Journal of Asthma

ISSN: 0277-0903 (Print) 1532-4303 (Online) Journal homepage: http://www.tandfonline.com/loi/ijas20

The association of environmental, meteorological, and pollen count variables with asthma-related emergency department visits and hospitalizations in the Bronx

Jonathan Witonsky, Ryan Abraham, Jennifer Toh, Tulsi Desai, Mili Shum, David Rosenstreich & Sunit P. Jariwala

To cite this article: Jonathan Witonsky, Ryan Abraham, Jennifer Toh, Tulsi Desai, Mili Shum, David Rosenstreich & Sunit P. Jariwala (2018): The association of environmental, meteorological, and pollen count variables with asthma-related emergency department visits and hospitalizations in the Bronx, Journal of Asthma, DOI: 10.1080/02770903.2018.1514627

To link to this article: https://doi.org/10.1080/02770903.2018.1514627

View supplementary material

Published online: 12 Sep 2018.

Submit your article to this journal

Article views: 19

View Crossmark data

Full Terms & Conditions of access and use can be found at
http://www.tandfonline.com/action/journalInformation?journalCode=ijas20

JOURNAL OF ASTHMA
https://doi.org/10.1080/02770903.2018.1514627

Taylor & Francis
Taylor & Francis Group

Check for updates

The association of environmental, meteorological, and pollen count variables with asthma-related emergency department visits and hospitalizations in the Bronx

Jonathan Witonsky, MD[a], Ryan Abraham, BA[b], Jennifer Toh, MD[b], Tulsi Desai, BA[b], Mili Shum, MD[b], David Rosenstreich, MD[b], and Sunit P. Jariwala, MD[b]

[a]Department of Pediatrics, University of California, San Francisco, CA, USA; Albert Einstein College of Medicine, Bronx, NY, USA; [b]Division of Allergy/Immunology, Albert Einstein College of Medicine; Bronx, NY, USA

ABSTRACT

Objective: To better understand how meteorological variables, air quality variables, and pollen counts collectively contribute to asthma-related emergency department visits (AREDV) and asthma-related hospitalizations (ARH) among pediatric and adult patients in the New York City borough of the Bronx. *Methods*: The numbers of daily adult and pediatric AREDV and ARH from 2001 to 2008 were obtained from three Bronx hospitals. After removing outliers, interpolating missing data, and standardizing variable values by scaling the data using *z*-scores, data were analyzed using Spearman rank tests and linear regression models for the full year and each season. *Results*: There were a total of 42,065 AREDV and 1,664 ARH at both Bronx hospitals. With the exception of a spring peak in AREDVs, AREDVs and ARHs follow a cyclical pattern, climbing in the fall, plateauing in the winter, dropping in the spring, and reaching a low in the summer. Among the 11 air quality, meteorological, and pollen count variables, temperature and tree pollen made the greatest contribution to AREDV with scaled coefficients of −0.337 and 0.311 respectively; equating to an additional AREDV for every 5.0-unit decrease in temperature and an additional AREDV for every 186.0-unit increase in tree pollen. These two variables were confirmed to have independent associations with AREDV prior to the data interpolation. Grass pollen was also found to have a relatively large contribution to AREDV during the summer with a scaled coefficient of 0.314, equating to an additional AREDV for every 2.3-unit increase in grass pollen. *Conclusion*: There are distinct peaks of increased AREDVs that are closely associated with increased tree pollen counts in the spring and decreasing temperatures in the fall. Early anticipation of these air quality, meteorological, and pollen factor changes based on ongoing surveillance could potentially guide clinical practice and minimize AREDVs in the Bronx.

ARTICLE HISTORY
Received 22 November 2017
Revised 17 August 2018
Accepted 18 August 2018

KEYWORDS
Asthma; emergency department visits; environmental; exacerbations; meteorological; pollen count

Introduction

The New York City borough of the Bronx has one of the highest levels of asthma prevalence and morbidity in the United States [1]. In the Bronx, asthma prevalence is 13.0% [2], far exceeding the national asthma rate of 7.7% [3]. Asthma morbidity, as reflected by asthma-related emergency department visits (AREDV) and asthma-related hospitalizations (ARH), is more than three times higher in the Bronx compared to nationwide [4,5].

The high rates of asthma morbidity in the Bronx can be partially explained by demographic factors. As known risk factors for asthma, demographic characteristics of Bronx residents include lower household incomes, a large African American population, and a large number of Puerto Rican individuals [6,7]. However, these risk factors do not account for the sharp seasonal increases in asthma exacerbations that we previously reported [8,9]. We found that distinct peaks of increased AREDV are associated with fluctuations in air pollutants and pollen counts [8,9]. In the Bronx, outdoor air pollutants, such as nitrogen oxides and sulfur dioxide (SO_2), are associated with increased AREDV during the winter months [8,10]. Additionally, high tree pollen counts in the mid-spring are associated with a concomitant peak in AREDV[9].

CONTACT Sunit P. Jariwala, MD sjariwal@montefiore.org 111 East 210th Street, Bronx, NY 10467, USA.
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ijas.
Supplemental data for this article can be accessed on the publisher's website.
© 2018 Taylor & Francis Group, LLC

Numerous studies have demonstrated associations between air quality and asthma AREDV and ARH [11–25]. Airborne concentrations of pollen have also been repeatedly found to be associated with increases in AREDV and ARH [26–33]. However, there is a paucity of research demonstrating how air quality, meteorological, and pollen count variables are collectively associated with AREDV and ARH [34–37]. In our study, we aim to demonstrate which of these factors correlate with asthma morbidity in the Bronx, the relative weight of each factor, how these factors collectively correlate with AREDV and ARH, and how the correlations vary by season. We therefore tracked daily AREDV and ARH for the Bronx for multiple years (1 January 2001–31 December 2008) and analyzed their association with NO_2, ozone (O_3), particulate matter with a diameter of 2.5 μm or less ($PM_{2.5}$), SO_2, temperature, precipitation, air pressure, humidity, tree pollen, grass pollen, and weed pollen. Moreover, given the peaks in AREDV and ARH, and the seasonal fluctuations in the air quality, meteorological, and pollen count variables, we evaluated associations in adult and pediatric patients for the full year and for the winter, spring, summer, and fall seasons.

Methods

Participants and background

Study participants were males and females of all ages, including pediatric patients (i.e. individuals <18 years old). All individuals were patients requiring AREDV or ARH at three major Bronx hospitals during the specified study period. Adult participants included individuals presenting to the Montefiore Medical Center's Moses and Montefiore Medical Center's Weiler divisions, and pediatric participants included individuals presenting to The Children's Hospital at Montefiore. The three hospitals in this study adequately represent the population of the Bronx with regards to sociodemographic characteristics, race, ethnicity, and asthma morbidity [38]. The data collection period was from 1 January 2001 to 31 December 2008. Only the daily number of asthma-related emergency department visits, asthma-related hospitalizations, and no personally identifiable information were used for our statistical analysis.

