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Air Pollutant Levels And Asthma Emergency Room Visits In A Highly Populous US Urban County During 2018-19

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ABSTRACT

Objective: Air pollutants are linked to asthma exacerbation. The study purpose was to demonstrate an association between air pollutants levels and asthma emergency room (ER) visit trends in a highly populated US urban county in Georgia during 2018-2019.

Methods: Time series analyses were conducted for the variations in daily numbers of children and adult asthma emergency room visits and changes in daily mean PM2.5, daily mean PM10 concentrations, daily max 1-hour SO2 concentrations, daily max 1-hour NO2 concentrations, daily max 8-hour ozone concentrations, and airborne pollen loads for 2018 to 2019 and potential trends were estimated by using the autoregressive integrated moving average or ARIMA model.

Results: During 2018-2019, 15,418 asthma-related ER visits occurred. The pollutants NO2, PM2.5, PM10, and pollen were strong predictors of children's asthma ER visits between 2018 and 2019. No significant associations were observed between the levels of SO2, ozone, and children's asthma emergency ER visits.

Conclusions: The findings from this time series study strongly suggest that there is a significant contributing relationship between certain air pollutants (NO2, PM2.5, PM10, and pollen) and asthma ER visits in children.

Keywords: Air pollutants, asthma, ambient air quality, emergency room visit, Fulton County, Georgia.

INTRODUCTION

Asthma is a chronic disease of the airways characterized by periods of reversible airflow obstruction known as episodes or attacks (CDC, 2013). An estimated 39.5 million people (12.9%, including 10.5 million (14.0%) children in the United States have been diagnosed with asthma in their lifetimes (CDC, 2013). The cause of asthma is largely unknown. Researchers have studied how environmental pollutants may play a role in the development and exacerbation of asthma symptoms. Increased air pollution has been associated with increased numbers of asthma-related hospital admissions and emergency room visits (Simoni et al., 2015). However, different air pollutants may play different roles in aggravating asthma attacks and associated ER visits.

PM2.5 (particulate matter smaller than 2.5 microns in aerodynamic diameter – less than one-hundredth of the width of a human hair) is linked to many health problems, from increased asthma attacks to hospital visits (Orellano et al., 2017). PM10 has been shown to positively impact asthma in outpatient and emergency settings (Chan et al., 2009). Contributing sources of particulate matter include traffic and transportation, electricity generation, and combustion processes (Orellano et al., 2017, Falcon-Rodriguez et al., 2016).

Sulfur dioxide (SO2) is a colorless gas with a pungent odor (CDC, 2021). Sulfur dioxide in the air comes mainly from industrial processes (Orellano et al., 2017, Guarnieri and Balmes, 2014).

Ozone (O3) is a colorless blue gas with a pungent odor (CDC, 2019). Ozone is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC) when pollutants are emitted by cars, power plants, industrial boilers, refineries, chemical plants, and other sources chemically react in the presence of sunlight (EPA, 2021a). Short-term exposure to ozone is strongly associated with an increased risk of respiratory disease and economic losses (Zhang et al., 2021).

Nitrogen dioxide (NO2) is one of a group of highly reactive gasses known as oxides of nitrogen (EPA, 2021c). Fossil fuel is a source of NO2 (Orellano et al., 2017, Masiol et al., 2014) Ozone, NO2, SO2, and aeroallergens were independently or interactively related to asthma symptoms in epidemiologic and laboratory studies (Botturi et al., 2011).

Pollen grains are the male microgametophytes of flowering plants including trees and grasses (CDC, 2020). Pollen
disrupts the immune system in both patients with underlying allergies as well as in healthy individuals (Gills et al., 2020).

