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

Khyati M. Kakkad[1], Chirantap Oza[1*], Priya Dutta[2], Varsha Chorsiya ⓘ[3], Prashant Rajput ⓘ[4†]

[1] A.M.C Medical Education Trust Medical College and LG hospital, Ahmedabad 380008, India
[2] Indian Institute of Public Health Gandhinagar 382042, India
[3] School of Physiotherapy, Delhi Pharmaceutical Sciences and Research University, New Delhi 110017, India
[4] Centre 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 $PM_{2.5}$ 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 1st November 2017–31st December 2018 at a tertiary care hospital in Ahmedabad has been conducted to decipher the seasonal impact of $PM_{2.5}$ 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 $PM_{2.5}$ 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, $PM_{2.5}$ pollution profile, WHO's updated counterfactual value for short-term $PM_{2.5}$ exposure (= 15 µg m^{-3}). Accordingly, the RR for the number of respiratory admissions of children due to ambient levels of $PM_{2.5}$ 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, $PM_{2.5}$, AirQ+, Respiratory admissions, India

1 INTRODUCTION

Air pollution (AP) affects severely human health and facet of life. The $PM_{2.5}$ 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 $PM_{2.5}$ (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 $PM_{2.5}$ is 15 µg m^{-3} for daily average exposure and 5 µg m^{-3} for annual average exposure (WHO, 2021). Several studies have provided evidence for both acute and chronic health effects of $PM_{2.5}$
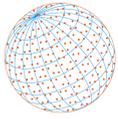
(Kampa and Castanas, 2008; Cohen *et al.*, 2005; Wong *et al.*, 2008; Laumbach and Kipen, 2012; Guttikunda *et al.*, 2014; Vos *et al.*, 2017). In the World Health Organization's (WHO) 2016 urban air quality assessment report, 13 out of the top 20 most polluted cities are located in India (Guttikunda *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 Pande, 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.

$PM_{2.5}$ 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). $PM_{2.5}$ 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 $PM_{2.5}$ 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, $PM_{2.5}$ 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 $PM_{2.5}$ 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 1st November 2017–31st 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 $PM_{2.5}$ 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
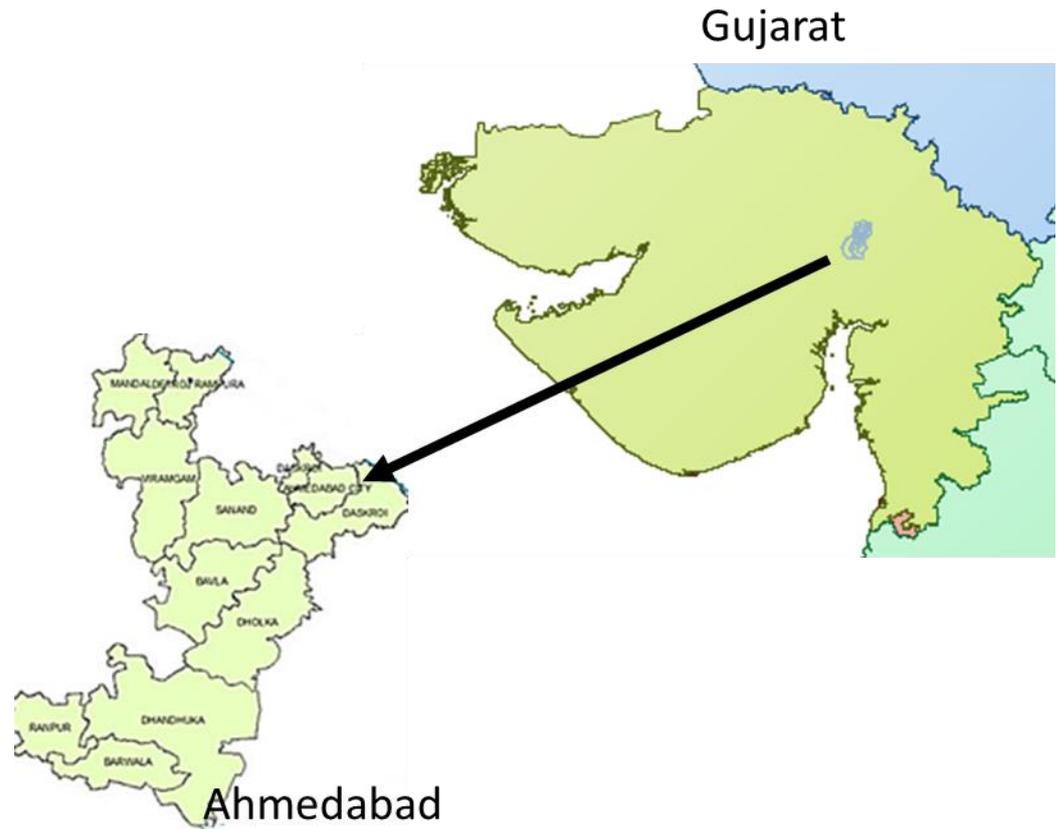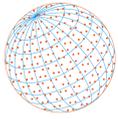
Fig. 1. Figure showing the study area of Ahmedabad city in the states of Gujarat in western India (source: map of India).

