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Meteorological parameters and pollutants on asthma exacerbation in Bangalore, India – an ecological retrospective time-series study

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Abstract

Background: Literature has shown a significant association between asthma exacerbations and pollutant levels during that time. There is very limited evidence in India, especially Bangalore, for impacts of meteorological changes and pollution on asthma hospital admissions in adults. The objective was to study the impact of air pollution and meteorological parameters on asthma exacerbation in Bangalore.
Methods: This study quantitatively analyzed the relation between acute exacerbations of asthma and related admissions to the hospital with the air pollution and the meteorological conditions during that time. Data regarding the daily hospital admissions in about 13 tertiary care centers in Bangalore, Karnataka and air pollutant levels and the meteorological conditions prevailing during each day over a year were collected from the Karnataka State pollution control board and meteorology departments, respectively.
Results: An average daily asthma admission of 4.84 ± 2.91, with clear seasonal variation and autocorrelations between meteorological parameters and pollutants was observed. Multiple linear regression analysis revealed that average temperature ($p = 0.005$) and nitrogen dioxide (NO_2) ($p = 0.034$) were the two factors that were affecting the number of admissions. Quasi-poisson regression analysis using multi-pollutants and meteorological variables showed that particulate matter and NO_2 had significant lag effect for up to 5 days ($p < 0.05$) and rainfall for 1 day ($p < 0.001$).
Conclusions: In Bangalore city, levels of NO_2 and particulate matter, temperature, rainfall, and season increase asthma exacerbations.

Keywords: ambient air pollution; asthma exacerbation; emergency visits; humidity; rainfall; temperature.

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Introduction

Numerous time series studies have shown that the external environment has a significant effect on human beings [1]. Asthma is a common chronic inflammatory disease of the airways, due to hypersensitivity of nerve endings, characterized by recurring episodic reversible breathlessness and wheezing, with acute exacerbations interspersed with symptom-free period, owing to airflow obstruction or bronchospasm, which vary in severity and frequency from person to person. The World Health Organization recently estimated that 235 million people suffer from asthma, worldwide [2].

Bangalore, the capital city of Karnataka, India (located at the center of the southern peninsula of India at 77°35′ E longitude and 12°58′ N latitude) has been christened the ‘Asthma Capital’ since 2007. The pollution levels in Bangalore are rising due to urbanization [‘Silicon Valley of India’ (Information technology capital)] and increasing population (from 4.301 million in 2001 to 9.621 million in 2011) as a result of migration [3]. Further, the atmosphere in Bangalore (‘Garden city of India’) is composed of a high density of pollens, which might trigger an asthma attack, behaving like allergens [4].

Among the various risk factors attributed in the causation of asthma, inhaled substances and particles are the strongest in provoking allergic reactions [2]. The meteorological parameters, having a significant effect on emergency room visits, include temperature [5], diurnal temperature range [6], coarse particles [7], air pollutants such as levels of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter of < 10 µm aerodynamic diameter (PM_{10}) [6, 8, 9], humidity [10, 11] and many other factors. Although air pollution is the fifth leading cause of death in India [12], very few studies have looked into respiratory health or asthma emergency room visits due to, prevailing or change in, weather and pollutant levels [13–18]. Although national air quality standards have been set in India [19], the pollutant levels have crossed the air quality limits in many cities, indicating the emergency of the situation to bring in necessary remedial measures to control the same [20, 21]. There is little current research from Bangalore to allow us to reliably estimate the public health effects of short term changes in air pollution in terms of its impact on hospital admissions and mortality.

We thus conducted a retrospective environmental study in Bangalore. Data of emergency room visits due to asthma in tertiary care hospitals across Bangalore was collected and correlated with the pollutant levels and weather conditions prevailing during the same time. The objective of the present study was to assess the effect of meteorological changes and pollutant levels on exacerbations of asthma, as measured by admissions due to acute asthma and related illnesses in Bangalore hospitals.

