042, India
³School of Physiotherapy, Delhi Pharmaceutical Sciences and Research University, New Delhi 110017, India
⁴Centre for Environmental Health, Public Health Foundation of India, Gurugram 122002, India

ABSTRACT

Worldwide research on public health suggests that air pollution (AP) has deleterious human health impacts. Children living in developing countries suffer a double burden of respiratory diseases. The present study aims to find out the risk of short-term exposure to PM\textsubscript{2.5} on respiratory admissions of children under 6 from Ahmedabad city in western India. A cross-section observational study of all patients, under 6, with respiratory illnesses admitted in the Pediatric ward from 1\textsuperscript{st} November 2017–31\textsuperscript{st} December 2018 at a tertiary care hospital in Ahmedabad has been conducted to decipher the seasonal impact of PM\textsubscript{2.5} on respiratory admissions. During the study period, respiratory illnesses accounted for 21.2% of the total admissions—60.6% were male, 48.4% were of infant age, 60.1% of the patients were suffering from wheezing disorders while 39.9% had infective disorders. The relative risk (RR) and the number of attributable cases per 100,000 children population at risk were estimated due to short-term exposure to PM\textsubscript{2.5} for different seasons in Ahmedabad city applying a log-linear integrated exposure-response function in WHO/Europe’s AirQ+ tool using national census-2011 city-level population of children and United Nation’s annual growth-rate, baseline incidence, PM\textsubscript{2.5} pollution profile, WHO’s updated counterfactual value for short-term PM\textsubscript{2.5} exposure (= 15 µg m\textsuperscript{-3}). Accordingly, the RR for the number of respiratory admissions of children due to ambient levels of PM\textsubscript{2.5} in winter was 1.16 (95% CI: 1.09–1.23), in summer was 1.15 (95% CI: 1.09–1.21), in monsoon was 1.08 (95% CI: 1.03–1.13) and in post-monsoon was 1.15 (95% CI: 1.07–1.23). The number of attributable cases (along with confidence interval (CI), per 100,000 population of children under 6 at risk, was 45 (95% CI: 21–68) in winter, 41 (95% CI: 19–63) in summer, 25 (95% CI: 11–39) in monsoon, and 42 (95% CI: 18–66) in the post-monsoon season.

Keywords: Air pollution, PM\textsubscript{2.5}, AirQ+, Respiratory admissions, India

1 INTRODUCTION

Air pollution (AP) affects severely human health and facet of life. The PM\textsubscript{2.5} produced from different sources, viz. transportation, industrialization, combustion of fossil-fuel, forest-fires, among others is dangerous from the viewpoint of public health. In rapidly developing countries such as India, the speedy progressing economy is among the major causes of high levels of ambient/ outdoor PM\textsubscript{2.5} (particulate matter with aerodynamic diameter ≤ 2.5 µm) (Manisalidis et al., 2020). As per the recent World Health Organization air quality guidelines, the safer level of ambient PM\textsubscript{2.5} is 15 µg m\textsuperscript{-3} for daily average exposure and 5 µg m\textsuperscript{-3} for annual average exposure (WHO, 2021). Several studies have provided evidence for both acute and chronic health effects of PM\textsubscript{2.5}.
Greenstone and Pande, 2012; Wong et al., 2008; Laumbach and Kipen, 2012; Guttikunda et al., 2014; WHO, 2016). In the World Health Organization’s (WHO) 2016 urban air quality assessment report, 13 out of the top 20 most polluted cities are located in India (Guttikunda et al., 2014; WHO, 2016). In 2010, the mean concentrations of ambient (PM) over 180 Indian cities were about six times higher than the WHO standard (Greenstone and Pand, 2014). AP is among the top listed risk factors for ill health in the country and is well above child and maternal malnutrition, diabetes, and high blood pressure.