Emergency department visits and hospitalizations

We conducted a retrospective search of adult AREDV, pediatric AREDV, and total ARH at the Montefiore-Moses hospital, the Montefiore-Weiler hospital, and The Children's Hospital at Montefiore. Daily adult and pediatric AREDV and daily total ARH were collected using our institution's Clinical Looking Glass analysis software with the primary diagnosis at discharge of asthma (ICD-9 code 493). If an individual study participant had more than one AREDV or ARH within a particular year, we counted all of these visits for that particular year.

Meteorological, air quality, and pollen count data

Meteorological data, including temperature, precipitation, air pressure, and humidity, were obtained from the National Climatic Data Center's Bronx station. The air-quality data were obtained from the Bureau of Air Quality Surveillance of the New York State Department of Environmental Conservation, which has several stations that collect air-quality data. NO_x (which include NO, NO_2, and N_2O) and O_3 data were acquired from the New York City Botanical Garden station in the Bronx, which is situated about 1.5 miles from, and midway between the Weiler hospital and the Moses/Children's hospitals (adjacent buildings). The $PM_{2.5}$ data were obtained from the New York City IS 52 station in the Bronx. The SO_2 data were obtained from the New York City IS 155 station, which is near the Bronx Botanical Garden station. All meteorological data were measured as daily averages.

Daily counts for tree, grass, and weed pollen from 1 March 2001 to 15 October 2008 were obtained from Fordham University's Louis Calder Center Aero-Allergen Monitoring Station in Armonk, NY, 21 miles north of the Montefiore Medical Center in the Bronx. This station is the closest certified pollen counting facility to the Bronx that supplied pollen counts most consistently over the entire 8-year period. Pollen counting at this site was performed using a Burkhard sampler, which yielded a microscopic slide for each day; the center's certified technicians then counted at least one horizontal traverse to calculate particles per cubic meter [39]. Pollen was counted every day, although certain pollen types predominated in certain seasons. In the Bronx, tree pollen is the main pollen type in the spring, grass in the summer, and weeds in the fall.

Statistical methods

Several studies informed our analysis methods, which involved conventional linear regression models and Spearman rank tests to respectively examine for

multivariate and univariate associations between AREDV/ARH and environmental variables [8,9,14,34,37,40]. Prior to performing association analyses, data smoothing procedures including outlier removal were utilized to limit the discovery of spurious associations. Outliers, defined as all air quality and meteorological variable values equal to or above the 98th percentile or equal to or below the 2nd percentile, were removed. For variables with the minimum value of zero—precipitation (inches) and tree, grass, and weed pollen counts—outliers were limited to just those values equal to or above the 98th percentile. Missing meteorological, air quality, and pollen count values were interpolated using an 11-day window moving average (5-days before and after the missing value). To impute an interpolated value, at least one value had to be in the 11-day window. We assessed whether our interpolation method introduced new associations by correlating daily air quality and meteorological values with AREDV and ARH using the Spearman rank test on just non-missing values. Using linear regression models, we examined the effect of meteorological, air quality, and pollen count data on the number of AREDV and ARH. Models included 11 covariates, including NO_2, O_3, $PM_{2.5}$, SO_2, temperature, precipitation, air pressure, humidity, tree pollen, grass pollen, and weed pollen. Variable values were standardized by scaling the data using z-scores in the multiple regression models to allow for comparison of the variables' relative impacts (based on resulting β coefficients). In these analyses, our *a priori* temporal metric for all air quality, meteorological, and pollen count values was a 3-day moving average, including the current day, the previous day, and 2 days prior. Analyses were performed for the adult and pediatric patients separately and combined for the full year and yearly quarters of December-February (winter), March-May (spring), June-August (summer), and September-November (fall). Pollen counts (tree, grass, and weed pollen) were excluded from winter and fall models. All statistical analyses were performed using R, version 3.3.1 (R Foundation for Statistical Computing).

Results

AREDV and ARH

There were a total of 42,065 AREDVs and 1,664 ARHs at the three Bronx hospitals over the 2,922 days from 1 January 2001 to 31 December 2008 (Table I). More than half of AREDVs were pediatric visits ($n = 22{,}717$). Over the full year, the median number of daily ED visits was 13.0 (6.0 adult and 7.0 pediatric AREDVs per day). Over the eight-year period, the winter had more AREDVs ($n = 12{,}968$) with the highest median daily ED visits (16.0) compared to any other season. Similarly, the winter had the most ARH (535). During the summer, AREDVs ($n = 6{,}205$) and ARHs ($n = 338$) were lowest, with the median daily ED visits (8.0) half of the number seen during the winter. As we previously reported, with the exception of a spike in AREDVs that peak in late spring, AREDVs and ARHs follow a cyclical pattern where they climb in the fall, plateau in the winter, drop in the spring, and bottom-out in the summer (Figure 1).

Outlier removal and data interpolation

The original dataset was missing a total of 10,755 observations across the 11 variables (supplementary Table 1a). Missingness ranged from 0% for humidity to 68.9% for weed pollen counts. Tree, grass, and weed pollen counts had the greatest seasonal variation in missingness with as many as 99.6% of observations missing during the winter and as few as 49.3% of observations missing during the summer. Outliers totaled an additional 912 observations across the 11 variables (supplementary Table 1b). The fewest outliers were removed from the pollen count variables (58, or 0.7% of observations, across all 3 variables). Among the meteorological variables, the temperature data had the most outliers (132, or 4.5% of observations). Among the air quality variables, SO_2 data had the most outliers (137, or 4.7% of observations). After removing outliers and applying our data interpolation method, a total of 6,605 observations were imputed across the 11 variables (supplementary Table 1c). Following the interpolation, there were a total 5,084 missing observations, with the majority of those (3,211) being pollen count observations during the fall and winter seasons. Prior to data interpolation, complete case analysis was only possible for 272 days (197 days after removing outliers). After data interpolation, complete case analysis was possible for 1,638 days. To allow for complete case analyses for the fall and winter, pollen count variables were dropped from the multiple regression models for these seasons.

Air quality variables

Among the four air quality variables, O_3 and SO_2 demonstrated the most dramatic seasonal variations. O_3 levels would peak during the summer months and were at their lowest levels during the winter (Figure 2).

Table I. Descriptive statistics for number of daily asthma-related emergency department visits and asthma-related hospitalizations in the Bronx, 2001–2008.