Highlights

- Effect of air pollutants and meteorological parameters on asthma was studied.
- Average temperature and NO_2 raised the number of asthma attacks.
- NO_2 and particulate matter had a lag effect for up to 5 days.
- Rainfall had a lag effect for 1 day.

Materials and methods

This is a retrospective ecological time-series study where we recorded admission to the emergency department due to acute asthma at 13 different tertiary care hospitals distributed geographically and across the socio-economic class spectrum of Bangalore during a 12 month period, with respect to date of admission. Data from the emergency and admission records in the hospitals was referred to the International Classification of Diseases (ICD) code 493 subtypes (493.01 for extrinsic asthma with status asthmaticus, 493.02 for extrinsic asthma with [acute] exacerbation, 493.11 for intrinsic asthma with status asthmaticus, 493.12 for intrinsic asthma with [acute] exacerbation, 493.21 for chronic obstructive asthma with status asthmaticus, 493.22 for chronic obstructive asthma with [acute] exacerbation, 493.91 for asthma, unspecified type, with status asthmaticus, 493.92 for asthma, unspecified type, with [acute] exacerbation, 786.07 for wheezing) [22]. All hospitals keeping records of visits in the form of ICD coding, situated in urban Bangalore were included. We included individuals presenting with wheeze, shortness of breath, difficulty in breathing and all patients who were given inhalers or treatment for asthma. All individuals above the age of 18 years of either gender were included. Participants who were admitted due to any other cause such as cardiac problems, cor pulmonale, renal failure, stroke, epilepsy, or any other acute illness were excluded. Mean daily admissions for asthma exacerbations to the hospitals were noted.

Data of daily temperature (°C), humidity (%), rainfall (in cm), levels of SO_2, NO_2, PM_{10} (or total suspended particulate matter, measured using respirable dust sampler) and $PM_{2.5}$ (those < 2.5 µm aerodynamic diameter; respirable suspended particulate matter, measured using respirable dust sampler) recorded twice a week at five air quality monitoring centers in Bangalore were collected from the Central laboratory of Karnataka State Pollution Control Board and meteorological department for that year. The monitoring of these pollutants was carried out for 24 h (4-hourly sampling for SO_2 and NO_2 and 8-hourly sampling for PM_{10}) with a frequency of twice a week, to have 104 observations in a year.

Days where there was > 2 standard deviation from the meteorological and pollution baseline values were mapped. The correlation of these changes with the number of admissions was analyzed. As admission for asthma exacerbation will not occur on the same day, we looked at admissions within 5 days up to 30 days of such changes (lag effect).

Statistical analysis

All the quantitative variables like temperature, humidity, etc. were summarized in terms of descriptive statistics such as mean, median, standard deviation and interquartile range. The number of cases occurring in each month was expressed in percentages. The χ^2-test for trends was used to compare the difference in proportion of cases occurring in each month over a 1 year period of time. Further, the months were classified according to data from meteorological department into two broad seasons: cold – August to February, warm – March to July; and four seasons: dry – December to February, summer – March to May, monsoon – June to September, post monsoon – October and November. Pearson's correlation was used to determine the correlation between daily concentrations of each air pollutant and meteorological variables and proportion of asthma cases, season wise and for the whole year. Multiple linear regression was used to find out the independent predictors of the number of asthma admissions (dependent variable) considering all the environmental factors as independent variables. Autocorrelation was used to determine the serial correlation between the different months and different lags (considering a lag of up to 30 days). Poisson's regression was used for assessing single pollutants and meteorological variables individually that have a lag effect for 5 days up to 30 days using DLNM package in R statistical package [23]. Quasi-poisson regression (using a general additive model) was then used to estimate the association between pollutants and meteorological variables at different lag and hospital admissions. A p value of < 0.05 was considered statistically significant.

Protection of human and animal participants

The authors declare that no experiments were performed on humans or animals for this investigation.

Results

Table 1 summarizes the descriptive statistics of the hospital admissions, pollutants and weather parameters. A daily average of 4.84 ± 2.19 asthma admissions was seen. The number of patients were 4.41 ± 2.84 during warmer seasons of the year and increased to 5.16 ± 2.92 during the cold season of the year ($p = 0.015$).