PM<sub>2.5</sub> harms many organs/systems of the human body resulting in respiratory diseases, improper functioning of the nervous system and cardiovascular system, irritation of the eyes, nose, and throat, and many unidentified consequences (Jiang et al., 2016; Mills et al., 2009; Sharma et al., 2013). PM<sub>2.5</sub> upon inhalation, being fine particles, penetrates deeper into the human respiratory system and through alveoli at least a fraction of it reaches the blood and several organs, thus, resulting in various personal health effects (U.S. EPA, 2021). WHO has identified acute respiratory infections as the leading cause of death among children under 5, more than diarrheal diseases, malaria, and other vector-borne diseases (Lanata et al., 2013; Walker et al., 2013; Denny and Loda, 1986). Towards this, it is widely believed that children are more vulnerable to respiratory infections resulting from exposure to harmful pollutants as compared to adults. There is an association between rising levels of PM<sub>2.5</sub> and respiratory diseases induced morbidity/mortality rates (Rajput et al., 2019). Furthermore, as compared to adults the children are more physically active, thus there is a high probability that their lungs are more exposed to AP. Moreover, children breathe faster than adults and they are higher mouth breathers which result in more inhalation of air pollutants and lead to experiencing a deeper dose into their lungs (Bateson and Schwartz, 2007; Kerem, 1996). High levels of exposure to air pollutants could relate to morbidity and mortality from diseases associated with acute respiratory infections, as well as newer threats associated with asthma and allergies (non-infective).

In the current scenario, PM<sub>2.5</sub> is a major public health issue in cities across the world. On a similar note, the city of Ahmedabad with a population of over 7.3 million is facing a great threat due to AP. The present study intends to: (i) evaluate the association between occurrences of respiratory hospital admissions and PM<sub>2.5</sub> and, (ii) perform the health impact assessment of children.

### 2 METHODS

#### 2.1 Study Site and Health Data Description

The city of Ahmedabad is situated in the states of Gujarat in the western part of India (Fig. 1). A cross-sectional observational clinical study was undertaken from 1<sup>st</sup> November 2017–31<sup>st</sup> December 2018 at the pediatric ward of a tertiary care center affiliated with the medical college in Ahmedabad. The study protocol was approved by the Institutional review board, A.M.C Medical Education Trust Medical College, and LG Hospital, Ahmedabad, India. The health outcome data were retrieved from this hospital. The study has been done following the National ethical guidelines of the Indian Council of Medical Research (ICMR) (Revised 2017) and the guidelines of the Helsinki declaration 2013 for Biomedical and Health Research involving human participants (ICMR, 2017; WMA, 2013). The written informed consent to participate in this study was taken from the parent/guardian of the children after informing the purpose of the study. Their demographic profile and detailed relevant history were documented as per pre-set proforma and the modified Kuppuswamy classification was used for the socio-economic classification (Saleem, 2020). After a detailed evaluation by an expert clinician and a review of appropriate investigations, the diagnosis of the patient was documented. The authors included bronchiolitis, WALRI, and asthma in “wheezing disorders” whereas pneumonia, empyema, and upper respiratory tract infections were included in “non- wheezing disorders” as mentioned in Table 1.

#### 2.2 Weather and Air Quality Data

Daily temperature (maximum, and minimum) and relative humidity data were obtained from the Indian Meteorology Department (IMD) at the district level for the study period. The PM<sub>2.5</sub> data were obtained from the System of Air Quality and Weather Forecasting and Research (SAFAR) (http://safar.tropmet.res.in/AQI-47-12-Details). Therefore, we are using only secondary data...
Table 1. Common signs and symptoms used for describing Wheezing and non-wheezing diseases.

| Classification of Respiratory Illness | Disorders       | Clinical features                                                                 | Chest X-ray                                      |
|--------------------------------------|-----------------|-----------------------------------------------------------------------------------|------------------------------------------------|
| Wheezing Disorders                   | Bronchiolitis   | Fast breathing, fever, intercostal retractions, respiratory distress out of proportion to physical signs | Hyperinflation with diaphragm pushed downwards    |
|                                      | Asthma          | Recurrent non-productive cough, dyspnoea, prolonged expiration, pulsum paradoxus   | Bilateral symmetric air trapping, patches of atelectasis |
|                                      | WALRI Pneumonia | Fever, cough, dyspnoea, grunting respiration, tachypnoea, signs of consolidation  | Non-specific                                     |
|                                      | Emphyema        | Fever, difficulty in breathing, toxic look, decreased movement of respiration      | Lobar consolidation, pneumatocele, hazy exudates from hilar region, Shift in mediastinum, obliteration of costophrenic angle, varying degree of opacification |
|                                      | URTI            | Fever, malaise, headache, nausea, sore throat, hoarseness, rhinitis, throat congestion | Normal                                           |