Particulate matter (PM) contains immunogenic substances which are linked to the worsening of asthmatic symptoms (Yu et al., 2020). SO\(_2\) can induce bronchospasms in asthmatic patients (Yu et al., 2020, Pierangeli et al., 2020, Zheng et al., 2015, Cai et al., 2008). There is evidence that ozone exposure can induce airway inflammation and airway hyperresponsiveness, leading to lung function impairment and asthma attacks (Yu et al., 2020, Delfino et al., 2014). NO\(_2\) might trigger bronchial inflammation (Botturi et al., 2011), high exposure is associated with a reduced bronchodilator effect, worsening lung function, and symptomatic exacerbations of asthma (CDC, 2021, Bowatte et al., 2015). The pathophysiology in asthmatics exposed to pollen involves bronchoconstriction and increased permeability of airway epithelium (Weinbeger et al., 2019, Anenberg et al., 2020).

Investigators have studied the impact of lagged daily effects and moving averages of ambient air pollutants on the incidence of ER visits and asthma mortality. The same day, 2-day lag, and 3-day moving average for Ozone were associated with increased risks for asthma ER visits in Indianapolis (Byers et al., 2015). A similar study showed ozone was positively associated with pediatric asthma ER visits in Newark, New Jersey while there were no associated increased risks for ER visits for PM\(_{2.5}\) (Gleason and Fagliano, 2015). In a study in New York City, the correlation coefficient between annual mean concentrations of ground ozone and the annual rates of asthma emergency visits was found to be negative (Gorai et al., 2014) while a positive correlation coefficient was observed between the annual mean concentration of PM\(_{2.5}\) and SO\(_2\) and annual rates of asthma emergency department visits (Gorai et al., 2014). Young adults showed the most cumulative number of ER visits for asthma attacks (Yu et al., 2020) while SO\(_2\) levels were associated with a decrease in asthma ER visits in children (Gorai et al., 2014). On the other hand, a study in Peru showed short-term exposure to ambient PM\(_{2.5}\) was associated with moderate increases in asthma ER visits in children under 19 years of age and among adults aged 19–64 years (Yu et al., 2021). A study in Atlanta, Georgia, showed that ozone and primary pollutants from traffic sources independently contributed to the burden of emergency department visits for asthmatic children at low ambient concentrations (Strickland et al., 2010).

Meanwhile, in a study in China, children with asthma were found to be more vulnerable to air pollution during the cold season (Chang et al., 2020). In another study, asthma patients were more sensitive to PM\(_{2.5}\) in the cold season with a slightly larger but not significant association during the warm season (Zuo et al., 2019). This was supported by other studies such as a study that reported a larger estimate during the warm (1.21%) compared to the cold (1.12%) season (Tian et al., 2019). A meta-analysis reported a 3.7% increase in the risk of asthma in the warm season (cold season, 2.6%) (Zuo et al., 2019, Fan et al., 2016) supporting this finding. However, in another study, the association of ozone and asthma exacerbations was found to be similar between the warm and cold seasons (Zheng et al., 2015). Further, seasonal effects of ambient air pollution on Asthma ER visits have shown a significant association between ambient air pollutants and Asthma ER visits during the warm season (Byers et al., 2015). In Atlanta, Georgia, ozone was, however, associated with emergency department visits of asthmatic children during both warm and cold months (November, March, and April) (Strickland et al., 2010). Another study from Atlanta area later supported the stronger warm-season’s effect on childhood asthma, where the authors found that increases in all the selected pollutant combinations including ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, and PM\(_{2.5}\) were associated with increases in warm-season pediatric asthma ED visits, when joint effects estimates were considered. ER visits during an increase in PM\(_{2.5}\) led to more asthma ER visits in the warm season than in the cold season (Fan et al., 2015). A 9.24-ppb increase in NO\(_2\) was also found to be associated with an 11.6% increase in the asthma ER visit rate during the month of June (Castner et al., 2018). A significant association was observed between PM\(_{2.5}\) and PM\(_{1.0}\) and asthma ER visits when wildfire smoke was present (Kiser et al., 2020). Tree pollen peaking in mid-spring exhibited substantial impacts on asthma exacerbations, particularly in children with the associations between spring tree pollen on asthma emergency ER visits, with strongest impacts in children aged 5-17 (Kazuhioko et al., 2015).