	Total	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum	Standard deviation
AREDV								
Total								
Full Year	42,065	0.0	9.0	13.0	14.4	19.0	53.0	7.7
Winter	12,968	0.0	12.0	16.0	17.6	22.0	46.0	7.7
Spring	11,821	2.0	11.0	15.0	16.2	20.0	53.0	7.9
Summer	6,205	0.0	5.0	8.0	8.5	11.0	30.0	4.5
Fall	11,071	2.0	10.8	15.0	15.2	19.0	42.0	6.7
Adult								
Full Year	19,348	0.0	4.0	6.0	6.6	9.0	28.0	4.0
Winter	5,763	0.0	5.0	7.0	7.8	10.0	23.0	4.1
Spring	5,446	0.0	4.0	7.0	7.5	10.0	28.0	4.4
Summer	3,597	0.0	3.0	4.0	4.9	7.0	18.0	3.2
Fall	4,542	0.0	4.0	6.0	6.2	8.0	21.0	3.6
Pediatric								
Full Year	22,717	0.0	4.0	7.0	7.8	11.0	32.0	5.1
Winter	7,205	0.0	6.0	9.0	9.8	13.0	32.0	5.1
Spring	6,375	0.0	5.0	8.0	8.8	11.0	30.0	4.9
Summer	2,608	0.0	2.0	3.0	3.6	5.0	17.0	2.6
Fall	6,529	0.0	6.0	8.0	9.0	12.0	28.0	4.7
ARH								
Total								
Full Year	1,664	0.0	0.0	0.0	0.6	1.0	10.0	0.8
Winter	535	0.0	0.0	0.0	0.7	1.0	10.0	0.9
Spring	428	0.0	0.0	0.0	0.6	1.0	5.0	0.8
Summer	338	0.0	0.0	0.0	0.5	1.0	10.0	0.8
Fall	363	0.0	0.0	0.0	0.5	1.0	4.0	0.7

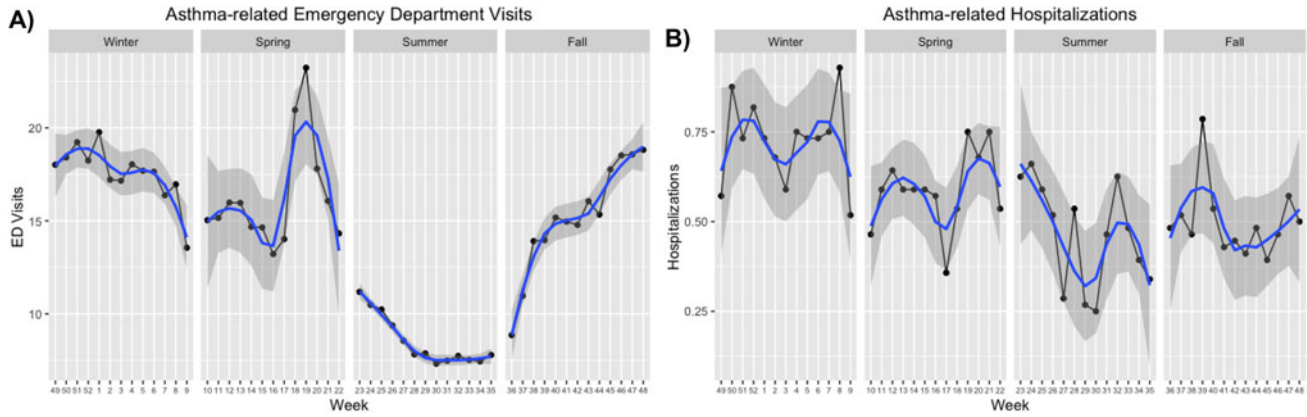

Figure 1. Plots displaying weekly averages in the Bronx, 2011–2008: (A) asthma-related emergency department visits, (B) asthma-related hospitalizations. In blue is the linear model of weekly asthma-related emergency department visits or hospitalizations on week number. The gray band represents the 95% confidence level interval for predictions from that linear model.

Conversely, SO_2 levels were at their lowest levels in the summer and would peak in the winter. NO_2 and $PM_{2.5}$ followed a similar pattern to O_3, peaking during the summer months. The same seasonal variation is observable after removing outliers, interpolating missing data, and applying a 3-day moving average.

Meteorological variables

Temperature was the only meteorological variable that showed seasonality (Figure 3). While there were week-to-week variations in the amount of precipitation and pressure, there were no seasonal trends. Pressure showed the least fluctuations among all 11 variables. Removing outliers, interpolating missing data, and applying a 3-day moving average did not change these seasonal patterns.

Pollen count variables

Pollen counts showed three distinct peaks (Figure 4). Tree pollen counts reached their highest levels in mid-to-late spring. Grass pollen counts were at their highest in late spring and early summer. Weed pollen counts would rise from late spring through summer and peak in late summer and early fall.

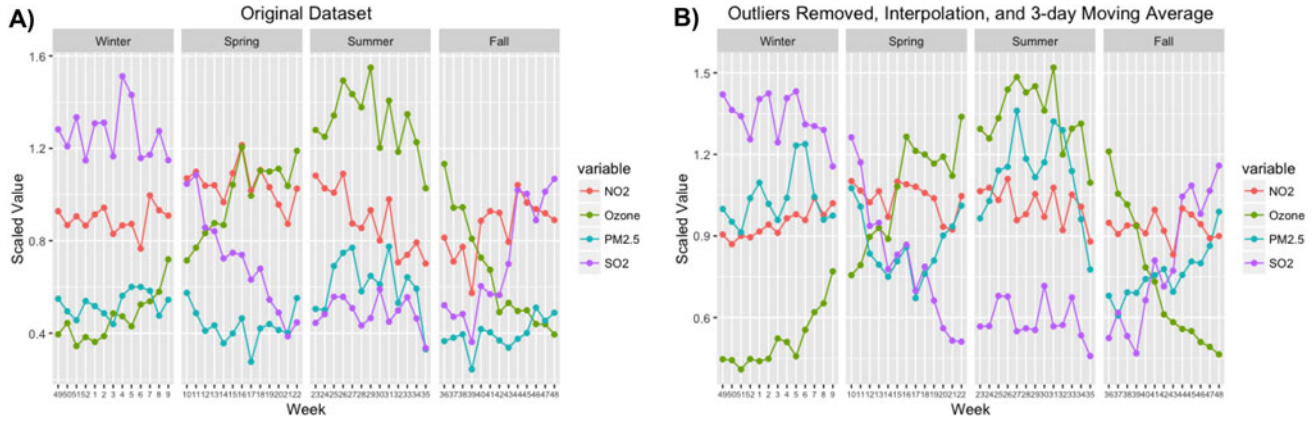

Figure 2. Scaled weekly averages of environmental variables of NO_2, O_3, $PM_{2.5}$, and SO_2 in the Bronx, 2001–2008: (A) from the original dataset, (B) the dataset after outliers were removed, the data interpolation, and a 3-day moving average.