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, pulsus paradoxus	Bilateral symmetric air trapping, patches of atelectasis
	WALRI	Fever, cough, dyspnoea	Non-specific
Non-wheezing Disorders	Pneumonia	Fever, dyspnoea, grunting respiration, tachypnoea, signs of consolidation	Lobar consolidation, pneumatocele, hazy exudates from hilar region,
	Empyema	Fever, difficulty in breathing, toxic look, decreased movement of respiration	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-Details). 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)
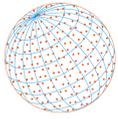
classification. For example, the Ahmedabad AQI uses five AQI categories: Good (0–100), Moderate (101–200), Poor (201–300), Very Poor (301–400), and Severe (401–500).

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 of 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-wheezer admissions with mean temperature and humidity are given in Table 3.
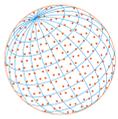
Table 2. Demographic risk factors for respiratory patients considered in this study.

Month	Respiratory admissions	Passive smoking		Distance < 500 m		Solid fuel		Kacha house		Zero windows in house		> 3 person in house	
		N	%	N	%	N	%	N	%	N	%	N	%
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
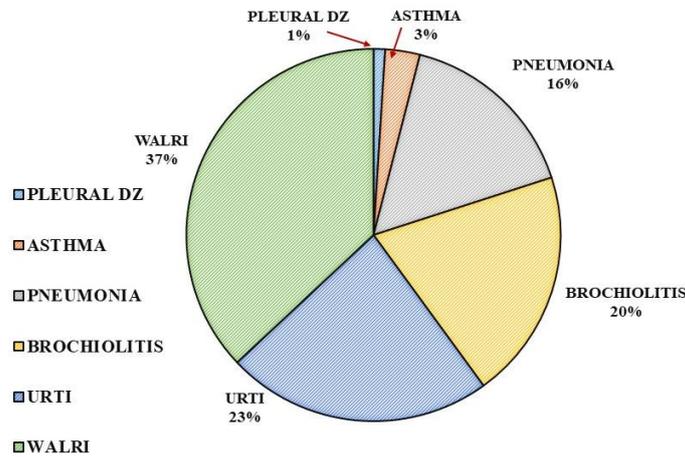
Fig. 2. Respiratory admissions for Wheezing (bronchiolitis, WALRI, asthma) and non-wheezing disorders (pneumonia, empyema, upper respiratory tract infections).

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
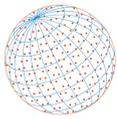
Table 4. Monthly average AQI and respiratory admissions.

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**

Good (0–50)	Satisfactory (51–100)	Moderate (101–200)	Poor (201–300)	Very Poor (301–400)	Severe (401–500)

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 ± 25.36 µg 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 µg 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 µg 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 µg 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 µg 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%)
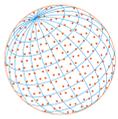
Table 5. Relative risk (RR) and population attributable risk of respiratory admissions of children under 6 due to short-term exposure to $PM_{2.5}$ during different seasons in Ahmedabad city.

Season	$PM_{2.5}$ (µg m^{-3})	RR			Estimated number of Attributable Cases per 100,000 Population at Risk
	Mean ± SD	Mean	Lower	Upper	(#)
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 socio-economic 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
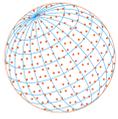
modified by improving the standard of living of an individual and by spreading awareness regarding these risk factors. A collective effort from all stakeholders may prove beneficial in this regard.

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, Vishakhapatnam 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:
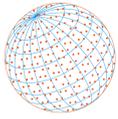
1. AP measured objectively by the $PM_{2.5}$ and Air Quality Index (AQI) has a detrimental effect on the respiratory health of children under 6.
2. The relative risk (estimated using WHO/Europe's AIRQ+ tool) for the number of respiratory admissions of children due to ambient $PM_{2.5}$ levels in winter 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.
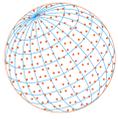
ACKNOWLEDGEMENTS

REFERENCES

Acharya, D., Prasanna, K.S., Nair, S., Rao, R.S.P. (2003). Acute respiratory infections in children: A community based longitudinal study in south India. Indian J. Public Health 47, 7–13.

