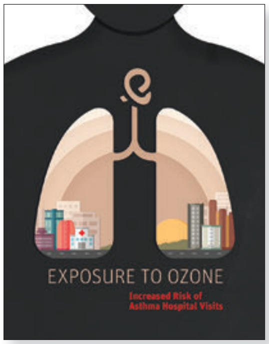

Association Between Asthma Hospital Visits and Ozone Concentration in Maricopa County, Arizona (2007–2012)

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Abstract **The objective of this study was to evaluate the association of asthma hospital visits with ozone concentrations in Maricopa County, Arizona. We used time plots and distributed lag nonlinear models to achieve these objectives while accounting for some potential confounders including temperature and day of the week. A total of 90,381 asthma hospitalizations were retrieved from the dataset (daily median = 39, range: 8–122). Asthma hospitalizations were highest in 2008 (16,949), during the months of November through December, and lowest in 2011 (13,213), during the months of June through July. By contrast, the average daily ozone concentration ranged from 27.05 parts per billion (ppb) in 2012 to 30.15 ppb in 2008 and from 13.96 ppb in December to 40.58 ppb in May. The association between asthma hospitalizations (relative risk [RR/per 10 ppb increase of ozone]) start at ~1.046 (95% confidence interval [1.029, 1.064] at lag 0) and gradually decrease over several days. Our findings suggest exposure to ozone is associated with increased RR of asthma hospital visits in Maricopa County lasting several days. This study used recently developed methods that are freely available and could be used to evaluate other health events that are measured over time.**

Introduction

Asthma is a chronic disease that affects a considerable number of adults and children. It has been a growing public health challenge in industrialized countries for the last few decades where it has reached epidemic levels, despite the introduction of new medications (Eder, Ege, & von Mutius, 2006; Le Moual et al., 2013). While there is a general consensus that, based on available data, the prevalence of asthma has been on the rise in western countries, the underlying causes of this increase are much less clear. On the one hand, it could be partially attributed to the advent of diagnostic tools and improved reporting; on the other hand, the role of air pollution, other environmental factors, genetics, and lifestyle changes cannot be ignored (Ebi & McGregor, 2008; Sheffield, Knowlton, Carr, & Kinney, 2011). Nonetheless, based on available evidence, it is now accepted that air pollution is a risk factor for asthma (Oosterlee, Marjon, Lebret, & Brunekreef, 1996; Venn, Lewis, Cooper, Hubbard, & Britton, 2001). Not only has this effect been found to be statistically significant, the biological mechanism through which exposure to air pollutants exacerbates the severity of asthma symptoms has been explained (Ciencewicki, Trivedi, & Kleeberger, 2008; Gent et al., 2003; Slaughter, Lumley, Sheppard, Koenig, & Shapiro, 2003).

Ozone is one of the pollutants that was found to be associated with increased risk of asthma hospitalizations and deaths in studies worldwide, including in the United States (Babin et al., 2007; Centers for Disease Control and Prevention, 2014; Delfino, Gong, Jr., Linn, Pellizzari, & Hu, 2003; Delfino et al., 2014; Jerrett et al., 2009; Mortimer, Tager, Dockery, Neas, & Redline, 2000). Additionally, ozone was found to be associated with development of new asthma cases in some studies (Künzli et al., 2009; McDonnell, Abbey, Nishino, & Lebowitz, 1999; Modig, Torén, Janson, Jarvholm, & Forsberg, 2009).

Although there is a general consensus in the literature on the adverse effect of ozone on asthma symptoms and hospitalizations (Burnett, Brook, Yung, Dales, & Krewski, 1997), some studies have produced inconclusive or conflicting results. This discordance is not completely unexpected and can be partly explained by differences in study population, designs, and analytic approach (Akinbami, Lynch, Parker, & Woodruff, 2010; Delamater, Finley, & Banerjee, 2012). Several studies have examined the association between asthma hospitalizations and/or emergency department visits in some metropolitan areas including Los Angeles and Seattle because

FIGURE **1**

Geographic Distribution of Location of Ozone Monitors Throughout Maricopa County With Illustration of Thiessen Polygons Used to Identify Ozone Exposure Areas for Each Monitor

