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Ambient $PM_{2.5}$ exposure during pregnancy and the risk of preterm delivery in Georgia, 1999 to 2006

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Abstract

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By Meilin Huang

Health effects of air pollution from vehicular emissions and other combustion sources on cardiovascular and respiratory outcomes have been well studied. But the relationship between air pollution and preterm birth is limited (Huynh, Woodruff el at, 2006). In this research, by using the Georgia statewide birth cohort, we investigated whether ambient air pollutant exposure during pregnancy was associated with the risk of preterm delivery. Our study included pregnant mothers in Georgia, whose home address at delivery were less than 5km or 10km from an Air Quality System (AQS) monitor and who conceived between January 1st 1999 and December 31st 2006. Associations between fine particulate matter air pollution ($PM_{2.5}$) and preterm delivery were examined over different gestational exposure windows. Using a discrete-time frame survival model, we first estimated the odds ratio of preterm birth for each exposure window and for each county. We then used a meta-analysis approach to combine county-specific odds ratios to obtain estimated pooled odds ratios for each exposure window in Georgia.

Overall, we did not identify significant associations between gestational $PM_{2.5}$ exposures and the risks of preterm birth. After controlling for race/ethnicity, maternal education, marital status, tobacco use during pregnancy, Medicaid status, conception date, conception season, maternal age and infant sex, we found that for mothers who lived within a 10-km buffer of an AQS monitor, an interquartile (3.542 $\mu g/m^3$) increase in the cumulative average $PM_{2.5}$ exposure was associated with a 3.4% increase in the risk of preterm birth (95% CI is [0.959, 1.115]); the adjusted odds ratio for the preterm birth per IQR range increase in trimester two average $PM_{2.5}$ exposure was 1.04 (95% CI is [0.988, 1.095]). Additionally, controlling for fine-scale spatial effects in our models did not make a difference in the risk estimates.

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Contents

Introduction

Preterm delivery and fine particulate matter

Preterm birth in humans is defined as a pregnancy less than 37 weeks of gestational age. The cause of preterm birth is unclear, but many factors have been found to be associated with the occurrence of preterm birth, such as young and older maternal age, low maternal weight, low or high parity, previous abortion, smoking, previous stillbirth and early pregnancy bleeding (Meis, Michielutte, et al, 1995). As neonatal intensive care units (NICU) have improved over the last 40 years, earliest gestational age for a preterm infant with at least 50% survival rate is approximately 24 weeks.

$PM_{2.5}$, the particulate matter denotes solid and liquid air pollutants that are 2.5 micrometers in aerodynamic diameter and smaller. It is made up of a number of components, including acids(such as nitrates and sulfates), organic chemicals, metals, soil or dust particles, and allergens (such as fragments of pollen or mold spores). According to the Environmental Protection Agency (EPA), there is a significant association between exposure to fine particles and premature death from heart or lung diseases. Fine particles can also aggravate heart and lung diseases and have been linked to effects such as: cardiovascular symptoms, cardiac arrhythmias, heart attacks, respiratory symptoms, asthma attacks, and bronchitis. People with heart or lung disease, older adults, and children may be particularly sensitive to fine particle exposure.

Problem Statement

Health effects of air pollution from vehicular emissions and other combustion sources related to cardiovascular and respiratory outcomes have been well studied, but research on the relationship between air pollution and preterm birth is limited (Mary Huynh, Tracy Woodruff, 2006). In the sections below, by using the Georgia statewide birth cohort, we investigate whether ambient air pollutant exposure during pregnancy was associated with the risk of preterm delivery. $PM_{2.5}$ exposure for pregnant women during different stages of the pregnancy may have different effects on preterm delivery. Thus, we examined different gestational exposure windows in our study.

Analysis will be conducted in two stages. First, controlling for the potential confounders, we will estimate the odds ratios of preterm birth associated with different exposure windows for each county. We will then use meta-analysis to combine county-specific odds ratios to obtain estimated pooled odds ratios for each exposure window.