We observed that the SO_2 levels (Table 1) were within the prescribed air quality standards (see Supplemental Table S1, Supplemental Figure S1), whereas NO_2 was higher by 27.6%, PM_{10} by 134.43% and $PM_{2.5}$ by 62.58% (Table 1).

We analyzed if there was any seasonal variation in asthma admissions, or if it was simply by chance. On χ^2 analysis, we found a significant difference between the observed number of admissions and the expected number, indicating that there is a monthly or seasonal variation in asthma admissions (Table 2).

On analysis of the number of admissions that significantly varied based on seasonal classification (Table 3), the highest number of admissions was during monsoon. Particulate matter is called the cold season pollutant. Here we found that the levels during warmer ($PM_{10} = 138.20 \pm 33.4$ μg/m^3 and $PM_{2.5}$ 60.49 ± 16.3 μg/m^3) and colder seasons ($PM_{10} = 147.84 \pm 48.5$ μg/m^3 and $PM_{2.5} = 70.79 \pm 26.6$ μg/m^3) were significantly different ($p = 0.084$ and $p = 0.001$ for PM_{10} and $PM_{2.5}$, respectively).

Table 1: Summary of environmental variables and daily hospital admissions data in Bangalore.

	Mean	SD	Min	Max	Percentiles			IQR
					25th	50th	75th	
Maximum temperature, °C	29.69	2.9	21.90	38.70	27.80	29.20	31.40	3.6
Minimum temperature, °C	19.28	2.2	13.40	24.20	17.90	19.60	20.50	2.6
Average temperature, °C	24.49	2.2	19.65	30.70	23.05	24.25	25.70	2.7
Temperature change (max–min)	– 10.42	2.7	– 18.8	– 3.4	– 12.5	– 10.5	– 8.4	4.1
Humidity, %	55.25	18.9	15.00	96.00	41.00	55.00	69.00	28
Rainfall, cm	4.12	9.6	0.10	73.40	0.15	1.10	4.00	3.9
SO_2, μg/m^3	7.82	2.6	5.15	33.90	6.73	7.40	8.10	1.4
NO_2, μg/m^3	51.04	10.4	6.50	88.60	45.10	52.50	58.05	12.9
$PM_{2.5}$, μg/m^3	65.03	23.4	21.00	176.00	47.35	62.50	77.50	30.2
PM_{10}, μg/m^3	140.66	43.8	23.00	301.00	106.75	137.00	170.50	63.8
Asthma admissions	4.69	2.9	0	19.00	3.00	4.00	6.00	3

IQR, interquartile range; NO_2, nitrogen dioxide; PM_{10}, aerodynamic diameter < 10 μm; $PM_{2.5}$, aerodynamic diameter < 2.5 μm; SO_2, sulfur dioxide; SD, standard deviation.

Table 2: Monthly seasonal variation of the number of asthma cases.

Month	Number of days	Number of cases in that month	Number of cases per day	Weighted average per day
June	30	135	4.50	2.29
July	31	172	5.55	3.02
August	31	198	6.39	3.47
September	30	165	5.50	2.80
October	31	141	4.55	2.47
November	30	150	5.00	2.55
December	31	162	5.23	2.84
January	31	155	5.00	2.72
February	28	122	4.36	1.93
March	31	129	4.16	2.26
April	30	93	3.10	1.58
May	31	145	4.68	2.54

Table 3: Variation in daily asthma admissions (expressed as median, interquartile range and percentage) based on seasons.

Season	Median no. of patients (IQR)	No. of patients	%	p-Value
Dry	4.50 (3.00–6.00)	90	22.7	0.048
Summer	4.00 (2.00–5.00)	92	23.29	
Monsoon	4.00 (2.00–7.00)	152	38.48	
Post monsoon	5.00 (3.00–6.00)	61	15.44	

IQR, interquartile range; No., number.

Table 4: Pearson correlation coefficients among environmental variables for the whole year and different seasons, Bangalore.