with formal approval from SAFAR and IMD. SAFAR and IMD data are freely available in the public domain. The daily averaged PM$_{2.5}$ data was retrieved from eight SAFAR stations across the city.

For air quality monitoring in Ahmedabad, the SAFAR program has installed and operates a network with 8 stations across the city of Ahmedabad at Navrangpura, Bopal, Rakhiyal, Satellite, Chandkheda, Pirana, Raikhad, and the Airport (http://safar.tropmet.res.in/AQI-47-12-Detail). The Ahmedabad AQI, as operated by the SAFAR, comprises eight pollutants with sub-indices and health breakpoints calculated for each: PM$_{10}$, PM$_{2.5}$, NO$_2$, SO$_2$, CO, O$_3$, NH$_3$, and Pb. These eight pollutants have short-term (up to 24-hours) India National Ambient Air Quality Standards (NAAQS)
classification. For example, the Ahmedabad AQI uses five AQI categories: Good (0–100), Moderate (101–200), Poor (201–300), Very Poor (301–400), and Severe (401–500).

2.3 Data Analysis

The number of admissions due to respiratory illnesses per day has been co-assessed with the pollutants and AQI data retrieved from the SAFAR program. Daily temperature (max. and min.), and relative humidity data were retrieved from the IMD and have also been co-assessed with the hospital admission rates in Ahmedabad.

Data analysis has been performed using the SPSS software (SPSS V.24), and R coding. For this purpose, the data has been sub-divided into four seasons based on the Indian Meteorological Department’s classification: Winter (January, February), Summer (March, April, May), Monsoon/Rainy Season (June, July, August, September) and Post-Monsoon/Autumn (October, November, December). For each month the number of patients has been segregated for particular diseases (Parthasarathy et al., 1987).

We have used the AirQ+ v.2.0 software tool developed by the WHO/Europe Regional Office for quantifying the health effects of AP (WHO-Europe, 2018). The information like air quality data of the study area (daily average PM$_{2.5}$ concentration), the total population of children under 6 years in the study area, and the daily number of respiratory admissions of children under 6 years were included in the program. The daily number of patients admitted to the hospital without respiratory disease was excluded from the study. Applying a log-linear integrated exposure-response (IER) function in WHO/Europe’s AirQ+ tool the health impact assessment study was conducted herein for respiratory admissions of children due to short-term exposure to PM$_{2.5}$. The Ahmedabad city population of children under 6 (~734,497) for the study year was estimated using 2011 census data and the United Nation’s annual growth projection (= 2.61%) for Ahmedabad (worldpopulationreview.com). The cut-off or counterfactual value for acute exposure to PM$_{2.5}$ was set at 15 μg m$^{-3}$ following the recent WHO standard guidelines (WHO, 2021). The counterfactual value of an exposure variable, e.g., PM$_{2.5}$ in this case, represents a dose below which no adverse health effect is being observed. Using the ambient PM$_{2.5}$ pollution profile, IER function, and the counterfactual value the relative risk values are calculated based on the log-linear method (Evans et al., 2013; Manojkumar and Srimuruganandam, 2021). In AirQ+, the population attributable risk of respiratory admissions of children due to short-term exposure to PM$_{2.5}$ during different seasons in Ahmedabad city was also estimated by incorporating the baseline respiratory admissions incidence.