Significance Statement

Air pollution exposure is ubiquitous and widespread, hence even small observed associations will have significant impacts for public health. This research utilizes a discrete-time frame survival analysis approach to estimate the associations between $PM_{2.5}$ exposure and the risk of preterm across Georgia.

Review of the Literature

Introductory

Low birth weight and preterm birth are well-known strong indicators of infant morbidity and mortality as well as possible increased morbidity in adulthood (Berman, Butler, 2007). In 2005, the prevalence of low birth weight and preterm birth were 8.2% and 12.6% separately in the US; and 43.3% of preterm infants were born with low birth weight and 67% of low birth weight babies were preterm birth (Martin, J.A., Hamilton, B.E, 2007). The annual economic burden of US government in 2005 related to preterm birth was estimated to be more than $26.2 billion ($51,600 per infant). This might be because preterm birth is associated with a wide range of complications, including early adverse effects on the respiratory, gastrointestinal, immunologic and central nervous systems as well as later effects on motor, cognitive, visual, hearing, behavioral, and social-emotional function, and diverse effects on health and growth (Behrman, Butler, 2007).

Over the last 10 years, numerous epidemiologic studies have been conducted and suggested relationships between ambient air pollutants, such as carbon dioxide, nitrogen dioxide, sulfur dioxide, ozone, PM_{10} and $PM_{2.5}$, and pregnancy outcome, including preterm delivery and low birth weight. Past study results varied across pollutants and exposure periods (month, trimester and other period), and often lacked control for conception season and other potential confounders. This makes it difficult to infer the associations between ambient air pollutant and preterm delivery.

Literature Review

In a study in Taiwan (Lin et al., 2001), among 51,700 births from non-industrial and industrial areas, after controlling for several confounders (including maternal age, season, marital status, maternal education, and infant sex), the adjusted odds ratio was significantly higher for preterm delivery in the more polluted area (OR=1.41, 95%CI=1.08-1.82), and women with over 35 years also had higher risk of preterm baby delivery.

A prospective register-based cohort study by Olsson, Mogren and Forsberg (2012) examined deliveries during 1998 to 2006 in Greater Stockholm, Sweden. An association was observed between first trimester ozone exposure (O_3) and preterm birth (OR 1.04, 95%CI 1.01 to 1.08) per 10 μg/m^3 increase in O_3. The results suggested that increasing levels of O_3 at the first trimester gestational window would increase the risk of preterm birth.

A study in Los Angeles, Ritz et al. (2007) highlighted the importance of reducing exposure misclassification when evaluating the effect of traffic-related pollutants that vary spatially. Their results showed that parous women experienced a strong escalated odds for preterm birth at high exposure levels of carbon monoxide during the last 6 weeks of pregnancy (0.59-0.91 ppm carbon monoxide: OR=1.13, 95%CI 1.08 to 2.19) compared with women with their first pregnancies (0.59-0.91 ppm carbon monoxide: OR=0.79, 95% CI 0.55 to 1.11). This suggested that higher exposure during the last 6 weeks of pregnancy may increase the odds of preterm birth. This study utilized a twophase sampling strategy, which may minimize selection or response bias. Yet, the study had low response rate because of inability to find or contact the women randomly selected form birth records.

Adverse social environment is defined as low socioeconomic status (SES) neighborhood, such as places of concentrated poverty, unemployment and dependence on public assistance. The interaction of traffic-related air pollution with economic hardship has also been studied. For example, in Ritz el al (2004), using birth records from 1994 to 1996 in Los Angeles County, California, traffic counts, census data and ambient air pollution measures, showed that in poorer neighborhoods, winter season may increase susceptibility of preterm birth among women. The likelihood for young mothers (maternal age<20 years old) of delivering preterm in the low SES during winter is relatively high (OR=1.4, 95% CI 1.19, 1.64) compared to mothers whose maternal age is between 20 and 30 years old, and the odds for women who delivered at 35 or more years of age in the low SES during winter also had a higher odds (OR=1.65, 95%CI 1.35, 2.02) compared to mothers whose maternal age is between 20 and 30 years old.