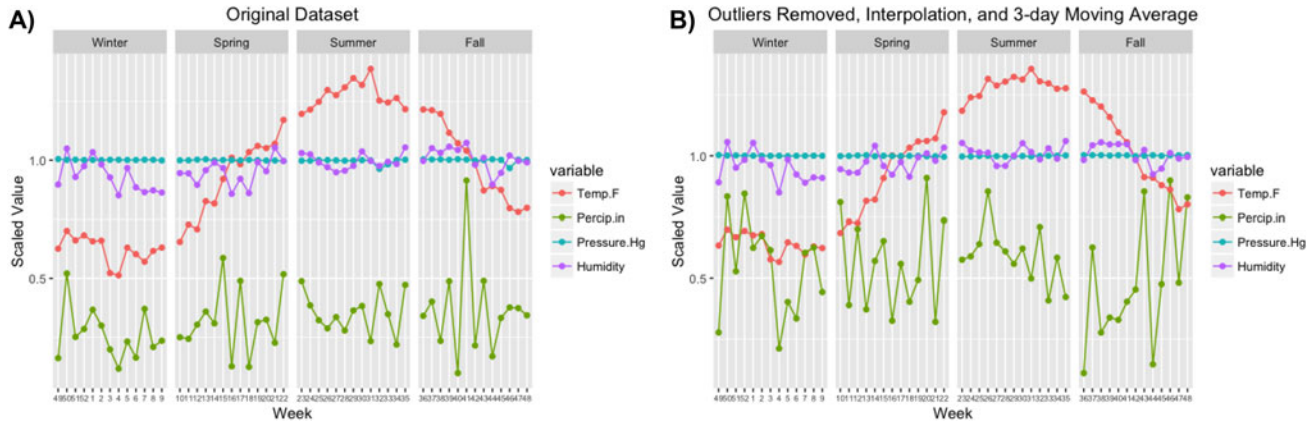

Figure 3. Scaled weekly averages of meteorological variables of temperature (°F), precipitation (inches), pressure (mmHg), and humidity in the Bronx, 2001–2008: (A) from the original dataset, (B) the dataset after outliers were removed, the data interpolation, and a 3-day moving average.

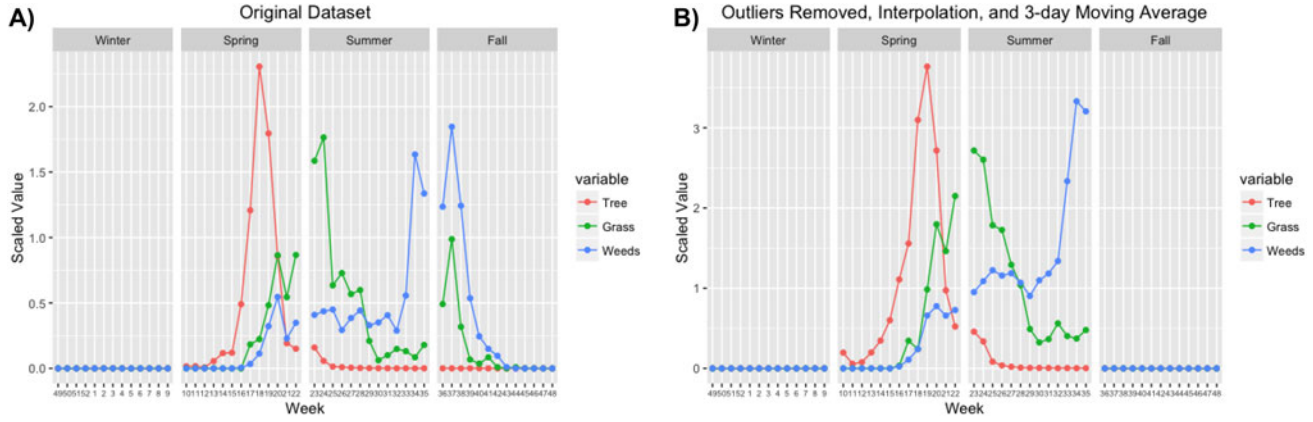

Figure 4. Scaled weekly averages of tree, grass, and weed pollen counts in the Bronx, 2001–2008: (A) from the original dataset, (B) the dataset after outliers were removed, the data interpolation, and a 3-day moving average.

Variables associated with AREDV

Full year

When combining adult and pediatric patients, seven variables showed a significant multivariate ($p < 0.05$) association with AREDV: $PM_{2.5}$, SO_2, temperature, precipitation, humidity, tree pollen, and grass pollen (Table II, Figure 5). Among these, the greatest contributors to AREDV are temperature with a scaled

Table II. Associations between asthma-related emergency department visits and covariates of environmental, meteorological, and pollen count models in the Bronx, 2001–2008.

	NO_2	Ozone	$PM_{2.5}$	SO_2	Temp	Precip	Pressure	Humidity	Tree	Grass	Weeds
Total[a]											
Full Year											
Beta	0.029	0.002	−0.053	0.097	−0.337	−0.118	0.017	0.101	0.311	0.129	−0.001
p-value	0.255	0.948	0.047	0.000	0.000	0.000	0.455	0.000	0.000	0.000	0.975
Winter											
Beta	0.104	−0.240	0.027	−0.033	−0.069	−0.051	−0.082	0.096	—	—	—
p-value	0.018	0.000	0.522	0.503	0.091	0.233	0.028	0.041	—	—	—
Spring											
Beta	−0.081	−0.022	−0.017	0.136	−0.040	−0.086	0.117	0.079	0.268	−0.002	0.186
p-value	0.117	0.689	0.738	0.025	0.551	0.042	0.004	0.098	0.000	0.969	0.000
Summer											
Beta	0.159	0.112	−0.094	0.091	−0.177	−0.141	−0.109	0.123	−0.062	0.314	0.019
p-value	0.000	0.024	0.023	0.023	0.000	0.001	0.003	0.004	0.111	0.000	0.602
Fall											
Beta	0.058	−0.034	0.125	0.124	−0.335	−0.056	0.007	0.110	—	—	—
p-value	0.196	0.525	0.001	0.013	0.000	0.156	0.841	0.016	—	—	—
Adult											
Full Year											
Beta	0.047	0.050	−0.059	0.089	−0.211	−0.089	0.018	0.104	0.240	0.163	−0.026
p-value	0.090	0.134	0.041	0.003	0.000	0.001	0.462	0.000	0.000	0.000	0.357
Winter											
Beta	0.133	−0.186	0.028	−0.027	−0.084	−0.073	−0.129	0.048	—	—	—
p-value	0.003	0.000	0.501	0.587	0.043	0.089	0.001	0.312	—	—	—
Spring											
Beta	−0.021	−0.067	−0.089	0.118	0.048	−0.041	0.138	0.067	0.183	0.043	0.209
p-value	0.680	0.230	0.082	0.051	0.471	0.327	0.001	0.159	0.000	0.432	0.000
Summer											
Beta	0.120	0.154	−0.094	0.062	−0.124	−0.082	−0.062	0.153	−0.122	0.277	−0.029
p-value	0.005	0.003	0.031	0.138	0.014	0.054	0.109	0.001	0.003	0.000	0.452
Fall											
Beta	0.003	0.041	0.074	0.166	−0.158	−0.063	−0.036	0.088	—	—	—
p-value	0.957	0.476	0.075	0.002	0.018	0.143	0.365	0.074	—	—	—
Pediatric											
Full Year											
Beta	0.006	−0.040	−0.033	0.077	−0.351	−0.110	0.011	0.071	0.287	0.064	0.021
p-value	0.817	0.203	0.215	0.006	0.000	0.000	0.617	0.006	0.000	0.008	0.425
Winter											
Beta	0.049	−0.213	0.017	−0.028	−0.037	−0.017	−0.019	0.107	—	—	—
p-value	0.267	0.000	0.679	0.574	0.376	0.687	0.612	0.025	—	—	—
Spring											
Beta	−0.111	0.023	0.051	0.114	−0.105	−0.101	0.066	0.067	0.269	−0.042	0.114
p-value	0.035	0.684	0.330	0.065	0.120	0.019	0.113	0.168	0.000	0.459	0.016
Summer											
Beta	0.132	0.011	−0.051	0.083	−0.158	−0.147	−0.114	0.031	0.037	0.214	0.067
p-value	0.002	0.835	0.240	0.046	0.002	0.001	0.003	0.489	0.359	0.000	0.080
Fall											
Beta	0.081	−0.079	0.122	0.050	−0.357	−0.033	0.037	0.090	—	—	—
p-value	0.072	0.135	0.001	0.310	0.000	0.408	0.303	0.048	—	—	—