	Min temp	Temp change	Average temp	Humidity	SO_2	NO_2	$PM_{2.5}$	PM_{10}	Rainfall
Whole year									
Max temp	0.47[b]	– 0.69[b]	0.89[b]	– 0.58[b]	– 0.01	0.00	0.08	0.11	– 0.01
Min temp		0.32[b]	0.81[b]	0.15[b]	– 0.01	0.05	– 0.50[b]	– 0.39[b]	0.09
Temp change (max–min)			– 0.29[b]	0.74[b]	0.00	0.05	– 0.50[b]	– 0.43[b]	0.08
Average temp				– 0.31[b]	– 0.01	0.02	– 0.21[b]	– 0.13	0.04
Humidity					0.00	0.03	– 0.49[b]	– 0.49[b]	0.24[b]
Humidity change					0.03	0.04	– 0.05	– 0.07	0.10
SO_2						0.18[b]	0.00	0.02	0.21[a]
NO_2							0.02	0.17[b]	– 0.05
$PM_{2.5}$								0.76[b]	– 0.19[a]
PM_{10}									– 0.22[a]
Cold season									
Max temp	0.35[b]	– 0.69[b]	0.87[b]	– 0.67[b]	0.13	0.22[a]	0.14	0.22[a]	– 0.33[b]
Min temp		0.43[b]	0.77[b]	0.14	0.16	0.19[a]	– 0.44[b]	– 0.25[b]	– 0.08
Temp change (max–min)			– 0.24[b]	0.75[b]	0.01	– 0.05	– 0.52[b]	– 0.43[b]	0.25[a]
Average temp				– 0.38[b]	0.17	0.25[a]	– 0.15	0.00	– 0.28[a]
Humidity					– 0.10	0.00	– 0.40[b]	– 0.39[b]	0.34[b]
Humidity change					– 0.03	– 0.02	– 0.01	0.02	0.21
SO_2						0.25[a]	0.09	0.13	– 0.17
NO_2							– 0.05	0.13	– 0.38[a]
$PM_{2.5}$								0.62[b]	– 0.01
PM_{10}									– 0.05
Warm season									
Max temp	0.71[b]	– 0.92[b]	0.98[b]	– 0.72[b]	– 0.06	– 0.191[a]	0.216[a]	0.180[a]	0.03
Min temp		– 0.38[b]	0.85[b]	– 0.53[b]	– 0.14	– 0.09	0.17	0.172[a]	– 0.01
Temp change (max–min)			– 0.82[b]	0.66[b]	0.01	0.19[a]	– 0.19[a]	– 0.14	– 0.05
Average temp				– 0.71[b]	– 0.09	– 0.17[a]	0.22[a]	0.19[a]	0.02
Humidity					0.06	0.10	–0.29[b]	– 0.32[b]	0.19
Humidity change					0.06	0.10	– 0.06	– 0.11	0.07
SO_2						0.15	–0.09	– 0.06	0.32[b]
NO_2							0.07	0.23[b]	0.03
$PM_{2.5}$								0.78[b]	– 0.24[a]
PM_{10}									– 0.27[a]

[a]Correlation is significant at the 0.05 level (two-tailed). [b]Correlation is significant at the 0.01 level (two-tailed). NO_2, nitrogen dioxide; PM_{10}, aerodynamic diameter < 10 µm; $PM_{2.5}$, aerodynamic diameter < 2.5 µm; SO_2, sulfur dioxide; temp, temperature.