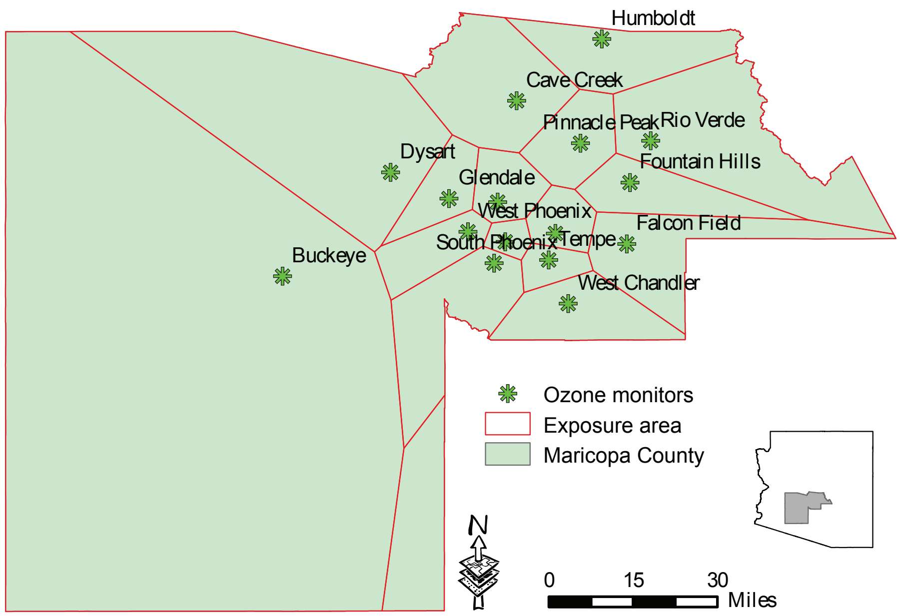
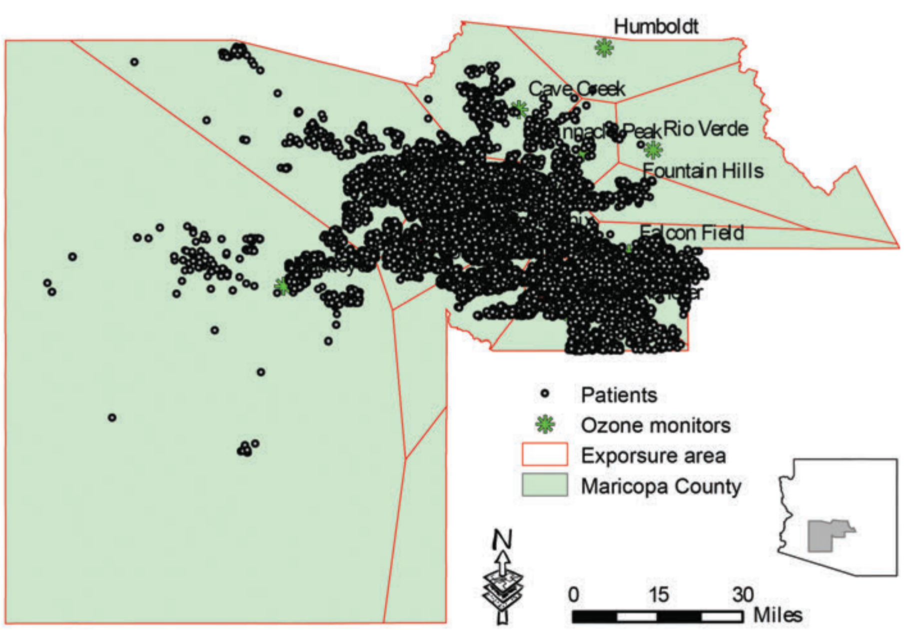


FIGURE **2**

Geographic Distribution of Asthma Patients Visiting Hospitals in Maricopa County (2007–2012)



of the known link between air pollution in highly populated areas and asthma hospital visits and admissions (Akinbami et al., 2010; Delamater et al., 2012).

Maricopa County has grown considerably in the recent decades from less than a million inhabitants to one of the most populous counties in the nation with close to four million residents (U.S. Census Bureau, 2013). This rapid growth probably was accompanied by a comparable increase in traffic volume producing high levels of volatile organic compounds, which are one of the main precursors of ozone (Ebi & McGregor, 2008; Hodnebrog et al., 2012). Consequently, epidemiological studies have found a higher risk of asthma hospitalizations and admissions among those living in close proximity to highways and streets with high traffic volume (Oosterlee, Drijver, Lebret, & Brunekreef, 1996; van Vliet et al., 1997). Given this reality and the fact that the Phoenix metropolitan area is among the most polluted cities in the nation (American Lung Association, 2013), it is important to examine the potential effect of ozone level on hospital visits and admissions among Maricopa County residents.