Thus, existing evidence shows that there are associations between the air pollutants selected in this study and asthma exacerbations. However, the association of each pollutant in relation to asthma ER visits is not completely understood and previous findings are still inconclusive. Seasonal dependency of each of these air pollutants on asthma ER visits were also reported inconsistent in some previous studies as described above.

Therefore, the aim of this study was to explore the association between asthma ER visits and air pollutants including two categories of airborne particulate matter (PM\(_{2.5}\) and PM\(_{1.0}\)), sulfur dioxide (SO\(_2\)), nitrogen dioxide (NO\(_2\)), ozone (O\(_3\)), pollen, and asthma emergency department visit rates among residents in the highly populous Fulton County of Georgia state during the years 2018 to 2019.

**MATERIALS AND METHODS**

The study area in Fulton County is the most populous county in the Georgia state of the U.S., as shown in Figure 1, with a population of 1,066,710 and a population density of 1,748 per square mile (U.S Census Bureau, 2020). Air pollutant data consisted of daily mean PM\(_{2.5}\), daily mean PM\(_{1.0}\) concentration, daily max 1-hour SO\(_2\) concentration, daily max 1-hour NO\(_2\) concentration, daily max 8-hour ozone concentration, and airborne pollen concentration in Fulton County for 2018 and 2019. Data for ozone and pollen concentrations were available from May through December while the data for other pollutants were available from January through December. Air pollutant data were obtained...
from the US Environmental Protection Agency (EPA) Outdoor Air Quality Database, which were recorded in the EPA air monitoring stations at Sandy Springs, Fulton County (EPA, 2021). PM$_{2.5}$ and PM$_{10}$ data were obtained from Sandy Springs monitoring stations with site ID 131210039, at latitude 33.8 and Longitude -84.4. SO$_2$, NO$_2$ and ozone data were obtained from the Sandy Springs monitoring stations with site IDs 131210055, 131210056 and 131210055, respectively at latitude 33.7 and longitude -84.4. Pollen data were also obtained from a monitoring station at Sandy Springs. Data on asthma emergency visits for adults and children were obtained from the Georgia Department of Public Health. The Asthma emergency visits data were collected from January through December 2018 and 2019. The study population included all children aged 0–17 years and adults 18 years and greater who lived in Fulton County, Georgia, who was admitted to the ER with the diagnosis of "asthma" (International Classification of Diseases, Tenth Revision). All patients that met these age groups and diagnosis definitions in Fulton County, were included, hence the study excluded patients who did not meet these inclusion criteria.

Monthly rates of adult and children ER visits were calculated using adult and children population estimates. Rates were per 100,000 individuals. Average concentrations of pollutants for every 15 days were calculated. Descriptive analysis of the air pollutants including the mean, maximum, minimum, and standard deviations were calculated. Time series plots of each of the pollutants and asthma ER visits for adults and children were used to demonstrate trends in the data. The ER visit data for both years were then combined. The ARIMA (Autoregressive integrated moving

**Figure 1**
The study area is Fulton County Georgia

![Map of Fulton County Georgia](map.png)

Map copyright, Google, 2021
average) procedure of Box-Jenkins was used for time series model identification and forecasting of the outcome variables - adult and children ER visits. The seasonality was also accounted for in data analyses. The hypothesis of white noise was accepted for adult asthma ER visits. Six separate models were built in a time series univariate regression of the outcome variable children's asthma ER visit and the air pollutant predictor variables using the MA1 model. The study was approved by the Institutional Review Board of Georgia Southern University (H21406). The Ethics Committee and Institutional Review Board of Georgia Southern University waived the need for informed consent. All analysis was conducted using SAS 9.4 while visualization of time-series plots was enhanced using Python software.

RESULTS

The trend of asthma ER visits of Children and adults is plotted separately for Fulton County, during 2018 and 2019 in Figure 2.

The two series A and B show an upward trend in ER visits for children and adults during winter/early Spring, a downward trend during summer, (May through August) followed by an upward trend in ER visits in late fall/winter.

The annual and monthly emergency ER visits rates of children and adults in Fulton County, during 2018 and 2019 are shown in Table 1.