3 RESULTS

During the study period, of the total 12,635 admissions in pediatric units, 2682 were due to respiratory causes accounting for 21.23%. Out of 2682 total admissions, 1611 (60.07%) were male while 1071 (39.93%) were female. In the present study, the infant age group is found to be the most affected. The infants (0–1 years) accounted for 1295 (48.48%) admissions. The representation of toddler and preschool age group (1‒5 yr) is 1057 (39.41%). The affected number of children in the age group 5–6 yr years is 330 (12.30%). Table 2 is showing demographic risk factors for respiratory diseases, 821 (30.6%) children admitted with respiratory complaints were exposed to tobacco smoke due to its use by the elderly family members. About 2006 children (74.83%) lived at a distance more than 500 meters from the main road. Around 311 (11.59%) children are affected by indoor AP due to the use of traditional ‘chulha’ for cooking purposes. Out of 2682, 683 (25.46%) children were admitted for respiratory illness that lived in ‘kutcha’ houses (i.e., houses made up of clay and bricks). About 281 (10.5%) children were living in houses with not even a single window. About 2559 (95.43%) children had more than 3 members in their house.

Out of 2682 respiratory admissions, 1612 (60.1%) were experiencing “wheezing disorders” while 1070 (39.9%) were with “non-wheezing disorders” as illustrated in Fig. 2. The city of Ahmedabad is situated in western India where the climate is mostly tropical with an average maximum temperature during the study period was 33.8 ± 4.6°C (Avg. ± SD), an average minimum temperature of 21.37 ± 4.99°C, and mean humidity of 51.63 %.

The month-wise reported wheezer and non-wheezee admissions with mean temperature and humidity are given in Table 3.
Table 2. Demographic risk factors for respiratory patients considered in this study.

| Month   | Respiratory admissions | Passive smoking | Distance < 500 m | Solid fuel | Kacha house | Zero windows in house | > 3 person in house |
|---------|------------------------|-----------------|------------------|------------|-------------|----------------------|---------------------|
| Nov. 2017 | 192                  | 50              | 26.04            | 171        | 89.06       | 29                   | 15.1                | 51                   | 26.56               | 42                   | 21.88               | 172                 | 89.58               |
| Dec. 2017 | 135                 | 34              | 25.19            | 98         | 72.59       | 24                   | 18.1                | 42                   | 31.11               | 21                   | 15.56               | 132                 | 97.78               |
| Jan. 2018 | 242                 | 102             | 42.15            | 181        | 74.79       | 6                    | 2.48                | 57                   | 23.55               | 8                    | 3.31                | 240                 | 99.17               |
| Feb. 2018 | 330                 | 106             | 46.09            | 271        | 82.12       | 52                   | 22.6                | 89                   | 26.97               | 31                   | 9.39                | 312                 | 94.55               |
| Mar. 2018 | 269                 | 58              | 21.56            | 188        | 69.89       | 3                    | 1.12                | 47                   | 17.47               | 19                   | 7.06                | 244                 | 90.71               |
| Apr. 2018 | 214                 | 66              | 30.84            | 168        | 78.5        | 29                   | 13.6                | 63                   | 29.44               | 30                   | 14.02               | 198                 | 92.52               |
| May 2018  | 120                 | 23              | 19.17            | 75         | 62.5        | 20                   | 16.7                | 29                   | 24.17               | 6                    | 5                   | 120                 | 100                 |
| June 2018 | 55                  | 20              | 36.36            | 38         | 69.09       | 8                    | 14.6                | 13                   | 23.64               | 8                    | 14.55               | 53                  | 96.36               |
| July 2018 | 108                 | 34              | 31.48            | 88         | 81.48       | 13                   | 12                  | 24                   | 22.22               | 14                   | 12.96               | 98                  | 90.74               |
| Aug. 2018 | 341                 | 131             | 38.42            | 262        | 76.83       | 22                   | 6.45                | 92                   | 26.98               | 27                   | 7.92                | 333                 | 97.65               |
| Sept. 2018 | 233                | 58              | 24.89            | 165        | 70.82       | 10                   | 4.29                | 66                   | 28.33               | 19                   | 8.15                | 228                 | 97.85               |
| Oct. 2018 | 175                 | 44              | 25.14            | 123        | 70.29       | 20                   | 12.2                | 44                   | 25.14               | 11                   | 6.29                | 172                 | 98.29               |
| Nov. 2018 | 118                 | 44              | 37.28            | 77         | 65.25       | 31                   | 26.27               | 27                   | 22.88               | 18                   | 15.25               | 113                 | 95.76               |
| Dec. 2018 | 150                 | 51              | 34               | 101        | 67.33       | 44                   | 29.33               | 39                   | 26                  | 27                   | 18                  | 144                 | 96                  |

Fig. 2. Respiratory admissions for Wheezing (bronchiolitis, WALRI, asthma) and non-wheezing disorders (pneumonia, empyema, upper respiratory tract infections).