Time-series studies assess the association of short-term variation in pollution and health outcomes within the same geographical area. In this way, the population acts as its own control and confounding by long-term changes population characteristics is negligible as they are stable day to day (Michelle Bell, 2004). A potential limitation of previous studies about preterm birth and ambient air pollution is inadequate control for confounding by individual risk factors. Sagiv et al (2005) conducted a time series analysis of air pollution and preterm birth in Pennsylvania to investigate the impact of air pollutants and controlling the influence of individual risk factors that do not vary over short periods of time. Adjusting for temperature, dew point temperature, and day of the week, they found an increased risk for preterm delivery with exposure to average PM_{10} in the 6 weeks before birth (relative risk=1.07, 95% CI 0.98-1.18 per 50 µg/m^3 increase).

Finally, a time-to-event analysis of fine particle air pollution and preterm study was conducted to estimate the association between $PM_{2.5}$ and the risk of preterm birth in North Carolina during 2001 and 2005. The study used a 2-stage discrete-time survival model (Chang et al, 2011). The authors found that an interquartile-range (1.73µg/m^3) increase in cumulative $PM_{2.5}$ exposure was associated with a 6.8% (95% posterior interval: 0.5, 13.6) increase in the risk of preterm birth.

Methodology

The state of Georgia has a population of 9.7 million people and land area of 150, 000km^2. Over half of Georgia's population lives in the 20-county metropolitan Atlanta. Ambient air pollutant monitors are located across Georgia, with the largest number of monitors located in metro Atlanta.

Data resource and management

To explore the relationship of preterm delivery and the air pollutant, our study took advantage of the Georgia birth records between the period 1999-2006. The inclusion criteria were: 1. conception dates during 1999 and 2005; 2. successful geocode (including imputed geocodes by Office of Health and Industry Programs (OHIP)); 3. singleton birth; 4. mother's race/ethnicity of Hispanic, Non-Hispanic black, Non-Hispanic white and Asian; 5. birth weight >400g; 6. mother ages between 15 and 44 years old; and 7. no congenital anomalies.

Our study only included pregnant mothers, whose home addresses at delivery were less than 5km or 10km from an Air Quality System (AQS) monitors. For each pregnancy, we assigned weekly average exposures from conception until birth. Thus, each woman had different weekly exposures across her pregnancy. Given an ongoing pregnancy at week *t*, we examined six gestational windows. Trimester one (T1), the average $PM_{2.5}$ exposure from week 1 to week 13; trimester two (T2), the average $PM_{2.5}$ exposure from week 13 to week 26; trimester three (T3), the average $PM_{2.5}$ exposure from week 27 to current gestational week *t* ; four-week window (W4), the average $PM_{2.5}$ exposure from conception to week 4; six-week window (W6), the average $PM_{2.5}$ exposure from conception to week 6; and total cumulative exposure (Total), the average $PM_{2.5}$ exposure from conception to current gestational week *t*.

Additionally, we will also consider two lagged effects in our model, Lag1 and Lag6. For example, if pregnancy *i* is at week *t*, Lag1 exposure was define as the $PM_{2.5}$ exposure for this pregnancy at pregnant week *t*, and Lag6 exposure was defined as the average $PM_{2.5}$ exposure for this pregnancy between week *t-5* to week *t*. In summary, each pregnancy had the same T1, T2, W4, W6 values at each gestational week, but different values for T3, Lag1, Lag6 and Total for different gestational weeks.

To deal with missing data, missing weekly exposures were filled by using the average of the week before and the week after. We dropped all records with more than two consecutive weeks of missing exposure.