Table 4 shows the Pearson correlation coefficients for all year and by season. Through the year, statistically significant ($p < 0.05$) autocorrelations were observed between temperature change and humidity ($r \sim 0.74$), PM_{10} and $PM_{2.5}$ ($r \sim 0.76$), maximum temperature and humidity ($r \sim -0.58$), minimum temperature and PM_{10} ($r \sim -0.39$) and $PM_{2.5}$ ($r \sim -0.50$), humidity and PM_{10} ($r \sim -0.49$) and $PM_{2.5}$ ($r \sim -0.49$), rainfall and PM_{10} ($r \sim -0.22$) and $PM_{2.5}$ ($r \sim -0.19$). During the cold seasons of the year the autocorrelations found were maximum temperature with NO_2 ($r \sim 0.22$), PM_{10} ($r \sim 0.22$), humidity ($r \sim -0.67$) and rainfall ($r \sim -0.33$); minimum temperature with $PM_{2.5}$ ($r \sim -0.44$) and PM_{10} ($r \sim -0.25$); temperature change with humidity ($r \sim 0.75$), rainfall ($r \sim 0.25$), $PM_{2.5}$ ($r \sim -0.52$)

and PM_{10} (r ~ – 0.43); average temperature with humidity (r ~ – 0.38) and rainfall (r ~ 0.28); humidity with rainfall (r ~ 0.34), $PM_{2.5}$ (r ~ – 0.40) and PM_{10} (r ~ – 0.39); SO_2 with NO_2 (r ~ 0.25); NO_2 with rainfall (r ~ – 0.38). A change was observed when cold changed to warm season, in the type of correlation from positive to negative or vice versa or stronger correlations like maximum temperature with humidity (r ~ – 0.72) and NO_2 (r ~ – 0.19); minimum temperature with humidity (r ~ – 0.53) and PM_{10} (r ~ 0.17); temperature change with humidity (r ~ 0.66), NO_2 (r = 0.19) and $PM_{2.5}$ (r = – 0.19); average temperature with humidity (r = – 0.71) and NO_2 (r = – 0.17); SO_2 with rainfall (r = 0.32); NO_2 with PM_{10} (r = 0.23) and rainfall with PM_{10} (r = – 0.27) and $PM_{2.5}$ (r = – 0.24).

The number of patients admitted daily significantly correlated with maximum temperature (r = –0.12), average temperature (r = – 0.11), rainfall (r = 0.15) in the whole year and with rainfall during cold seasons (r = 0.29).

Since there were increased autocorrelations between meteorological parameters and pollutants, multiple linear regression analysis was carried out, which showed that average temperature (p = 0.005) and NO_2 (p = 0.034) were the two factors that affected the number of admissions. However, the model was able to predict only to an extent of 10.7% of the total variation in the asthma admissions. Durbin Watson estimate value was 1.6, revealing the presence of a slight positive autocorrelation. Thus, autocorrelation function analysis was employed to represent the degree of similarity between the number of cases occurring in a given month and lagged version of it in the previous months (Figures 1 and 2).

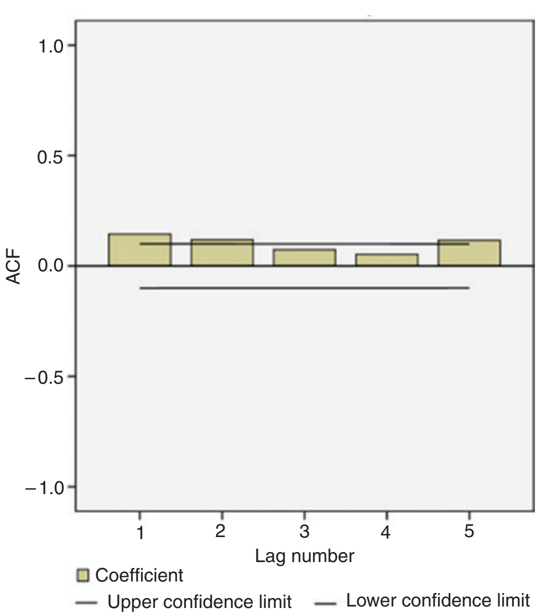

Figure 1: Autocorrelation at different lags for 5 lag days.
The Y axis indicates the value of correlation and X axis indicates the number of lags. The spike at lag 1 indicates a positive correlation between each series and the preceding value (r = 0.144). All the autocorrelations were statistically significant (p < 0.0001).