Table 3. Respiratory admissions and weather conditions during the study period.

| MONTH   | Respiratory admissions (N) | Respiratory admissions (%) | Wheezers (%) | Non-Wheezers (%) | Min Temp mean (°C) | Max Temp mean (°C) | Relative humidity mean (%) |
|---------|----------------------------|----------------------------|--------------|------------------|--------------------|--------------------|--------------------------|
| Nov. 2017 | 192                      | 35.36                      | 53.12        | 46.87            | 17.65              | 31.83              | 49.94                    |
| Dec. 2017 | 135                      | 26.16                      | 64.44        | 35.55            | 16.47              | 27.13              | 52.92                    |
| Jan. 2018 | 242                      | 29.66                      | 59.91        | 40.08            | 14.6               | 28.79              | 48.87                    |
| Feb. 2018 | 330                      | 34.55                      | 62.42        | 37.57            | 17.14              | 31.91              | 43.7                     |
| Mar. 2018 | 269                      | 26.9                       | 66.91        | 33.08            | 20.54              | 36.53              | 32.39                    |
| Apr. 2018 | 214                      | 24.65                      | 50.93        | 49.06            | 24.29              | 39.98              | 31.97                    |
| May 2018  | 120                      | 15.52                      | 61.66        | 38.33            | 27.86              | 42.45              | 40.27                    |
| June 2018 | 55                       | 7.96                       | 47.27        | 52.72            | 29.17              | 39.32              | 54.59                    |
| July 2018 | 108                      | 12.08                      | 52.77        | 47.22            | 26.52              | 32.56              | 78.72                    |
| Aug. 2018 | 341                      | 24.05                      | 59.82        | 40.17            | 25.62              | 32                 | 77.6                     |
| Sept. 2018 | 233                     | 16.69                      | 59.22        | 40.77            | 24.17              | 33.58              | 70.79                    |
| Oct. 2018 | 175                      | 12.58                      | 59.42        | 40.57            | 22.32              | 37.13              | 49.64                    |
| Nov. 2018 | 118                      | 18.02                      | 66.94        | 33.05            | 18.53              | 33.46              | 46.81                    |
| Dec. 2018 | 150                      | 20.86                      | 67.33        | 32.66            | 14.32              | 27.73              | 44.75                    |
Table 4. Monthly average AQI and respiratory admissions.

| Month          | Average AQI | % Respiratory admissions |
|----------------|-------------|--------------------------|
| November, 2017 | 227.14      | 35.36                    |
| December, 2017 | 134.72      | 26.16                    |
| January, 2018  | 197.21      | 29.66                    |
| February, 2018 | 235.49      | 34.55                    |
| March, 2018    | 166.85      | 26.90                    |
| April, 2018    | 208.16      | 24.65                    |
| May, 2018      | 201.88      | 15.52                    |
| June, 2018     | 144.82      | 7.96                     |
| July, 2018     | 96.71       | 12.08                    |
| August, 2018   | 96.51       | 24.05                    |
| September, 2018| 89.22       | 16.69                    |
| October, 2018  | 238.18      | 12.58                    |
| November, 2018 | 227.16      | 18.02                    |
| December, 2018 | 192.58      | 20.86                    |

Note **

Winter (January, February), Summer (March, April, May), Monsoon (June, July, August, September) and Post-Monsoon (October, November, December).