Models and analysis

We examined the demographic information for women's address within a 5 km buffer and a 10 km buffer around a $PM_{2.5}$ monitor separately. We calculated the total number of women, counties and tracts in our dataset, as well as the percentage of preterm birth, and distributions of race/ethnicity, tobacco use, marital status, Medicaid status, and infant sex.

After examining descriptive statistics of our data, we estimated the risk of preterm birth for each demographic variable. We fitted the following logistic regression:

$$\text{Logit P } (Y_i) = \beta_0 + \beta_1(\text{individual\_level covariate}_i),$$

where Y_i is a dichotomous outcome indicating whether or not pregnancy i was preterm; β_1 is the association between the risk of preterm and individual-level covariate, such as maternal education, smoking status, race/ethnicity, Medicaid status, infant sex, and the conception year/season of the mother. We then considered a model where all individual-level covariates entered the model simultaneously.

To estimate the odds ratio associate with $PM_{2.5}$ exposures, we considered the following model:

$$\text{Logit P}(Y_{it}) = \beta_0 + \beta_1(\text{individual\_level covariates}_i) + \delta(X_{it}) + \xi(\text{time}_{it}),$$

where Y_{it} is the dichotomous outcome indicating whether or not pregnancy i was born preterm during gestational week t; β_1 is a vector of effects for the individual-level covariates for pregnancy i; δ is the association of $PM_{2.5}$ exposure during the pregnancy window of interests; X_{it} is the $PM_{2.5}$ exposure for subject i at t week; and ξ represents the effects of temporal trends in preterm birth.

We used three different ways to control for the unmeasured temporal confounders using conception date: (1) treat the season of conception and the year of conception as categorical variables; (2) model conception date using a natural cubic spline with 7 degrees of freedom and treat the season of conception as categorical variables; and (3) model conception date using a natural cubic spline with 28 degrees of freedom.

We also considered controlling for the effects of unmeasured spatial variation on the risk of preterm birth within each county. For example, would women from a specific area in a county have a higher risk of preterm birth? In this case, within specific county, we also controlled for Census tracts in this county as fixed effects in our model.

$$\text{Logit P}(Y_{it}) = \beta_0 + \beta_1(\text{individual level covariates}_i) + \delta(X_{it}) + \xi(\text{time}_{it}) + \gamma(\text{spatial}),$$

where γ is a vector that represents the effects of spatial effects in this model.

Meta-analysis

The above models were fitted separately for each county and separately for the 5 km buffer and 10 km buffer study populations. After obtaining the county-specific risk ratios for each exposure, we used meta-analysis to estimate an overall risk ratio for each exposure: T1, T2, T3, W4, W6, Lag1, Lag6 and cumulative average exposure windows. To better reflect the population exposure associated with the adjusted risk ratio for preterm delivery, we also scaled the risk ratios by the interquartile range of each exposure window.

Results

The analysis included a total of 22 and 33 counties for the 5km and 10km buffers respectively. Table 1 shows some descriptive characteristics of the study populations. The percentage of preterm delivery was about 10%~11%. In the 5km buffer, most of the subjects were non-Hispanic black (49.6%), 69% of the women completed high school or had higher education (30% completed high school and 38.4% completed college or higher education), 5.6% women reported tobacco use during pregnancy, and 28.8% women gave birth when they were over 30 years old. Similar results were shown in the 10km buffer.

Table 2 gives unadjusted odds ratio for preterm delivery in buffer 5 and buffer 10. We found that reported smoking during pregnancy was associated with a large increased the risk of preterm birth delivery (for buffer 5km: OR=1.61, 95%CI 1.50 to 1.73; for buffer 10km OR=1.61, 95%CI 1.54 to 1.69). Non-Hispanic blacks had higher risk of preterm birth compared to Non-Hispanic whites, Hispanics and Asians. Pregnant mothers with education less than 9^{th} grade had a protective effect for preterm delivery. Greater maternal age was associated with decreased risk of preterm birth compared to women younger than 21 years old.