[a]Total includes both adult and pediatric patients.
Beta is the value of the scaled coefficient, using z-scores.
Beta values and *p*-values derived using linear regression models.
Bold type indicates a significant association ($p < 0.05$).

coefficient of –0.337 and tree pollen with a scaled coefficient of 0.311. These scaled coefficients equate to an additional AREDV for every 5.0-unit decrease in temperature and an additional AREDV for every 186.0-unit increase in tree pollen. The same seven variables also had a significant multivariate association with AREDV among adults, and all but $PM_{2.5}$ among pediatric patients. Temperature and tree pollen variables had greater multivariate associations with AREDV in pediatric patients than adult patients. In pediatric and adult patients, the scaled coefficients for temperature were –0.351 and –0.211, respectively; for tree pollen scaled coefficients were 0.287 and 0.240, respectively. Among those seven variables, univariate analysis using the original data set (i.e. prior to removing outliers, interpolating missing data, and applying a 3-day moving average) showed six of these seven variables to have significant associations with AREDV: SO_2 (Spearman rho = 0.286, $p < 0.001$), temperature (Spearman rho = –0.427, $p < 0.001$), and tree pollen (Spearman rho = 0.349, $p < 0.001$) (supplementary Table 2a). O_3 had a significant univariate association with AREDV (Spearman rho = –0.354, $p < 0.001$), but was not statistically significant in the multivariate model.

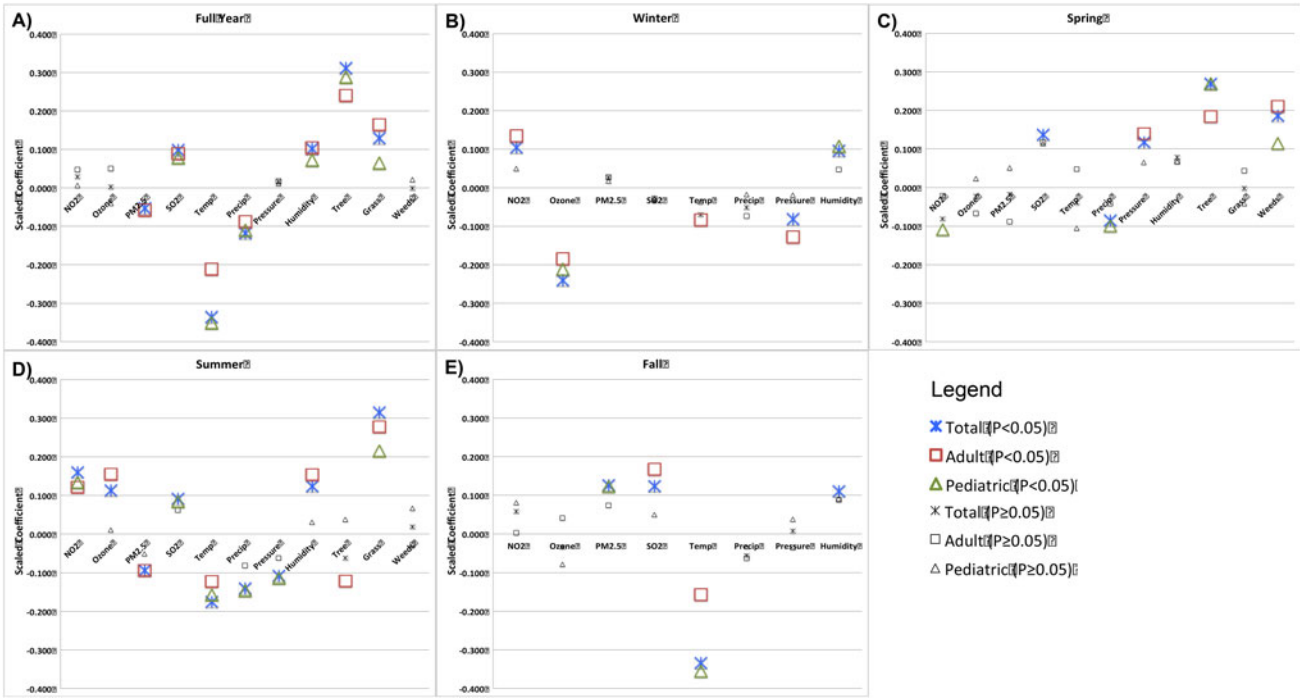

Figure 5. Relative contribution of each variable on total, adult, and pediatric asthma-related emergency department visits, 2001–2008, for the (A) full year, (B) winter, (C) spring, (D) summer, (E) fall. Larger markers in red, blue, and green are for variables with statistically significant ($p < 0.05$) associations with asthma-related emergency department visits. Smaller markers in black are for variables whose associations with asthma-related emergency department visits are not statistically significant ($p \geq 0.05$).

Winter

During the winter, NO_2, O_3, pressure, and humidity are the variables with significant multivariate associations with AREDV when combining adult and pediatric patients (Table II). O_3 is the greatest contributor to AREDV in the winter with a scaled coefficient of –0.240; this equates to an additional AREDV for every 0.003-unit decrease in O_3. O_3 is also the greatest contributor for adult and pediatric patients independently, with scaled coefficients of –0.186 and –0.213, respectively.

Spring

In the multivariate analysis, tree pollen is the greatest significant contributor to AREDV in the spring with a scaled coefficient of 0.268 when combining adult and pediatric patients (Table II); this equates to an additional AREDV for every 271.7-unit increase in tree pollen. Again, the effect is greater in pediatric patients than adult patients with scaled coefficients of 0.269 for pediatric and 0.183 for adult. Other variables associated with AREDV include SO_2, precipitation, pressure, and weed pollen. Weed pollen is the second greatest contributor to AREDV with a scaled coefficient of 0.186.