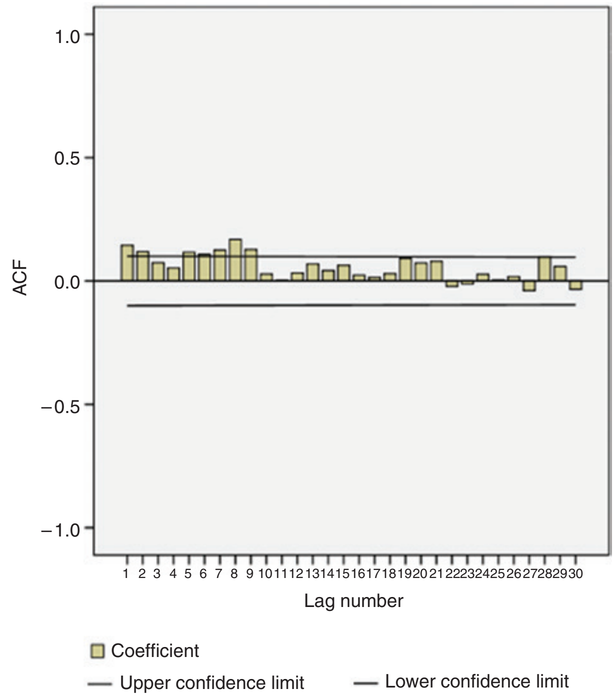

Figure 2: Autocorrelation at different lags for 5 lag days.
The Y axis indicates the value of correlation and X axis indicates the number of lags. The spike at lag 1 indicates a positive correlation between each series and the preceding value (r = 0.144). All the autocorrelations were statistically significant (p < 0.0001).

We then entered single pollutant into the regression to study the effects of each pollutant on the day of admission and the previous 5 days (i.e. at lag 0, 1, 2, 3, 4 and 5). This was done to account for potential delays in disease incidence after important exposures (Figures 3 and 4). On

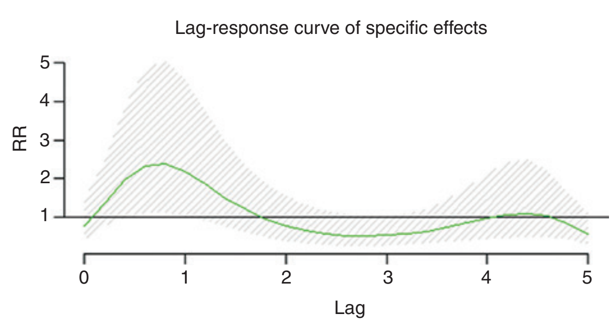

Figure 3: Relationship between NO_2 and asthma hospital admissions along 5 lag days in Bangalore.
ACF, autocorrelation function; RR, relative risk on Y axis, lag of 5 days on X axis.

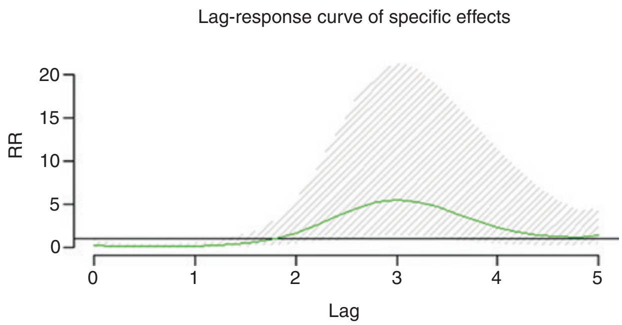

Figure 4: Relationship between PM_{10} and asthma hospital admissions along the lag days in Bangalore.
ACF, autocorrelation function; RR, relative risk on Y axis, lag of 5 days on X axis.