In a multivariate model, the risk for male infants being preterm was slightly higher than female infants (OR=1.068, 95%CI 1.03 to 1.11 for buffer 5km; OR=1.071, 95%CI 1.05 to 1.10 for buffer 10km, Table 3); tobacco use during pregnancy had an strong association for preterm delivery; maternal age older than 30 years old had increased risk of preterm delivery compared to women's maternal age was between 15 to 21(OR=1.13, 95%CI 1.06 to 1.21 for buffer 5km; OR=1.16, 95%CI 1.11 to 1.21 for buffer 10km). After controlling for confounders, Medicaid had a significant protective association on preterm birth (OR=0.911, 95% CI 0.86, 0.96 for buffer 5); education higher than college had a protective association on preterm delivery (OR=0.83, 95%CI 0.76, 0.92); and maternal age over 30 years old was associated with an increased risk of preterm delivery compared to maternal age between 15 to 21 (OR=1.13, 95% CI 1.06, 1.21).

Table 4 gives the interquartile ranges and median values for the exposure metrics of $PM_{2.5}$. We used the average exposure for the entire pregnancy to describe the cumulative exposure. We used the average exposure for our 6 different exposure windows. Variation in exposure measured by interquartile range was lowest for total exposure because of the longer exposure window lengths.

Table 5 and 6 show the statewide adjusted odds ratio estimates and the corresponding 95% confidence intervals for the risk of preterm birth per interquartile-range increase in each of the $PM_{2.5}$ exposures. The AQS burffer5 result utilized only estimates from 17 counties in total, five counties were deleted due to small numbers of birth records. Similarly, the AQS buffer 10 results only included 28 counties. Using Akaike information criterion (AIC)as a model selection criterion, we found the best fitting county-specific models to be those using a natural cubic spline of conception date (7 degrees of freedom) and conception seasons to adjust for unmeasured temporal confounders, and without controlling for space. Under this model, for women who lived within a 5-km buffer of an AQS monitor, an interquartile range (3.341 $\mu g/m^3$) increase in the cumulative average $PM_{2.5}$ exposure was associated with a 9.1% increase in the risk of preterm birth (95% CI is [0.971,1.224]) (Table 5). The odds ratio for the preterm birth per IQR range (4.436 $\mu g/m^3$) increase in trimester two average $PM_{2.5}$ exposure was 1.064 (95% CI is [0.988, 1.145]). An interquartile range (4.607 $\mu g/m^3$) increase in Lag6 $PM_{2.5}$ exposure was associated a 1% higher risk of preterm birth (95% CI is [0.942, 1.082]). For women who lived within a 10-km buffer of an AQS monitor, an interquartile range (3.542 $\mu g/m^3$) increase in the cumulative average $PM_{2.5}$ exposure was associated with a 3.4% increase in the risk of preterm birth (95% CI is [0.959,1.115]) (Table 6). And the adjusted odds ratio for the preterm birth per IQR range in trimester two average $PM_{2.5}$ exposure was 1.04 (95% CI is [0.988, 1.095]). Note that none of these results is significantly significant.

The two different ways to control for spatial effects did not result in considerable differences in the estimated odds ratios. From Table 5 and 6, it appears that controlling for spatial effects led to slightly smaller estimates. For example, in AQS buffer 5, the estimated odds ratio for trimester two average $PM_{2.5}$ exposure controlling for spatial effects was 1.05 (95% CI= 0.976 to 1.129), and the corresponding odds ratio without controlling for spatial effects was 1.04 (95% CI = 0.965 to 1.121), again not statistically significant.