While there are more ER visits for asthma among children in Fulton County compared to adults, there was a decrease in ER visits for children and an increase in ER visits for adults between 2018 and 2019 as shown in Table 1.

Figure 2

Children and adult emergency ER visits trend in Fulton County, during 2018 and 2019
### Table 1

**Monthly and annual Emergency Room Visit Rates for Fulton County, Georgia**

<table>
<thead>
<tr>
<th>Months</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Children</td>
<td>Adult</td>
</tr>
<tr>
<td>January</td>
<td>12</td>
<td>6.88</td>
</tr>
<tr>
<td>February</td>
<td>18</td>
<td>5.31</td>
</tr>
<tr>
<td>March</td>
<td>25.56</td>
<td>4.1</td>
</tr>
<tr>
<td>April</td>
<td>19.28</td>
<td>6.28</td>
</tr>
<tr>
<td>May</td>
<td>17.56</td>
<td>5.43</td>
</tr>
<tr>
<td>June</td>
<td>5.14</td>
<td>4.22</td>
</tr>
<tr>
<td>July</td>
<td>9.85</td>
<td>4.34</td>
</tr>
<tr>
<td>August</td>
<td>13.71</td>
<td>5.31</td>
</tr>
<tr>
<td>September</td>
<td>9.42</td>
<td>4.59</td>
</tr>
<tr>
<td>October</td>
<td>11.14</td>
<td>4.36</td>
</tr>
<tr>
<td>November</td>
<td>15.42</td>
<td>7.48</td>
</tr>
<tr>
<td>December</td>
<td>6.85</td>
<td>7.72</td>
</tr>
<tr>
<td>Total</td>
<td>1557.1</td>
<td>498.3</td>
</tr>
</tbody>
</table>

**Emergency Room Visit (ER Visit) Rate**

Formula = \[ \frac{\text{Number of ER Visits}}{\text{Population}} \times 100,000 \].

Numerator: GDPH Office of Health Indicators for Planning (OHIP), Asthma ER Visit 2018-2019

Denominator: Census data, 2018 and 2019 children (233437, 236194), and adult (828595, 838382), population estimate

Rates are per 100,000 individuals

Descriptive analysis results for the pollutants are listed in Table 3. The average annual concentration for PM$_{2.5}$ was 10.24 μg/m$^3$ in 2018 and this concentration decreased to 9.59 μg/m$^3$ in 2019. These concentrations were higher than the WHO annual threshold guideline (5 μg/m$^3$) (WHO, 2021) and lower than the current Environmental Protection Agency’s (EPA) primary and secondary annual average standards for PM$_{2.5}$ (12.0 μg/m$^3$ and 15.0 μg/m$^3$ respectively) (EPA, 2021c). PM$_{10}$ average annual concentrations increased from 14.76 μg/m$^3$ in 2018 to 15.53 μg/m$^3$ in 2019. These concentrations were higher than the WHO annual threshold guideline (15 μg/m$^3$). According to the EPA, a 24-hour threshold of 150 μg/m$^3$ should not be exceeded more than once per year for PM$_{10}$. Ozone average annual concentration in 2018 was 0.04 ppm and this level was increased to 0.05 ppm in 2019. These concentrations were both lower than the EPA annual thresholds guideline (0.07 ppm). SO$_2$ average annual concentration in 2018 was 0.41 ppb, which increased to 1.76 ppb in 2019. Based on EPA annual threshold guidelines, a concentration of 0.5 ppm should not be exceeded more than once per year. NO$_2$ average annual concentration was 25.38 ppb in 2018 which was slightly increased to 25.72 ppb in 2019. These concentrations were lower than their EPA annual average standard threshold values (53 ppb). The WHO annual threshold guideline is 10 μg/m$^3$. So, overall, the concentrations of selected air pollutants were below the health-related US and international regulatory standards in most cases.