Arlington, L., Patel, A.B., Simmons, E., Kurhe, K., Prakash, A., Rao, S.R., Hibberd, P.L. (2019). Duration of solid fuel cookstove use is associated with increased risk of acute lower respiratory infection among children under six months in rural central India. PLoS One 14, e0224374. https://doi.org/10.1371/journal.pone.0224374

Bassani, D.G., Jha, P., Dhingra, N., Kumar, R. (2010). Child mortality from solid-fuel use in India: A nationally-representative case-control study. BMC Public Health 10, 491. https://doi.org/10.1186/1471-2458-10-491

Bateson, T.F., Schwartz, J. (2007). Children's response to air pollutants. J. Toxicol. Environ. Health Part A 71, 238–243. https://doi.org/10.1080/15287390701598234

Central Bureau of Health Intelligence (CBHI) (2018). National Health Profile. https://www.cbhidghs.nic.in/index1.php?lang=1&level=2&sublinkid=88&lid=1138

Chang, A.B., Masel, J.P., Boyce, N.C., Torzillo, P.J. (2003). Respiratory morbidity in central Australian Aboriginal children with alveolar lobar abnormalities. Med. J. Aust. 178, 490–494. https://doi.org/10.5694/j.1326-5377.2003.tb05322.x

Clary-Meinesz, C.F., Cosson, J., Huitorel, P., Blaive, B. (1992). Temperature effect on the ciliary beat frequency of human nasal and tracheal ciliated cells. Mol. Biol. Cell 76, 335–338. https://doi.org/10.1016/0248-4900(92)90436-5

Cohen, A.J., Ross Anderson, H., Ostro, B., Pandey, K.D., Krzyzanowski, M., Künzli, N., Gutschmidt, K., Pope, A., Romieu, I., Samet, J.M., Smith, K. (2005). The global burden of disease due to outdoor air pollution. J. Toxicol. Environ. Health Part A 68, 1301–1307. https://doi.org/10.1080/15287390590936166

Cook, D.G., Strachan, D.P. (1997). Health effects of passive smoking. 3. Parental smoking and prevalence of respiratory symptoms and asthma in school age children. Thorax 52, 1081–1094. https://doi.org/10.1136/thx.52.12.1081

Deb, S.K. (1998). Acute respiratory disease survey in Tripura in case of children below five years of age. J. Indian Med. Assoc. 96, 111–116.
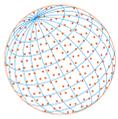
Denny, F.W., Loda, F.A. (1986). Acute respiratory infections are the leading cause of death in children in developing countries. Am. J. Trop. Med. Hyg. 35, 1–2. https://doi.org/10.4269/ajtmh.1986.35.1

Evans, J., van Donkelaar, A., Martin, R.V., Burnett, R., Rainham, D.G., Birkett, N.J., Krewski, D. (2013). Estimates of global mortality attributable to particulate air pollution using satellite imagery. Environ. Res. 120, 33–42. https://doi.org/10.1016/j.envres.2012.08.005

Graudenz, G.S., Landgraf, R.G., Jancar, S., Tribess, A., Fonseca, S.G., Fae, K.C., Kalil, J. (2006). The role of allergic rhinitis in nasal responses to sudden temperature changes. J. Allergy Clin. Immunol. 118, 1126–1132. https://doi.org/10.1016/j.jaci.2006.07.005

Greenstone, M., Pande, R. (2014). India's Particulate Problem. The New York Times. https://www.nytimes.com/2014/02/10/opinion/indias-particulate-problem.html

Gupta, R.K., Kumar, A., Singh, P. (1999). Factor analysis of acute respiratory infections among under fives in Delhi slums. Indian Pediatr. 36, 1144–1149.