Discussion

This study examined the relationship between ambient $PM_{2.5}$ exposure and the risk of preterm birth in 1999 to 2006 of Georgia. Based on pooled estimates across counties, we found no significant associations for all exposure windows. But from the results, cumulative average, trimester two and Lag 6 $PM_{2.5}$ exposure period seemed to suggest positive associations with preterm delivery. Our results were also controlled for unmeasured spatial and temporal confounders. However, previous studies have indicated potential associations between $PM_{2.5}$ and preterm birth. And future research will examine these differences in more detail.

One limitation of the study is the restriction to only pregnancies within 5 and 10km of a monitor. When estimating county-specific adjusted odds ratios, some counties had small numbesr of birth records such that the gestational age spreads sparsely between week 27 and 36. We removed those counties in our analysis because these counties' models did not converge. This limited the number of counties that we examined.

Further studies could focus on the potential interactions in associations between ambient $PM_{2.5}$ levels and preterm delivery. Additionally, we found interesting relationship between Medicaid status and the risk of preterm delivery. After adjusting for other individual-level covariates, the effect of Medicaid seems to be associated with lower risk of preterm delivery. This could be the result of controlling other confounders, and further examination about how Medicaid status affect the risk of preterm delivery will be of interest in future research.

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Tables

Table1: Descriptive analysis for pregnant women

	AQS Buffer 5	AQS Buffer 10
Number of women	103392	268688
Number of counties	22	33
Number of tracts	375	675
Preterm%	0.113	0.109
Non-Hispanic white%	0.273	0.317
Non-Hispanic black%	0.496	0.453
Hispanic%	0.191	0.187
Asian%	0.040	0.042
Mother's education <9th grade %	0.097	0.089
Mother's education 9th -12th grade %	0.212	0.188
Mother's education is high school or GEP %	0.306	0.296
Mother's education is college or higher%	0.384	0.428
Unmarried status %	0.534	0.481
Male%	0.509	0.508
Tobacco use during pregnancy%	0.056	0.049
Medicaid status %	0.410	0.384
Conception year=1999%	0.120	0.119
Conception year=2000%	0.129	0.128
Conception year=2001%	0.131	0.132
Conception year=2002%	0.151	0.151
Conception year=2003%	0.136	0.150
Conception year=2004%	0.160	0.158
Winter%	0.242	0.246
Spring%	0.241	0.248
Summer%	0.250	0.247
Fall%	0.266	0.259
Maternal age=[15-21]%	0.202	0.184
Maternal age=[21-25]%	0.250	0.230
Maternal age=[25-30]%	0.259	0.260
Maternal age=[30-44]%	0.288	0.324

Abbreviations: GEP: general education group.

Table 2: Unadjusted odds ratio for preterm delivery

	AQS Buffer 5		AQS Buffer10	
	OR	95% CI	OR	95% CI
Tobacco use during pregnancy	1.61	[1.497,1.730]	1.613	[1.537,1.692]

Medicaid	1.023	[0.984,1.064]	1.100	[1.073,1.128]
Married	0.654	[0.628,0.680]	0.652	[0.636,0.668]
First born	0.894	[0.859,0.930]	0.919	[0.897,0.942]
Mother's education				
<9th grade	Reference			
9th grade-12th grade	1.598	[1.478,1.730]	1.511	[1.436,1.591]
High school or GEP	1.429	[1.325,1.543]	1.370	[1.301,1.439]
College or higher	1.108	[1.028,1.196]	1.061	[1.011,1.114]
Mother's conception year				
1999	Reference			
2000	1.062	[0.981,1.150]	1.016	[0.967,1.068]
2001	1.017	[0.938,1.101]	1.003	[0.955,1.054]
2002	1.030	[0.953,1.112]	1.031	[0.983,1.082]
2003	1.089	[1.007,1.178]	1.045	[0.996,1.096]
2004	1.157	[1.074,1.248]	1.117	[1.066,1.171]
2005	1.314	[1.222,1.413]	1.216	[1.162.1.273]
Season of conception				
Fall	Reference			
Winter	0.974	[0.923,1.028]	0.975	[0.942,1.009]
Spring	0.970	[0.919,1.023]	0.987	[0.954,1.021]
Summer	0.962	[0.912,1.015]	0.975	[0.943,1.009]
Maternal age (years old)				
15~21	Reference			
21~25	0.853	[0.806,0.902]	0.874	[0.842,0.906]
25~30	0.777	[0.735,0.822]	0.775	[0.748,0.804]
30~44	0.824	[0.782,0.871]	0.818	[0.790,0.846]
Race/ethnicity				
Non-Hispanic black	Reference			
Non-Hispanic white	0.565	[0.538,0.593]	0.566	[0.550,0.583]
Hispanic	0.531	[0.501,0.561]	0.508	[0.473,0.545]
Asian	0.488	[0.432,0.548]	0.547	[0.528,0.567]
Male	1.064	[1.023,1.105]	1.069	[1.044,1.096]