The percentage of respiratory admission in each season clearly shows the highest percentage in the winter as given in Table 3. The most humid month in the study period was July 2018, with a mean humidity of 78.72% and it had 12.08% respiratory admissions of which 52.77% were wheezers. The least humid month was April 2018 with a mean humidity of 31.97%. It had 24.65% respiratory admissions out of which 50.93% were wheezers.

The annual average PM$_{2.5}$ concentration at Ahmedabad was $80.27 \pm 25.36 \mu g m^{-3}$ which is about a factor of two higher than that recommended by the NAAQS (India), 2009 and more than eight times as recommended by the WHO. The average PM$_{2.5}$ for February is the highest (102.9 $\mu g m^{-3}$) with the highest percentage of respiratory admission of 34.55% including 62.42% of wheezers. The lowest monthly mean PM$_{2.5}$ was for September when PM$_{2.5}$ was 50.9 $\mu g m^{-3}$ with only 16.69% respiratory admissions including 59.22% of wheezers. The months with average PM$_{2.5}$ higher than the annual average of 80.2 $\mu g m^{-3}$ had on average of 23.12% respiratory admissions including 61.17% wheezers while the months with PM$_{2.5}$ less than the annual average of 80.2 $\mu g m^{-3}$ had on average of 17.38% respiratory admissions including 56.70% wheezers.

The results revealed that AQI was Good or Satisfactory on 18% (n = 68) days, Moderate on 50% (n = 181) days, Poor on 28% (n = 101) days and Very Poor on 4% (n = 15) days. The month-wise average of PM$_{2.5}$ for winter (January–February; 59 days), summer (March–May; 92 days), monsoon (June–September; 122 days), and post-monsoon (October–December; 153 days) are shown in Table 4. The relative risk for the number of respiratory admissions (Table 5) due to ambient PM$_{2.5}$ levels in winter was 1.16 (95% CI: 1.09–1.23), in summer was 1.15 (95% CI: 1.09–1.21), in monsoon was 1.08 (95% CI: 1.03–1.13) and in post-monsoon was 1.15 (95% CI: 1.07–1.23). This study also estimated, using the WHO/Europe’s software tool AirQ+, the number of attributable cases per 100,000 population (of children under 6) at risk was 45 (95% CI: 21–68) in winter, 41 (95% CI: 19–63) in summer, 25 (95% CI: 11–39) in monsoon, and 42 (95% CI: 18–66) in the post-monsoon season. Thus, the issue of PM$_{2.5}$ linked to respiratory admissions in Ahmedabad city in western India seems conspicuous throughout the year with substantially high admissions during winter, summer, and post-monsoon seasons.

4 DISCUSSION

The present research work is a prospective observational study of the effect of environmental factors on the respiratory health of children. The study reported more male admissions (~20%)
Table 5. Relative risk (RR) and population attributable risk of respiratory admissions of children under 6 due to short-term exposure to PM$_{2.5}$ during different seasons in Ahmedabad city.

| Season       | PM$_{2.5}$ (µg m$^{-3}$) | Mean ± SD | RR | Estimated number of Attributable Cases per 100,000 Population at Risk |
|--------------|---------------------------|-----------|----|---------------------------------------------------------------------|
| Winter       | 96.00 ±20.54              | 1.16      | 1.09 | 1.23 | 45 (21‒68) |
| Summer       | 88.07± 14.92              | 1.15      | 1.09 | 1.21 | 41 (19‒63) |
| Monsoon      | 57.98± 18.81              | 1.08      | 1.03 | 1.13 | 25 (11‒39) |
| Post-monsoon | 88.99 ± 25.28             | 1.15      | 1.07 | 1.23 | 42 (18‒66) |

Note: Winter (January, February), Summer (March, April, May), Monsoon (June, July, August, September), and Post-Monsoon (October, November, December).

as compared to female admissions. This is in synchrony with a study that presented a hypothesis that gender plays a role in susceptibility to respiratory diseases in childhood (Urooj et al., 2017). The predominance of males might be because of being more vulnerable to infections. Secondly, in developing countries, society pays more attention to the health of male children and seeks early medical help for their survival. The infant’s age is most susceptible for respiratory problems that are probably because young children have less compliant lungs, a larger proportion of small airways, compliant chest wall, the composition of tracheal cartilage and bronchial smooth muscles, and less immature immune system, making them more vulnerable to respiratory diseases and other infections and thus increasing their morbidity and mortality (Chang et al., 2003).