analysis of the results of the single pollutant analysis for asthma admission up to 5 lag days, the parameters that had a lag effect were rainfall on Day 1 ($p=0.0027$) and Day 2 ($p=0.0371$), NO_2 on Day 1 ($p<0.05$), and average temperature on Day 1 ($p=0.0019$). However, humidity, SO_2, PM_{10} and $PM_{2.5}$ had no lag effects. Further, we carried out the Quasi-poisson regression method (with generalized additive models) to analyze the lag effect of various meteorological and air pollution parameters on asthma exacerbations. In this multi-pollutant model analysis, NO_2 had an effect on lag Day 2 ($p=0.0049$), Day 3 ($p=0.0049$), Day 4 ($p=0.0077$) and Day 5 ($p=0.0112$); PM_{10} on all 5 lag days (1st day P : 0.0405; 2nd day P : 0.0382; 3rd day P : 0.0146; 4th day P : 0.0226; 5th day P : 0.0379), $PM_{2.5}$ on Day 1 ($p=0.0139$) and rainfall on Day 1 ($p=0.0024$).

Discussion

This study represents one of first few time series studies on health effects of air pollution and meteorological variables reported in Bangalore, the fifth metropolitan city in India. The study period was short (1 year) but the mean daily admissions for asthma and related illnesses were quite large (mean = 4.84). Bangalore climate is known to be pleasant throughout the year, but since the past two decades, the city has become over-populated. This has led to increased pollution and its adverse health effects. In this study, we attempted to find the relation between air pollution and meteorological variables with the asthma exacerbations occurring in the city. For this, we adopted time series analysis methodology. However, this study can be approached in two ways. Using cross-sectional population studies, it has been shown that asthmatics are severely affected on days and areas with high levels of pollutants [24–26]. However, the drawback of such studies is the difficulty in diagnosis of asthma in susceptible populations. In order to avoid this, time series studies were started [27].

In the present study, we found significant and positive associations between air pollution and respiratory morbidity in the form of asthma admissions. We observed a seasonal variation in the number of asthma admissions in Bangalore, as a significant difference existed between the observed and the expected asthma admissions. The percentage of patients was highest during monsoon. On study of the correlation between the pollutants and the environmental factors, increased auto-correlation was observed similar to other studies. However, the degree of correlation between parameters varies across studies. Some degree of co-linearity was found between NO_2 and PM_{10} through the whole year and during warmer seasons of the year [28]. Pollutants were inversely correlated with humidity and temperature in a study by Farhat et al. [29], whereas in our study we observed a shift in this association when the climate shifted from warm to cold or vice versa. However, in that study, data was collected from a single tertiary care center. It has been frequently shown that air pollution or the weather conditions have an adverse effect on children [29, 30]. We excluded children from this study because they frequently present with wheeze and dyspnea even for non-asthmatic conditions. One of the important observations in this study is that average temperature and NO_2 were the two factors that affected asthma admissions.

It is a proven fact that hot and cold climates stress the body. In order to maintain a constant temperature, different homeostatic mechanisms are activated. Cold temperatures cause acute exacerbations of asthma, whereas warm temperatures are associated with higher asthma prevalence, due to increased exposure to allergens and pollutants [31, 32]. Studies have shown that temperature can not only affect hospital admissions on that day but on several subsequent days (lag effect) [28, 29]. In this study, we observed that the numbers of admissions were higher during the colder seasons of the year and that average temperature had a significant 1 day lag effect. Further average temperature was negatively correlated with the number of admissions, similar to previous studies [33, 34]. Similarly, rainfall has shown to increase asthma incidence in previous studies [35, 36]. Rainfall had a statistically significant lag effect for a day.