Summer

All but two of the variables had significant multivariate associations with AREDV during the summer (Table II). When combining adult and pediatric patients, NO_2, O_3, $PM_{2.5}$, SO_2, temperature, precipitation, pressure, humidity, and grass pollen had significant associations with AREDV. Among, these, grass pollen had the largest scaled coefficient of 0.314; this equates to an additional AREDV for every 2.3-unit increase in grass pollen. Grass pollen had a larger scaled coefficient in adult (0.277) than pediatric patients (0.214).

Fall

$PM_{2.5}$, SO_2, temperature, and humidity are the four variables with significant multivariate associations with AREDV during the fall (Table II). Temperature had the largest effect with a scaled coefficient of –0.335; this equates to an additional AREDV for every 4.8-unit decrease in temperature. Temperature is also the only variable that is significant in both pediatric and adult patients with a larger scaled coefficient in pediatric (–0.357) than adult patients (–0.158).

Variables associated with ARH

For the full year, only SO_2, humidity, and grass pollen were shown to have significant multivariate associations with ARH when combining adult and pediatric patients (Table III). All three variables only

Table III. Associations between asthma-related admissions and covariates of environmental, meteorological, and pollen count models in the Bronx, 2001–2008.

	NO_2	Ozone	$PM_{2.5}$	SO_2	Temp	Precip	Pressure	Humidity	Tree	Grass	Weeds
Full Year											
Beta	0.030	−0.065	0.022	**−0.071**	−0.050	0.010	0.019	**−0.093**	0.042	**0.061**	−0.010
p-value	0.310	0.073	0.474	**0.027**	0.200	0.731	0.470	**0.002**	0.112	**0.026**	0.732
Winter											
Beta	−0.053	0.055	−0.034	−0.016	0.072	0.020	−0.067	−0.055	—	—	—
p-value	0.243	0.240	0.429	0.750	0.089	0.652	0.085	0.255	—	—	—
Spring											
Beta	0.010	**−0.143**	−0.010	−0.104	0.072	−0.016	0.079	**−0.120**	−0.002	0.030	−0.013
p-value	0.851	**0.015**	0.853	0.104	0.307	0.720	0.065	**0.017**	0.960	0.602	0.786
Summer											
Beta	−0.047	0.019	0.037	−0.041	−0.036	0.051	−0.007	−0.035	0.085	0.054	0.022
p-value	0.301	0.727	0.427	0.357	0.509	0.266	0.867	0.465	0.052	0.255	0.587
Fall											
Beta	0.059	−0.082	0.011	**−0.156**	0.031	0.026	−0.010	**−0.126**	—	—	—
p-value	0.240	0.164	0.802	**0.005**	0.651	0.562	0.796	**0.013**	—	—	—

Beta is the value of the scaled coefficient, using *z*-scores.
Beta values and *p*-values derived using linear regression models.
Bold type indicates a significant association ($p < 0.05$).

made relatively small contributions ARH with scaled coefficients of −0.071, −0.093, and 0.061 for SO_2, humidity, and grass pollen respectively. Among the three variables, only humidity (Spearman rho = −0.044, $p < 0.02$) had a significant univariate association with ARH in the original dataset (supplementary Table 2b). There were no significant associations with ARH during the winter or summer. During the spring, O_3 and humidity had significant multivariate associations with ARH (Table III). During the fall, SO_2 and humidity had significant multivariate associations with ARH. Humidity was most commonly found to be associated with ARH, with a scaled coefficient as large as −0.126 during the fall.

Discussion

This study examined the multivariate association between air quality, meteorological, and pollen count factors, and asthma-related ED visits and hospitalizations. Our previous study revealed a positive correlation between asthma-related ED visits and increased spring tree pollen levels [9]. During the spring, there is a distinct peak in AREDV at the same time when tree pollen counts are at their annual high. This study reexamines that association when taken together with covariates, including NO_2, O_3, $PM_{2.5}$, SO_2, temperature, precipitation, air pressure, humidity, grass pollen, and weed pollen. We found that, when examined together, other variables also have statistically significant associations with AREDVs, and the associated variables vary by season and patient population. As measured by the scaled coefficients, we also found that temperature had the largest overall association, especially during the fall as falling temperatures seem to correspond with increasing AREDVs. Unlike most variables, which had similar coefficients in both adult and pediatric patients, temperature had a considerably greater association among pediatric patients. Tree pollen was the only other variable to have a noteworthy difference in association size between the two populations, also being greater among pediatric patients. The larger associations in pediatric patients are potentially explained by the smaller size of the airways in this population. Additionally, the larger associations may be related to the greater risk of decompensation among pediatric patients having an asthma exacerbation [41]. Other variables found to have a relatively large and statistically significant association with AREDVs include grass pollen during the summer, O_3 during the winter, and weed pollen during the spring. In terms of ARH there are also variables with statistically significant associations; however, the sizes of these associations are relatively small.

Furthermore, this study illustrates both the relative impact (using scaled coefficients) and the absolute impact of the air quality, meteorological, and pollen count factors that have the greatest and statistically significant contribution to AREDV. In the Bronx and similar urban environments where AREDV far exceed the nationwide average, recognizing how changes in air quality, meteorological, and pollen count factors influence AREDV and ARH can potentially help emergency departments and hospitals prepare for an influx of patients. For example, emergency departments can forecast an additional AREDV for every 5.0-unit decrease in temperature or every 186.0-unit increase in tree pollen. More importantly, early anticipation of environmental changes based on ongoing surveillance could potentially guide clinical

practice and minimize AREDV and ARH. When expecting a temperature drop or an increase in tree pollen, clinicians can notify their most vulnerable patients to ensure appropriate usage of their controller medication.

Associations between asthma exacerbations and air quality, meteorological, and pollen count factors have been previously reported [34–37]. Garty et al. reported correlations between AREDV among children and levels of nitric oxides (NO, NO_2, and N_2O), SO_2, barometric pressure, O_3, and temperature [34]. Other studies have examined pollutants, climate, and allergens independently. In their systematic review and meta-analysis, Zheng et al. found statistically significant associations between asthma-related ED-visits and hospitalizations and six major air pollutants: O_3, carbon monoxide, NO_2, SO_2, and particulate matter [25]. Using multiple linear regression analyses, Hervás et al. showed that asthma exacerbations were independently associated with several meteorological variables: pressure, humidity, temperature, and wind speed [14]. Darrow et al. observed a positive correlation between asthma- and wheeze-related ED visits and *Quercus* tree pollen and Poaceae grass pollen [28]. Similarly, Ito et al. showed that both over-the-counter allergy medication sales and asthma ED visits increase within a few days following an increase in mid-spring pollen levels in New York City [31]. Consistent with our findings, most prior studies found temperature to be negatively correlated with AREDV [11–13,15,19]. As Kim et al. demonstrate, this might be an effect of temperature change in terms of absolute difference of mean temperature between the current day and the previous day; they found the most prominent association during the fall season, with a 17.9% increase in AREDV per 1-unit increase of temperature change [16].