Therefore, the objective of this study was to evaluate the association between ozone concentration and asthma hospitalization from inpatient hospitalizations and emergency department visits in Maricopa County for the period from January 2007 through December 2012.

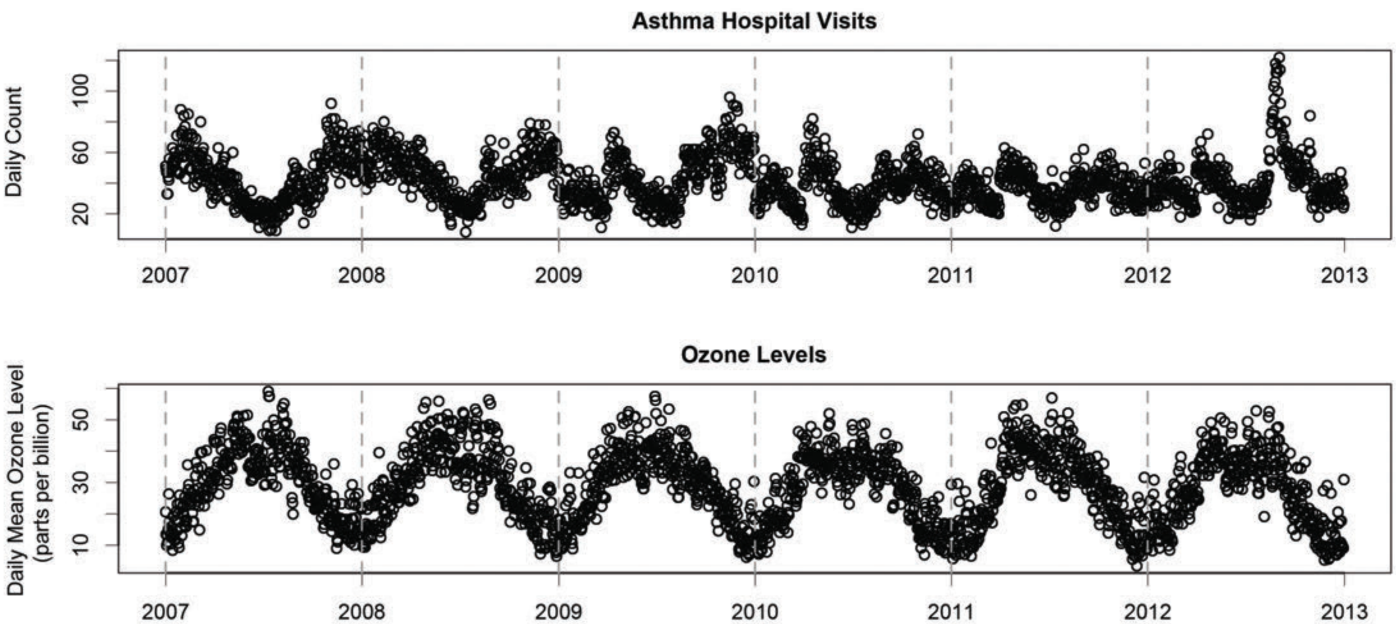
Materials and Methods

Data Sources

Inpatient and emergency department visits occurring in Maricopa County with an asthma diagnosis code (49300, 49301, 49302, 49310, 49311, 49320, 49321, 49322, 49381, 49382, 49390, 49391, and 49392) from January 1, 2007, through December 31, 2012, were extracted from the hospital discharge database accessible to the Maricopa County Department of Public Health. Extracted data include the date of visit (the day of the visit but not the time was available) and the patient's address, which was used to geocode the records. The Maricopa County Air Quality Department provided hourly ozone and temperature measurement from 16 monitoring stations distributed throughout Maricopa County urban and suburban areas (Figure 1).

FIGURE **3**

Time Plots of the Count of Asthmatic Patient Hospital Visits and Ozone Levels in Maricopa County (2007–2012)



Data Management

Thiessen polygons were drawn around each air quality monitoring station to determine the most plausible source of exposure for each individual patient. Thiessen polygons are generated to ensure that any point (an asthma patient) inside the polygon is closer to the polygon center (ozone monitor) than any other polygon center (ozone monitor) in the area. This approach was used to ensure that all patients were assigned an ozone reading from the closest monitor.