Guttikunda, S.K., Goel, R., Pant, P. (2014). Nature of air pollution, emission sources, and management in the Indian cities. Atmos. Environ. 95, 501–510. https://doi.org/10.1016/j.atmosenv.2014.07.006

Hedlund, U., Eriksson, K., Rönmark, E. (2006). Socio-economic status is related to incidence of asthma and respiratory symptoms in adults. Eur. Respir. J. 28, 303–410. https://doi.org/10.1183/09031936.06.00108105

Indian Council of Medical Research (ICMR) (2017). National ethical guidelines for biomedical and health research involving human participants. Indian Council of Medical Research, New Delhi. https://main.icmr.nic.in/sites/default/files/guidelines/ICMR_Ethical_Guidelines_2017.pdf

Jiang, X.Q., Mei, X.D., Feng, D. (2016). Air pollution and chronic airway diseases: what should people know and do? J. Thorac. Dis. 8, E31–E40. https://doi.org/10.3978/j.issn.2072-1439.2015.11.50

Jing, W., Wang, W., Liu, Q. (2019). Passive smoking induces pediatric asthma by affecting the balance of Treg/Th17 cells. Pediatr. Res. 85, 469–476. https://doi.org/10.1038/s41390-019-0276-0

Kampa, M., Castanas, E. (2008). Human health effects of air pollution. Environ. Pollut. 151, 362–367. https://doi.org/10.1016/j.envpol.2007.06.012

Kerem, E. (1996). Why do infants and small children breathe faster? Pediatr. Pulmonol. 21, 65–68. https://doi.org/10.1002/1099-0496(199601)21:1<65::aid-ppul1950210104>3.0.co;2-r

Kim, J.J., Huen, K., Adams, S., Smorodinsky, S., Hoats, A., Malig, B., Lipsett, M., Ostro, B. (2008). Residential traffic and children's respiratory health. Environ. Health Perspect. 116, 1274–1279. https://doi.org/10.1289/ehp.10735

Koskela, H., Tukiainen, H. (1995). Facial cooling, but not nasal breathing of cold air, induces bronchoconstriction: A study in asthmatic and healthy subjects. Eur. Respir. J. 8, 2088–2093.

Lanata, C.F., Fischer-Walker, C.L., Olascoaga, A.C., Torres, C.X., Aryee, M.J., Black, R.E. (2013). Global causes of diarrheal disease mortality in children< 5 years of age: A systematic review. PLoS One 8, e72788. https://doi.org/10.1371/journal.pone.0072788

Larsson, K., Tornling, G., Gavhed, D., Muller-Suur, C., Palmberg, L. (1998). Inhalation of cold air increases the number of inflammatory cells in the lungs in healthy subjects. Eur. Respir. J. 12, 825–830. https://doi.org/10.1183/090319 36.98.12040825

Laumbach, R.J., Kipen, H.M. (2012). Respiratory health effects of air pollution: Update on biomass smoke and traffic pollution. J. Allergy Clin. Immunol. 129, 3–11. https://doi.org/10.1016/j.jaci.2011.11.021

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., Bezirtzoglou, E. (2020). Environmental and health impacts of air pollution: A review. Front. Public Health. 8, 14. https://doi.org/10.3389/fpubh.2020.00014

Manojkumar, N., Srimuruganandam, B. (2021). Health effects of particulate matter in major Indian cities. Int. J. Environ. Health Res. 31, 258–270. https://doi.org/10.1080/09603123.2019.1651257

McConnell, R., Berhane, K., Yao, L., Jerrett, M., Lurmann, F., Gilliland, F., Künzli, N., Gauderman, J., Avol, E.D., Thomas, D., Peters, J. (2006). Traffic, susceptibility, and childhood asthma. Environ. Health Perspect. 114, 766–772. https://doi.org/10.1289/ehp.8594

Millett, B., Shah, M. (2012). The Effects of In-Utero Shocks on Cognitive Test Scores: Evidence

from Droughts in India. https://www.semanticscholar.org/paper/The-Effects-of-In-Utero-Shocks-on-Cognitive-Test-%3A-Millett-Shah/ac2b75f0ba39d0e9b93489689fea7aa042302d1d

Mills, N.L., Donaldson, K., Hadoke, P.W., Boon, N.A., MacNee, W., Cassee, F.R., Sandström, T., Blomberg, A., Newby, D.E. (2009). Adverse cardiovascular effects of air pollution. Nat. Clin. Pract. Cardiovasc. Med. 6, 36–44. https://doi.org/10.1038/ncpcardio1399

Mitra, N.K. (2001). A longitudinal study on ARI among rural under-fives. Indian J. Community Med. 26, 8–11.