Pollen’s average annual concentration was 34.97 pollen/m$^3$ in 2018, while in 2019, this was decreased to 21.35 pollen/m$^3$. According to the National Allergy Bureau of the American Academy of Allergy, Asthma, and Immunology standards (AAAAI, 2021), the levels were mostly low to moderate considering the existing standards for the tree, grass, and weed pollen loads in the air.
Table 2

Descriptive statistics of air pollutants in Fulton County, Georgia

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Unit</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2018</td>
<td>2019</td>
<td></td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>µg/m$^3$</td>
<td>23.3</td>
<td>24.5</td>
<td>9.59</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>µg/m$^3$</td>
<td>33.3</td>
<td>30</td>
<td>15.53</td>
</tr>
<tr>
<td>Ozone</td>
<td>ppm</td>
<td>0.08</td>
<td>0.09</td>
<td>0.05</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>ppb</td>
<td>6.6</td>
<td>10.1</td>
<td>1.76</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>ppb</td>
<td>45.5</td>
<td>50.3</td>
<td>25.72</td>
</tr>
<tr>
<td>Pollen</td>
<td>count/m$^3$</td>
<td>201.81</td>
<td>83.45</td>
<td>21.35</td>
</tr>
</tbody>
</table>

Abbreviations: SD, standard deviation; PM$_{2.5}$, particles with aerodynamic diameter ≤ 2.5 µm; PM$_{10}$, particles with aerodynamic diameter ≤ 10 µm; NO$_2$, nitrogen dioxide; SO$_2$, sulfur dioxide; O$_3$, ozone. All pollutants were observed from January to December except pollen and ozone which were observed from May to December.

The trend of the air pollutants in Fulton County, between 2018 and 2019 is plotted separately and displayed in Figures 3, 4, and 5.

Mostly, there is a markedly negative trend effect of the air pollutants in Figures 3, 4 and 5 which shows the air pollutants PM$_{2.5}$, PM$_{10}$, NO$_2$, SO$_2$, ozone and pollen, were increasing first and then decreasing over time (series A to F). Some pollutants showed a similar pattern in 2018 and 2019 (series B); there was an increase in pollen concentrations during the warm months in 2019 compared to 2018 (series F); PM$_{2.5}$ levels (series A), were lower between January and April in 2019 compared to 2018 while NO$_2$ levels (series D) were significantly lower between January and April in 2019 compared to 2018. SO$_2$ and pollen showed a decrease during the warm months (April to August) for both years (series C and F) and corresponded with reduced asthma ER visits during these months in Fulton County.

ARIMA model identification and forecasting for the outcome variables, adult, and children ER visits were positive for children ER visits. No seasonality was detected. The hypothesis of white noise was accepted for adult ER visits. Time-series regression analysis of children's ER visits with air pollutants in 6 separate models showed a statistically significant association between children's asthma ER visits and some air pollutants, “NO$_2$, PM$_{10}$, Pollen, and PM$_{2.5}$,” while “ozone and SO$_2$” were not significant predictors of children's ER visits between 2018 and 2019 as shown in Table 4.
Figure 3
Air pollutant (PM$_{2.5}$ and PM$_{10}$) trend in Fulton County during 2018 and 2019

(A) PM$_{2.5}$ ug m$^{-3}$ for 2018 and 2019

(B) PM$_{10}$ ug m$^{-3}$ for 2018 and 2019
Figure 4
Air pollutant (SO₂ and NO₂) trend in Fulton County during 2018 and 2019
Figure 5
Air pollutant (ozone and pollen) trend in Fulton County during 2018 and 2019

Table 3
Time series regression analysis from separate models for each air quality indicator and children emergency room visits, Atlanta, Georgia, 2018-2019