According to the modified Kuppuswamy classification, all patients were from a lower socioeconomic class, as the majority of patients are from lower-income groups. Low socioeconomic status can become a risk factor for the development of asthma, symptoms common in asthma, and chronic productive cough. Similar findings were reported from a study conducted in North Sweden on socio-economic status and incidence of asthma and respiratory symptoms (Hedlund et al., 2006). Their study reported that most disease and poor health, in general, was associated with low socioeconomic status. There are several possible confounders, including lifestyle factors, smoking habits, diet, physical activity, body mass index, and occupational exposure that may be of importance. Occupational exposure to dust and fumes may contribute to increased risk amongst the lower socioeconomic class. Poorer access to healthcare in lower socioeconomic classes might also be a contributory factor. Several studies have found a significant association between acute respiratory infection (ARI) and social class (Gupta et al., 1999; Deb, 1998). Children of the lower socio-economic class were at higher risk of ARI episodes, and ARI decreases with the rise in per capita income. Mitra et al. (2001) evaluated a risk ratio of 3.19 in children belonging to lower socioeconomic class for developing episodes of ARI. The research findings demonstrate that most of the children admitted were exposed to tobacco smoke. Furthermore, Singh et al. (1996) in their descriptive report on the impact of passive smoking reported that passive smoking irritates mucous membranes of the eyes and respiratory tract, predisposing passive smokers to more frequent upper respiratory tract infections, aggravation of asthma, particularly a problem for infants and children. Jing et al. (2019) in a study of 378 children with asthma showed that passive smoking induces pediatric asthma by significantly reducing the ratio of T-reg/Th17 cells ($p < 0.05$). The incidence and recurrence of wheezing illness in early life is increased if there is smoking activity by the household/s. A stronger influence of parental smoking has been noted earlier on viral associated wheezing and a weaker relationship with atopic wheezing (Cook and Strachan, 1997).

The majority of the children were residents of remote areas in the current study. They are exposed to dust and particulate matter as well as to automobile exhaust emissions which have adverse effects on respiratory mucosa. Epidemiological studies have linked residing in proximity to busy roads with adverse health outcomes, including respiratory symptoms and asthma (Kim et al., 2008; McConnell et al., 2006). At a global level, the ill-effects of indoor AP result in 2 million premature deaths per annum, of which 44% is only due to pneumonia. Young children are affected more as they spend maximum time at home (Bassani et al., 2010). Studies have observed a higher prevalence of ARI in children of mothers who were exposed to emissions from smoky chulhas (Thakur et al., 2017; Arlington et al., 2019). These individual environmental risk factors can be
modified by improving the standard of living of an individual and by spreading awareness regarding these risk factors. A collective effort from all stakeholders may prove beneficial in this regard.

The findings of our study showed that 438 children (16.33%) suffered from pneumonia. It is much lower than a study conducted by Nantanda et al. (2020), in under-five children in Uganda that estimated the proportion of pneumonia as 61.9%. About 601 (22.4%) children suffered from an upper respiratory infection and 31 children suffered from empyema. The proportion of empyema in total hospital admissions was 0.25%. The total respiratory admission is estimated at 1.15%. In a similar study carried out by the Department of Pediatrics, King George Hospital, Vishakapatnam observed that out of 5407 total cases admitted 72 (1.44%) cases were having empyema (Acharya et al., 2003). Many hosts, agents, and environmental factors play a role in regulating a spectrum of diseases. Due to climate change, these factors are getting affected to some or more and the spectrum of disease is changing over the past few decades. For example, climate-related extreme events like floods and droughts have been found to be linked with the mental health of children (UNICEF, 2021). For instance, a previous study has found that children exposed in-utero to drought have significantly lower scores on math and reading tests (Millett and Shah, 2012). Furthermore, changing climate scenario is altering the precipitation patterns and increasing the average temperature of the globe leading to an alteration in vectors ecology and hence facilitating the spread of vector-borne infections such as dengue into new areas (CBHI, 2018). A long-term study would be required to understand these climatic influenced changes in more detail.