Nantanda, R., Siersma, V., Ndeezi, G., Tumwine, J.K., Østergaard, M.S. (2020). Symptom-based screening tool for asthma syndrome among young children in Uganda. npj Prim. Care Respir. Med. 30, 1–6. https://doi.org/10.1038/s41533-020-0175-1

Parthasarathy, B., Sontakke, N.A., Monot, A.A., Kothawale, D.R. (1987). Droughts/floods in the summer monsoon season over different meteorological subdivisions of India for the period 1871-1984. J. Climatol. 7, 57–70. https://doi.org/10.1002/joc.3370070106

Rajput, P., Izhar, S., Gupta, T. (2019). Deposition modeling of ambient aerosols in human respiratory system: Health implication of fine particles penetration into pulmonary region. Atmos. Pollut. Res. 10, 334–343. https://doi.org/10.1016/j.apr.2018.08.013

Rao, M.S.P., Chandra, P.S. (2018). A study of paediatric empyema thoracis presentation in a tertiary care hospital in Visakhapatnam, India. Int. J. Contemp. Pediatr. 5, 572–575. https://doi.org/10.18203/2349-3291.ijcp20180557

Saleem, S.M. (2020). Modified Kuppuswamy socioeconomic scale updated for the year 2020. Indian J. Forensic Community Med. 7, 1–3. https://doi.org/10.18231/j.ijfcm.2020.001

Sharma, S.B., Jain, S., Khirwadkar, P., Kulkarni, S. (2013). The effects of air pollution on the environment and human health. Indian J. Res. Pharm. Biotechnol. 1, 391–396.

Singh, U.K., Suman, S., Singh, V.K., Sinha, R.K. (1996). Impact of Passive smoking. Indian J. Pediatr. 63, 139–141. https://doi.org/10.1007/BF02845234

Thakur, M., Boudewijns, E.A., Babu, G.R., Winkens, B., de Witte, L.P., Gruiskens, J., Sushama, P., Ghergu, C.T., van Schayck, O.C.P. (2017). Low-smoke chulha in Indian slums: study protocol for a randomised controlled trial. BMC Public Health 17, 454. https://doi.org/10.1186/s12889-017-4369-6

United Nations International Children's Emergency Fund (UNICEF) (2021). The climate crisis is a child rights crisis, United Nations Children's Fund. UNICEF, USA. https://www.unicef.org/media/105376/file/UNICEF-climate-crisis-child-rights-crisis.pdf

Urooj, S., Shaista, E., Farah, A. (2017). Frequency and pattern of respiratory diseases in children. Int. J. Contemp. Pediatr. 4, 1567–1571. https://doi.org/10.18203/2349-3291.ijcp20173765

U.S. EPA (2021). Particle pollution exposure. https://www.epa.gov/pmcourse/particle-pollution-exposure

Vos, T., Abajobir, A.A., Abate, K.H., Abbafati, C., Abbas, K.M., Abd-Allah, F., Abdulkader, R.S., Abdulle, A.M., Abebo, T.A., Abera, S.F., Aboyans, V. (2017). Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990–2016: A systematic analysis for the Global Burden of Disease Study 2016. Lancet 390, 1211–1259. https://doi.org/10.1016/S0140-6736(17)32154-2

Walker, C.L.F., Rudan, I., Liu, L., Nair, H., Theodoratou, E., Bhutta, Z.A., O'Brien, K.L., Campbell, H., Black, R.E. (2013). Global burden of childhood pneumonia and diarrhoea. Lancet 381, 1405–1416. https://doi.org/10.1016/S0140-6736(13)60222-6

Wong, C.M., Vichit-Vadakan, N., Kan, H., Qian, Z. (2008). Public Health and Air Pollution in Asia (PAPA): A multicity study of short-term effects of air pollution on mortality. Environ. Health Perspect. 116, 1195–1202. https://doi.org/10.1289/ehp.11257

World Health Organization (WHO) (2016). 7 million deaths annually linked to air pollution. http://www.who.int/phe/health_topics/outdoorair/databases/en/ (accessed 23 March 2021).

World Health Organization (WHO) (2021). What are the WHO Air quality guidelines? Improving health by reducing air pollution. https://www.who.int/news-room/feature-stories/detail/what-are-the-who-air-quality-guidelines

World Health Organization-Europe (WHO-Europe) (2018). AirQ+: software tool for health risk assessment of air pollution. https://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/airq-software-tool-for-health-risk-assessment-of-air-pollution (accessed 2 October 2018).
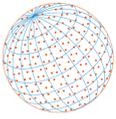
World Medical Association (WMA) (2013). World medical association declaration of Helsinki: Ethical principles for medical research involving human subjects. JAMA 310, 2191–2194. https://doi.org/10.1001/jama.2013.281053