Table 3: Adjusted odds ratio for preterm delivery

	AQS Buffer 5		AQS Buffer10	
	OR	95% CI	OR	95% CI
Male	1.068	[1.027,1.111]	1.071	[1.046,1.098]
Tobacco use during pragnancy	1.495	[1.384,1.613]	1.515	[1.440,1.593]
Medicaid	0.911	[0.865,0.960]	0.955	[0.925,0.987]
Married	0.839	[0.798,0.882]	0.83	[0.804,0.856]
Firstbon	0.952	[0.911,0.994]	0.979	[0.953,1.007]
Race/ethnicity				
Non-Hispanic black	Reference			

Non-Hispanic white	0.602	[0.569,0.636]	0.608	[0.588,0.629]
Hispanic	0.535	[0.499,0.573]	0.542	[0.519,0.566]
Asian	0.545	[0.482,0.616]	0.567	[0.527,0.611]
Mother's education				
<9th grade		Reference		
9th grade-12th grade	1.074	[0.983,1.174]	1.043	[0.985,1.104]
High school or GEP	0.963	[0.881,1.052]	0.946	[0.894,1.001]
College or higher	0.833	[0.758,0.915]	0.819	[0.771,0.870]
Mother's conception year				
1999		Reference		
2000	1.089	[1.006,1.180]	1.042	[0.991,1.095]
2001	1.084	[1.000,1.175]	1.058	[1.006,1.113]
2002	1.100	[1.017,1.189]	1.099	[1.047,1.154]
2003	1.156	[1.068,1.251]	1.119	[1.066,1.175]
2004	1.168	[1.079,1.263]	1.162	[1.107,1.220]
2005	1.294	[1.196,1.400]	1.253	[1.192,1.317]
Season of conception				
Fall		Reference		
Winter	0.978	[0.927,1.033]	0.971	[0.938,1.005]
Spring	0.971	[0.919,1.025]	0.981	[0.948,1.015]
Summer	0.966	[0.915,1.020]	0.977	[0.945,1.012]
Maternal age (years old)				
15-21		Reference		
21-25	0.930	[0.875,0.988]	0.971	[0.933,1.010]
25-30	0.956	[0.895,1.021]	0.986	[0.945,1.029]
30-44	1.132	[1.056,1.213]	1.162	[1.111,1.214]

Table 4: Interquartile Range (IQR) and Median values ($\mu g/m^3$) for Exposure Metrics in a Study of $PM_{2.5}$ Levels and Risk of Preterm Birth, Georgia, 1999-2006

	AQS Buffer 5		AQS Buffer 10	
Exposure	Median	IQR	Median	IQR
T1	15.808	4.714	15.992	4.925
T2	15.726	4.436	15.913	4.745
T3	15.736	5.048	15.894	5.291
W4	15.680	5.595	15.838	5.595
W6	15.787	5.18	15.948	5.375
Lag1	15.890	4.737	16.008	5.03
Lag6	15.865	4.607	15.941	4.958
Total	16.034	3.341	16.215	3.542