Our study demonstrates that when air quality, meteorological, and pollen factors are examined together, increased springtime tree pollen levels and decreasing fall temperatures are likely the two greatest contributors to peaks in asthma-related ED visits. Our study strength is the use of linear regression models for a broad range of factors with full year and seasonal analyses for both adult and pediatric patients. However, we acknowledge several study limitations. Respiratory infection, a major factor that is involved in asthma exacerbations among pediatric and adult patients, is likely a sizeable confounder during the fall season [42]. Specifically, respiratory infection could explain the large negative association seen for temperature in both pediatric and adult patients. Prior studies have shown a large correlation between the seasonal distribution of respiratory infections and both AREDV and ARH, especially during spring and fall seasons [43,44]. Future studies should aim to correct for this confounder; for example, after a more thorough chart review, patients with respiratory infection as a presumed asthma trigger could be filtered from the analysis.

Our study is limited in that the original dataset was missing a total of 10,755 observations, requiring data interpolation and the removal of the pollen variables for the winter and fall seasons. To ensure our interpolation method did not introduce correlations, univariate analyses were completed using Spearman rank tests. While we did find statistically significant associations following interpolation that were not found in univariate analysis, the size of these associations, as measured by the scaled coefficients, were relatively small. Moreover, the full year analyses are difficult to interpret because there are many different confounding and collinear relationships that differ throughout the seasons. Such a limitation could potentially be addressed using alternative analysis methods such as autoregressive integrated moving average (ARIMA) models or case-crossover analyses.

Our study is also limited in that the data collection period was from 2001 to 2008, potentially not reflecting current-day pollution, weather, and aeroallergen cycles. It could be useful to repeat the analysis with data from the past decade to examine contemporary associations as well as to evaluate for the potential impact of climate change. Finally, our study does not include the personal exposure of individual patients to air quality, meteorological, and pollen count factors. Nor does our study stratify the study population by gender, age, or other demographic factors, preventing further analysis of how air quality, meteorological, and pollen count factors differentially impact specific patient types. Future research is needed to determine how these factors can be used to predict AREDV and ARH. Nevertheless, the data presented here support the hypothesis that multiple factors correlate with asthma morbidity in the Bronx.

Conclusion/Key Messages

In conclusion, this study demonstrates that in the Bronx, there are distinct peaks of increased asthma-related ED visits that are closely associated with increased tree pollen counts in the spring and decreasing temperatures in the fall. Other variables found to have a relatively large and statistically

significant association with AREDVs include grass pollen during the summer, O_3 during the winter, and weed pollen during the spring. While they made relative small contributions, SO_2, humidity, and grass pollen were shown to have significant associations with ARH. Early anticipation of changes in these air quality, meteorological, and pollen count factors based on ongoing surveillance could potentially guide clinical practice and minimize asthma-related ED visits and hospitalizations in the Bronx.

Acknowledgements

None

Declaration of Interest

The authors have no financial, consulting, or personal relationship(s) disclosures to report. No external scientific writing assistance was obtained, and no grant funding has supported this manuscript.

Authors contribution

Jonathan Witonsky participated in the conceptualization and design of the study, data analysis, interpretation of the data, development of the figures and tables, and preparation of the manuscript.

Ryan Abraham participated in the interpretation of the data and preparation of the manuscript.

Jennifer Toh participated in the design of the study, data analysis, and interpretation of the data.

Tulsi Desai participated in the design of the study and data analysis. Mili Shum participated in the design of the study, data analysis, and interpretation of the data. David Rosenstreich participated in the design of the study, data analysis, interpretation of the data, and preparation of the manuscript.

Sunit P. Jariwala participated in the conceptualization and design of the study, data analysis, interpretation of the data, development of the figures and tables, and preparation of the manuscript. All authors approved the final version of the manuscript. None of the authors have conflicts of interest to report.

References

1. Crain EF, Weiss KB, Bijur PE, Hersh M, Westbrook L, Stein RE. An estimate of the prevalence of asthma and wheezing among inner-city children. Pediatrics 1994;94:356–362.
2. The Prevalence and Cost of Asthma in New York State. Comptroller Web site. April 2014. Available from: http://www.osc.state.ny.us/reports/economic/asthma_2014.pdf
3. Centers for Disease Control and Prevention. Most Recent Asthma Data. National Data/State Data. 2014. http://www.cdc.gov/asthma/most_recent_data.htm
4. New York State Asthma Surveillance Summary Report. New York State Department of Health Web site. October 2013. Available from https://www.health.ny.gov/statistics/ny_asthma/pdf/2013_asthma_surveillance_summary_report.pdf
5. Centers for Disease Control and Prevention. National Surveillance of Asthma: United States, 2001–2010. Available from http://www.cdc.gov/nchs/data/series/sr_03/sr03_035.pdf
6. Keet CA, McCormack MC, Pollack CE, Peng RD, McGowan E, Matsui EC. Neighborhood poverty, urban residence, race/ethnicity, and asthma: rethinking the inner-city asthma epidemic. J Allergy Clin Immunol 2015;135:655–662.
7. United States Census Bureau. QuickFacts. 2014. Available from: http://quickfacts.census.gov/qfd/states/36/36005.html
8. Jariwala SP, Kurada S, Moday H, Thanjan A, Bastone L, Khananashvili M, Fodeman J, Hudes G, Rosenstreich D. Association between tree pollen counts and asthma ED visits in a high-density urban center. J Asthma 2011;48:442–8.
9. Jariwala S, Toh J, Shum M, de Vos G, Zou K, Sindher S, Patel P, Geevarghese A, Tavdy A, Rosenstreich D. The association between asthma-related emergency department visits and pollen and mold spore concentrations in the Bronx, 2001–2008. J Asthma 2014;51:79–83.
10. Luttinger D, Wilson L. A study of air pollutants and acute asthma exacerbations in urban areas: status report. Environ Pollut 2003;123:399–402.
11. Abe T, Tokuda Y, Ohde S, Ishimatsu S, Nakamura T, Birrer RB. The relationship of short-term air pollution and weather to ED visits for asthma in Japan. Am J Emerg Med 2009;27:153–159.
12. Gosai A, Salinger J, Dirks K. Climate and respiratory disease in Auckland, New Zealand. Aust N Z J Public Health 2009;33:521–526.
13. Grech V, Balzan M, Asciak RP, Buhagiar A. Seasonal variations in hospital admissions for asthma in Malta. J Asthma 2002;39:263–268.
14. Hervás D, Utrera JF, Hervás-Masip J, Hervás JA, García-Marcos L. Can meteorological factors forecast asthma exacerbation in a paediatric population? Allergol Immunopathol (Madr) 2015;43:32–36.
15. Ivey MA, Simeon DT, Monteil MA. Climatic variables are associated with seasonal acute asthma admissions to accident and emergency room facilities in Trinidad, West Indies. Clin Exp Allergy 2003;33:1526–1530.
16. Kim J, Lim Y, Kim H. Outdoor temperature changes and emergency department visits for asthma in Seoul, Korea: a time-series study. Environ Res 2014;135:15–20.
17. Kloog I, Nordio F, Zanobetti A, Coull BA, Koutrakis P, Schwartz JD. Short term effects of particle exposure on hospital admissions in the Mid-Atlantic states: a population estimate. PLoS One 2014;9:e88578.