Mean daily ozone and temperature measurements were calculated from hourly measurements in preparation to merge them with patient data. Daily measurements were chosen to match the time scale of hospitalization records, which were available only in daily format. Patient data were then divided by location into subsets corresponding to each Thiessen polygon, as previously discussed. Each patient subset was merged with daily ozone and temperature data from the corresponding monitoring station by date, and all subsets were appended together to form the full dataset containing the patient's admission date along with ozone and temperature measurements. Lastly, the total patient daily counts indexed by visit date (days) and the overall daily mean of ozone and temperature measurement were calculated, along with the day of the week, to prepare the dataset for time-series analysis. Hospitalization records and ozone/temperature readings in two exposure areas (Cave Creek and Rio Verde) had very small numbers of asthma visits during the study period and therefore were exclude from the analysis (Figure 2).

Statistical Analysis

We used time plots and the distributed lag linear and nonlinear model (Bhaskaran, Gasparrini, Hajat, Smeeth, & Armstrong, 2013; Gasparrini, 2011) to evaluate the association between asthma hospital visits and ozone levels while accounting for trend, season, temperature, and day of the week. Time plots were used to illustrate the overall pattern over time. The association between the daily number of asthma hospital visits and ozone concentration was evaluated using a Poisson model, taking into account the effect of seasonality, long-term trend, temperature, and day of the week. Also, a lag component was added to the model to evaluate how long the effect of ozone exposure on the number of asthma hospitalizations lasts. Distribution of the model residuals over time was checked for sign of anomalies or indications for deviation from the model assumptions.

Results

A total of 90,381 asthma hospitalizations were retrieved from the dataset (daily median = 39, range: 8–122). Asthma hospitalizations were highest in 2008 (16,949), from November through December, and lowest in 2011 (13,213) and from June through July (Figure 3). By contrast, the average daily ozone concentration ranged from 27.05 parts per billion (ppb) in 2012 to 30.15 ppb in 2008 and from 13.96 ppb in December to 40.58 ppb in May (Figure 3). Additionally, the median number of daily asthma hospitalized visits during weekdays [median = 39; range (16–115)] did not vary considerably from the number of visits during weekends [median = 40; range (14–122)]. Similarly, mean daily ozone concentration ranged from 29.34 ppb on weekdays to 30.09 ppb in weekends (Table 1).

TABLE **1**

Descriptive Statistics

Variable	# of Observations	Mean	Median	*SD*	Minimum	Maximum
Asthma hospitalizations count (per day)	2192	41.23	39	15.37	8	122
Mean daily temperature (°F)	2192	74.05	73.7	15.9	35.11	102.62
Mean daily ozone (ppb[a])	2192	28.67	29.53	11.39	3.37	59.09
Year					2007	2012

[a]ppb = parts per billion.

TABLE **2**

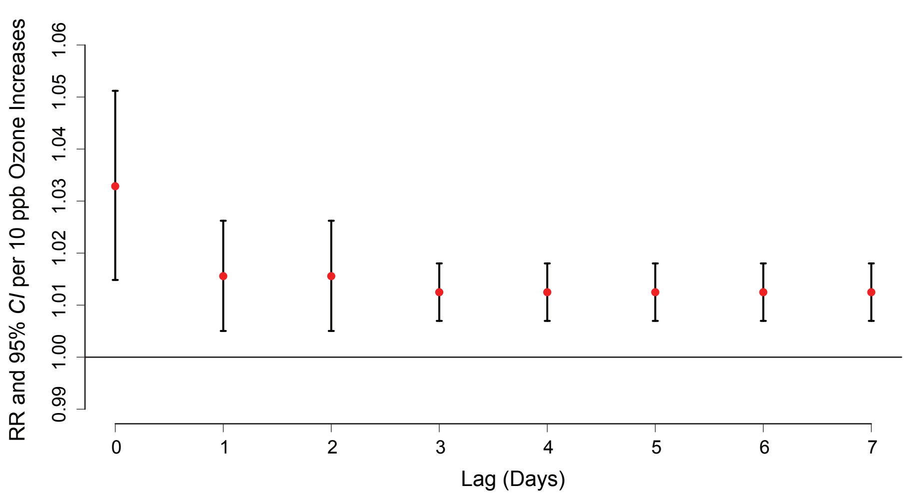
Ozone Coefficients and Relative Risk (RR) for Asthma Hospital Visit Counts Obtained From Poisson Model

Model	Coefficient	*SE*	*z*-Score	*p*-Value	RR	95% *CI*[a]
Model 1[b]	-0.051	0.007	-7.404	<.0001	0.95	0.937, 0.963
Model 2[c]	1.046	0.009	5.107	<.0001	1.047	1.029, 1.065
Model 3[d]	1.045	0.008	5.386	<.0001	1.047	1.029, 1.064

[a]*CI* = confidence interval.
[b]Not adjusted.
[c]Adjusted for trend and seasonality.
[d]Adjusted for trend, seasonality, temperature, and day of the week.