Air pollutants induce inflammation via elastase predominant pathways and oxidative stress and cause airway mucosal damage and impair mucociliary clearance. They increase the release of immunoglobulin E causing airway sensitization [31, 32]. NO_2 can irritate the lungs to cause bronchitis and pneumonia, and lowers resistance to infections such as influenza. It may also cause pulmonary edema on long term, continuous exposure. The main sources of NO_2 include traffic related sources and stationery fuel combustion from electrical utilities and industrial boilers. It was shown that for a 1 day lag in change in NO_2 levels, asthma admissions increased by 10.7% [28], and for 2 days, it was 31.4% [29]. The more soluble gas SO_2 produces upper respiratory irritation (may not show a lag in exposure and response), whereas NO_2 being less soluble produces a cumulative lag effect, as it produces lung inflammation [37]. NO_2 has been highlighted as the single pollutant related to asthma admissions [29, 38]. The contribution of NO_2 to exacerbations of asthma has been explained as an effect that primes the circulating eosinophils, impairs action of alveolar macrophages and enhances the eosinophilic activity in sputum in response to inhaled allergen. This is postulated to be an important mechanism by which air pollutants amplify the inflammatory reactions in the airways [39–41]. In this study, we saw that NO_2 was positively correlated with the maximum temperature and particulate matter, but negatively with rainfall. However, the most important effect was that NO_2 had a significant effect for all the 5 days of lag tested. NO_2 curves showed two peaks on lag 0-1 and lag 4 (Figure 3). Few studies have shown a significant association between NO_2 and asthma admissions on the same day [42], 1 day lag [28], 2 days [43], 3 days or long lag patterns [44, 45]. The effect of NO_2 has been shown to be significantly affected by age (children affected higher), gender (males affected more), and season (stronger association during warm season). In one study among boys, NO_2 showed no effect until 3 days of exposure, after which it increased slightly with increasing number of days of exposure averaging up to 6 days of accumulation. In girls, 7 day exposure to NO_2 showed significant effects on asthma hospitalization [46]. Further, urban outdoor levels vary according to the time of day, the season of the year and meteorological factors. There exists diurnally, low background levels of ambient NO_2 levels, superimposed by one or two peaks of higher levels during peak traffic emissions [47]. The concentration (C) of NO_2 has more influence than exposure duration (time, T), when $C \times T$ is constant, and the effect of C was greater with intermittent exposure than with continuous exposure. The temporal pattern of NO_2 effects is complex. To explain, after 2 months of 1-month exposure was ceased, some interstitial changes in lungs were still present. Another study has found that after 5.5 years of exposure, the decrements in pulmonary function persisted for a 2.5-year postexposure period [48]. It is also suggested that the increase in airway resistance by NO_2 may not be like the expected monotonic concentration–response relationship [49]. Thus, a second maximum in relative risk seen in this study may be due to several factors, as explained above.

On testing multi-pollutants, PM_{10} also had a significant lag effect for all 5 days; $PM_{2.5}$ on Day 1 and rainfall on Day 1. PM_{10} and $PM_{2.5}$ are called the cold season pollutants. Even in this study, the levels during warmer and colder seasons were significantly different. The lag effects were similar to previous studies [50, 51]. It is postulated that the PM not only act as an acute trigger (increasing airway inflammation), but also builds up over hours to days increasing bronchial hyper reactivity [52].

Strengths

To the best of our knowledge, this is one among the few studies done in India looking into the acute exacerbations of asthma due to variations in pollutant or weather conditions. This study has specifically included individuals with asthma and asthma related conditions, unlike previous studies that have included chronic obstructive pulmonary disease, and other respiratory conditions. This study throws light on the levels which are harmful to individuals with pre-existing respiratory diseases.

Limitations

We did not include the levels of carbon monoxide, ozone, indoor air quality and pollen levels, as they were not collected by the monitoring centers in Bangalore. Weather changes can cause dissemination of aeroallergens (pollen, mold spores) and increase incidence of asthma. The stratification analysis based on type of asthma was not carried out. As the sampling method was purposive, the final results may not be representative of all the areas and hospitals in Bangalore. As with any ecological study, colinearity issues and time series retrospective design, preclude the identification of the exact underlying pollutant or climatic variable causing the health effects.

Conclusions

Epidemiological studies across the world have given evidence, independently and consistently, for the association between the ambient air quality and meteorological changes on the respiratory system. In Bangalore, it was found that temperature, rainfall, the season, NO_2 and PM levels increased asthma exacerbations in Bangalore. The levels of the pollutants were much higher than the air quality standards set in India. There is thus a high need to implement stricter measures to control air pollutants at source (by means of vehicle policies). Further, early recognition of meteorological changes and intimation to the health officers may help the patients to take necessary preventive measures to control exacerbations.

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