18. Malig BJ, Pearson DL, Chang YB, Broadwin R, Basu R, Green RS, Ostro B. A time-stratified case-crossover study of ambient ozone exposure and emergency department visits for specific respiratory diagnoses in California (2005–2008). Environ Health Perspect 2016;124:745–753.
19. Nastos PT, Paliatsos AG, Papadopoulos M, Bakoula C, Priftis KN. The effect of weather variability on pediatric asthma admissions in Athens, Greece. J Asthma 2008;45:59–65.
20. Paulu C, Smith AE. Tracking associations between ambient ozone and asthma-related emergency department visits using case-crossover analysis. J Public Health Manag Pract 2008;14:581–591.
21. Peel JL, Tolbert PE, Klein M, Metzger KB, Flanders WD, Todd K, Mulholland JA, Ryan PB, Frumkin H. Ambient air pollution and respiratory emergency department visits. Epidemiology 2005;16:164–174.
22. Sacks JD, Rappold AG, Davis JA Jr, Richardson DB, Waller AE, Luben TJ. Influence of urbanicity and county characteristics on the association between ozone and asthma emergency department visits in North Carolina. Environ Health Perspect 2014;122: 506–512.
23. Szyszkowicz M, Kousha T, Castner J, Dales R. Air pollution and emergency department visits for respiratory diseases: a multi-city case crossover study. Environ Res 2018;163:263–269.
24. Tétreault LF, Doucet M, Gamache P, Fournier M, Brand A, Kosatsky T, Smargiassi A. Severe and moderate asthma exacerbations in asthmatic children and exposure to ambient air pollutants. Int J Environ Res Public Health 2016;13:771.
25. Zheng XY, Ding H, Jiang LN, Chen SW, Zheng JP, Qiu M, Zhou YX, Chen Q, Guan WJ. Association between air pollutants and asthma emergency room visits and hospital admissions in time series studies: a systematic review and meta-analysis. PLoS One 2015; 10:e0138146.
26. Dales RE, Cakmak S, Judek S, Dann T, Coates F, Brook JR, Burnett RT. Influence of outdoor aeroallergens on hospitalization for asthma in Canada. J Allergy Clin Immunol 2004;113:303–306.
27. Dales RE, Cakmak S, Judek S, Coates F. Tree pollen and hospitalization for asthma in urban Canada. Int Arch Allergy Immunol 2008;146:241–247.
28. Darrow LA, Hess J, Rogers CA, Tolbert PE, Klein M, Sarnat SE. Ambient pollen concentrations and emergency department visits for asthma and wheeze. J Allergy Clin Immunol 2012;130:630–638.
29. Erbas B, Chang J-H, Dharmage S, Ong EK, Hyndman R, Newbigin E, Abramson M. Do levels of airborne grass pollen influence asthma hospital admissions? Clin Exp Allergy 2007;37:1641–1647.
30. Héguy L, Garneau M, Goldberg MS, Raphoz M, Guay F, Valois M-F. Associations between grass and weed pollen and emergency department visits for asthma among children in Montreal. Environ Res 2008;106: 203–211.
31. Ito K, Weinberger KR, Robinson GS, Sheffield PE, Lall R, Mathes R, Ross Z, et al. The associations between daily spring pollen counts, over-the-counter allergy medication sales, and asthma syndrome emergency department visits in New York City, 2002–2012. Environ Health. 2015;14:71.
32. Osborne NJ, Alcock I, Wheeler BW, Hajat S, Sarran C, Clewlow Y, McInnes RN, et al. Pollen exposure and hospitalization due to asthma exacerbations: daily time series in a European city. Int J Biometeorol 2017;61:1837–1848.
33. Tobías A, Galán I, Banegas JR. Non-linear short-term effects of airborne pollen levels with allergenic capacity on asthma emergency room admissions in Madrid, Spain. Clin Exp Allergy 2004;34:871–878.
34. Garty BZ, Kosman E, Ganor E, Berger V, Garty L, Wietzen T, Waisman Y, et al. Emergency room visits of asthmatic children, relation to air pollution, weather, and airborne allergens. Ann Allergy Asthma Immunol 1998;81:563–570.
35. Gleason JA, Bielory L, Fagliano JA. Associations between ozone, PM2.5, and four pollen types on emergency department pediatric asthma events during the warm season in New Jersey: a case-crossover study. Environ Res 2014;132:421–429.
36. Makra L, Puskás J, Matyasovszky I, Csépe Z, Lelovics E, Bálint B, Tusnády G. Weather elements, chemical air pollutants and airborne pollen influencing asthma emergency room visits in Szeged, Hungary: performance of two objective weather classifications. Int J Biometeorol 2015;59:1269–1289.
37. Rossi OV, Kinnula VL, Tienari J, Huhti E. Association of severe asthma attacks with weather, pollen, and air pollutants. Thorax 1993;48:244–248.
38. Montefiore Medical Center Health Center Profile (Health Resources & Services Administration), 2016. Available from https://bphc.hrsa.gov/uds/datacenter.aspx?q=d&state=NY&year=2013&bid=020800
39. Frenz DA. Comparing pollen and spore counts collected with the Rotorod Sampler and Burkard spore trap. Ann Allergy Asthma Immunol 1999;83:341–349.
40. Wargon M, Guidet B, Hoang TD, Hejblum G. A systematic review of models for forecasting the number of emergency department visits. Emerg Med J 2009;26:395–399.
41. Taussig LM, Wright AL, Holberg CJ, Halonen M, Morgan WJ, Martinez FD. Tucson children's respiratory study: 1980 to present. J Allergy Clin Immunol 2003;111:661–675.
42. Dondi A, Calamelli E, Piccinno V, Ricci G, Corsini I, Biagi C, Lanari M. Acute asthma in the pediatric emergency department: infections are the main triggers of exacerbations. Biomed Res Int 2017;2017: 9687061.
43. Busse WW, Lemanske RF, Gern JE. The Role of viral respiratory infections in asthma and asthma exacerbations. Lancet 2010;376:826–834.
44. Johnston SL, Pattemore PK, Sanderson G, Smith S, Campbell MJ, Josephs LK, Cunningham A, Robinson BS, Myint SH, Ward ME, Tyrrell DA, Holgate ST. Relationship between upper respiratory infections and hospital admissions for asthma: a time-trend analysis. Am J Respir Crit Care Med 1996;154:654–660.