<table>
<thead>
<tr>
<th>Model</th>
<th>Air pollutant</th>
<th>Unit</th>
<th>Estimate</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NO₂</td>
<td>ppb</td>
<td>0.08</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>2</td>
<td>Ozone</td>
<td>ppm</td>
<td>0.02</td>
<td>0.32</td>
</tr>
<tr>
<td>3</td>
<td>PM₁₀</td>
<td>µg/m³</td>
<td>0.1</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>4</td>
<td>SO₂</td>
<td>ppb</td>
<td>0.02</td>
<td>0.15</td>
</tr>
<tr>
<td>5</td>
<td>Pollen</td>
<td>counts/m³</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>6</td>
<td>PM₂.₅</td>
<td>µg/m³</td>
<td>0.09</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Abbreviations: SD, standard deviation; PM₂.₅, particles with aerodynamic diameter ≤ 2.5 µm; PM₁₀, particles with aerodynamic diameter ≤ 10 µm; NO₂, nitrogen dioxide; SO₂, sulfur dioxide; O₃, ozone. All pollutants were observed from January to December except pollen and ozone which were observed from May to December. Significance used 0.05.
DISCUSSION

We conducted a time series analysis of asthma ER visits in adults and children and air pollutants to predict the impact of air pollution on 15,418 asthmatic subjects. We used time-series plots to demonstrate the trends of air pollutants with ER visits. We observed a downward trend in asthma ER visits in the warmer months and a negative trend in most of the air pollutants in Fulton County over time. We used the ARIMA procedure of Box and Jenkins for time series model identification and forecasting of our outcome variables, which are adult and children asthma ER visits numbers. There was no seasonality observed in our model identification for both outcome variables. We further modeled the outcome variable, children's asthma ER visit with the predictor variables, air pollutants, using the MA1 model. Our time series regression analysis showed a positive association between pediatric asthma ER visit numbers and the air pollutants NO\textsubscript{2}, PM\textsubscript{10}, pollen, and PM\textsubscript{2.5}, when modeled individually.

Previous reports that have investigated the relationship between air pollutants and asthma ER visits in Atlanta Georgia - for example, Winquist et al., (2014) - used a joint effects approach as a method for examining air pollution mixture effects on pediatric asthma ER visits and reported that increases in all the selected pollutant combinations were associated with increases in warm-season pediatric asthma ED visits for the criteria pollutants, such as ozone, CO, SO\textsubscript{2}, NO\textsubscript{2}, and PM\textsubscript{2.5} (Winquist et al., 2014). Significant associations between pediatric ER visits and the air pollutants for NO\textsubscript{2} and PM\textsubscript{2.5} in our study were consistent with the results of the study of Winquist and colleagues (Winquist et al., 2014) although no seasonality effect was detected in our model.

The other pollutants of interest in this study, ozone and SO\textsubscript{2}, did not show a positive association with pediatric asthma ER visits contrary to a previous Atlanta study by Strickland and colleagues (Strickland et al., 2010), which showed ambient concentrations of ozone and primary pollutants from traffic sources independently contributed to the burden of emergency department visits for pediatric asthma in a case crossover time series analysis.

Previous asthma ER visits and pollen study in Atlanta showed the association for Quercus species of pollen was strongest for children aged 5 to 17 years (Darrow et al., 2012). This is corroborating to our findings, which showed a significant association between pollen and children's asthma ER visits, though we have considered all children less than 18 years.

The air pollutant levels analyzed in our study showed that 2018-19 levels of pollutants in Fulton County were mostly below the national ambient air quality standards, but still this is striking that some of them were associated with significant increases in asthma problems in children and were strong predictors of children's asthma ER visits.

This study has a few limitations. We used the air pollution data collected by stationary monitors. These data do not represent actual personal exposures to pollutants for the people who visited the ER on account of asthma and residing away from the monitoring stations. Hence, there is uncertainty about individual exposure levels. Further, data from nearby counties was not obtained. Thirdly, confounding variables such as meteorological factors were not considered.

CONCLUSION

Our study showed significant statistical associations between some of the air pollutants (NO\textsubscript{2}, PM\textsubscript{1.0}, PM\textsubscript{10}, and pollen) and children's asthma ER visits in Fulton County during the observation periods of 2018 and 2019. This study contributes to the body of knowledge that some air pollutants may aggravate asthma ER visits in children. Other risk factors may contribute to seasonal variations in Asthma ER visits.

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DISCLOSURE

The authors declare no conflict of interest.

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