FIGURE **4**

Relative Risk (RR) of Asthma Hospital Visits in Maricopa County for Ozone Lags 1–7



CI = confidence interval; ppb = parts per billion.

The final model was Poisson regression with daily asthma hospitalization count as the dependent variable and ozone as the independent variable adjusted for temperature and day of the week (Table 2). There was a significant association between the daily count of asthma hospitalizations and ozone concentration with a relative risk (RR) of 1.046; 95% confidence interval [1.029, 1.064] or equivalently 4.6% for every 10 ppb increase in ozone level. The ozone effect seemed to decrease gradually after the first day of exposure and level off by lag day 5 (Figure 4).

Discussion and Conclusions

Our findings suggest that ozone level is positively associated with asthma hospital visits and that this effect lasts for several days after the exposure. Our results are in agreement with other studies that reported comparable, but slightly varying, effect size or RR estimates (Barnett et al., 2005; Cakmak, Dales, & Coates, 2012; Fauroux, Sampil, Quenel, & Lemoullec, 2000; Holmen et al., 1997). These variations are not surprising and probably could be due to the differences in study population and statistical modeling methods (Akinbami et al., 2010; Delamater et al., 2012; Mar & Koenig, 2009). For instance, a study conducted in Seattle reported an approximate 10% increase in asthma emergency department visits per 10 ppb increase in ozone, which may seem substantially higher from the estimate (RR = 4.6%) reported here in Maricopa County. A closer look, however, reveals that the Seattle study used data only from May through October, months characterized by high ozone levels, which may explain the higher RR estimates.

Maricopa County has been growing noticeably over the past decades and its ozone concentrations often exceed the national ambient air quality standards (NAAQS). Accordingly, it is important from a public health standpoint to estimate the effect of ozone concentrations on asthma hospital visits. This is the first study, to our knowledge, to evaluate this effect in Maricopa County.

Two of the main challenges in environmental and time-series analysis pertain to the method of exposure assessment and the time scale of the analysis. To increase the validity of the exposure variable and account for geographic variation, we chose to assign individuals to the closest air monitoring station rather than use a countywide average over all stations. We were particularly interested in the lag time from exposure to hospitalization, so we wanted to use a finer time scale than monthly or weekly. Additionally, the hospitalization information did not have time of admission, which prevented us from examining a time scale smaller than daily.

The range of daily average ozone measurements reported in this study was within the acceptable standards set by the U.S. Environmental Protection Agency (U.S. EPA). Data presented here, however, are based on a daily average, which is an aggregation of the hourly recordings. This means that an individual station could have exceeded the U.S. EPA limit at a given hour of the day and that would not be discernable from the data presented here. In fact, there were 12 high ozone days (8-hour maximum ozone >75 ppb) in the Phoenix metropolitan area in 2012 alone.

Similarly, the daily number of asthma hospital visits probably varied by admission type, age groups, and other demographic characteristics not considered here. It has been reported, however, that for asthma and respiratory disease, children are more sensitive to ozone concentrations compared with adults (Delfino et al., 2014; Künzli et al., 2009; Oosterlee et al., 1996) and were probably affected disproportionately (Mar & Koenig, 2009). Day of the week did not have any considerable effect on the asthma RR, indicating that ozone's persistence in the ambient environment does not—in general—vary by different day of the week over our study area. This is supported by known temporal dynamics of ozone, which tends to follow a diurnal pattern within urban areas, even on weekends, and a more constant pattern in suburban and rural areas (Gregg, Jones, & Daws, 2003; Seinfeld & Pandis, 2006).

Currently, the NAAQS list ozone concentrations higher than 75 ppb in an 8-hour average as unhealthy for sensitive groups. According to some advocate groups, however, the current standards need to be reviewed and updated (American Lung Association, 2013); this review is currently in progress by the U.S. EPA in accordance with requirements in the 1990 Amendment to the Clean Air Act (U.S. EPA, 1990).

Future areas for research include examining the number of high ozone days as well as the magnitude of ozone levels and their impact on asthma hospital visits among the local population. As with other hospital discharge data, it should be acknowledged that some asthmatic patients might not seek treatment at hospitals depending on the severity of their conditions and the influence of socioeconomic factors on healthcare access. Consequently, the actual number of people with asthma as well as the magnitude of symptoms experienced in Maricopa County is probably higher than reported here.

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