Laboratory and clinical studies based evidences suggest that temperature can directly influence Respiratory Tract Infections (RTIs) in children by affecting inflammation pathways or pathophysiological responses, such as vasoconstriction in the respiratory tract mucosa and suppression of immune response (Graudenz et al., 2006). Exposure to cold air could induce an increased number of granulocytes and macrophages in the lower airways and be possibly associated with the development of RTIs (Rao et al., 2018). Koskela and Tukiainen (1995) showed that cooling of the skin of the face might be a trigger for bronchoconstriction during resting nasal ventilation in cold air (Larsson et al., 1998). In addition, low temperature may also indirectly affect RTI triggers, such as viral infections, bacterial activity, and time spent outdoors (Clary-Meinesz et al., 1992). This is evident in the present study by the higher relative risk of the number of admission of patients with respiratory illness in the post-monsoon season that covers the month October to December which is transitional months in western India and demonstrates a decline in temperature followed by winter in January and February. Thus, changes in meteorological factors affect the respiratory system and in particular are thought to be substantial causes of induced bronchial asthma, tracheitis, bronchitis, pneumonia, among other respiratory diseases. Furthermore, an increase in the concentration of PM$_{2.5}$ was found to be associated with an increase in the percentage of respiratory admissions in this study.

One of the limitations of this study is that it is an observational study that only assesses the individual association between the PM$_{2.5}$ and other environmental factors and the number of respiratory admissions without looking into underlying host factors and infective agents. It will be a massive task to disseminate such information to end-users as it requires literacy, good socio-economic status, and awareness, among others. Furthermore, we have the health data only for one year so we will be continuing this study for a decade or so to build up good statistics for future studies. Nevertheless, this study provides baseline information from the city of Ahmedabad on the linkage between AP and respiratory admissions which could be utilized by policymakers and concerned stakeholders to synthesize a framework to provide a better air quality not only to the children but to everyone.

5 CONCLUSIONS

As observed in the study, the outdoor environmental factors affect the respiratory health of children in varying proportions. The residential distance of fewer than 500 meters from the main road could be one of the most significant risk factors. These contributors can be avoided by a good living standard for an individual. The major findings from this study are summarized below:
1. AP measured objectively by the PM$_{2.5}$ and Air Quality Index (AQI) has a detrimental effect on the respiratory health of children under 6.

2. The relative risk (estimated using WHO/Europe’s AIRQ+ tool) for the number of respiratory admissions of children due to ambient PM$_{2.5}$ levels in winter was 1.16 (95% CI: 1.09–1.23), in summer was 1.15 (95% CI: 1.09–1.21), in monsoon was 1.08 (95% CI: 1.03–1.13) and in post-monsoon was 1.15 (95% CI: 1.07–1.23).

3. Air pollution impact seems substantially high for children during winter, summer, and post-monsoon season as evident from the number of attributable cases for respiratory admissions – 45 (95% CI: 21–68) in winter, 41 (95% CI: 19–63) in summer, 25 (95% CI: 11–39) in monsoon, and 42 (95% CI: 18–66) in post-monsoon season per 100,000 population of children under 6 at risk.

4. Mitigation of AP if done appropriately may significantly reduce the burden of disease. AQI should be developed as a tool to predict the occurrence of exacerbations in patients with respiratory illnesses to significantly reduce the morbidity due to AP. Efforts should be made to maintain a good AQI to decrease the proportion of respiratory diseases in the pediatric population. It is a joint task by all stakeholders to achieve clean air for all.

ACKNOWLEDGEMENTS

We thank Dr. Dipti M. Shah (Dean & Institutional head and Prof. of Gynaecology) for providing support by approving this study. The authors express special gratitude and thank all our patients and their family for their kind support. We thank the anonymous reviewers for providing constructive comments and suggestions. Authors would also like to thank Prof. R. Balasubramanian for the editorial handling of the manuscript.

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