Abbreviations: AQS, Air Quality System; $PM_{2.5}$, particulate matter<2.5 μm in aerodynamic diameter

Table5: Adjusted average odds ratio estimates in AQS buffer 5

Exposure	Space	Odds ratio	Lower 95% CI	Upper 95% CI
Total	none	1.091	0.971	1.224
Total	tract	1.07	0.953	1.202
T1	none	1.003	0.921	1.092
T1	tract	0.987	0.905	1.077
T2	none	1.064	0.988	1.145
T2	tract	1.055	0.978	1.139
T3	none	0.993	0.922	1.07
T3	tract	0.986	0.920	1.057
W4	none	0.967	0.915	1.022
W4	tract	0.962	0.909	1.018
W6	none	0.985	0.922	1.051
W6	tract	0.976	0.913	1.043
Lag1	none	1.006	0.979	1.033
Lag1	tract	1.003	0.977	1.03
Lag6	none	1.01	0.942	1.082
Lag6	tract	1.007	0.944	1.075

These are statewide average odds ratio estimates and 95% confidence intervals for preterm delivery per interquartile-rage increase in different metrics of exposure to particulate matter <2.5 μm in aerodynamic diameter, Georgia, 1999-2006. Temporal control included a natural cubic spline with 7 degree of freedom for the conception date. Space =tract represents the effect of the tract on the risk of preterm delivery; space =none represents the model does not use spatial factor.
Abbreviation: AQS, air quality system. AQS buffer 5: birth to women living within a 5-km radius of an Air Quality System monitor. Seasonc: conception season.

Table 6: Adjusted average odds ratio estimates in AQS buffer 10

Exposure	Space	Odds ratio	Lower 95%CI	Upper 95%CI
Total	none	1.034	0.959	1.115
Total	tract	1.045	0.969	1.128
T1	none	0.995	0.952	1.041
T1	tract	0.997	0.954	1.043
T2	none	1.040	0.988	1.095
T2	tract	1.043	0.993	1.095

T3	none	0.990	0.946	1.037
T3	tract	0.998	0.955	1.042
W4	none	0.994	0.959	1.030
W4	tract	0.995	0.964	1.027
W6	none	0.998	0.957	1.041
W6	tract	0.999	0.961	1.038
Lag1	none	1.002	0.986	1.018
Lag1	tract	1.003	0.987	1.018
Lag6	none	0.992	0.956	1.028
Lag6	tract	0.991	0.957	1.027

These are statewide average odds ratio estimates and 95% confidence intervals for preterm delivery per interquartile-rage increase in different metrics of exposure to particulate matter <2.5 μm in aerodynamic diameter, Georgia, 1999-2006. Temporal control included a natural cubic spline with 7 degree of freedom for the conception date. Space =tract represents the effect of the tract on the risk of preterm delivery; space=none represents the model does not use spatial factor.

Abbreviation: AQS, air quality system. AQS buffer 10: birth to women living within a 10-km radius of an Air Quality System monitor. Seasonc: conception season.

Appendix

Adjusted average odds ratio estimates in AQS buffer 5

Exposure	Time	Space	Odds ratio	Lower 95% CI	Upper 95% CI
Total	year+ seasonc	none	1.062	0.953	1.183
Total	year + seasonc	tract	1.046	0.934	1.172
Total	ns(cdate,7) + seasonc	none	1.091	0.971	1.224
Total	ns(cdate,7) + seasonc)	tract	1.070	0.953	1.202
Total	ns(cdate, 4*7)	none	1.101	0.945	1.283
Total	ns(cdate, 4*7)	tract	1.091	0.923	1.289
T1	year+ season	none	0.998	0.909	1.095
T1	year+ seasonc	tract	0.988	0.897	1.088
T1	ns(cdate,7) + season	none	1.003	0.921	1.092
T1	ns(cdate,7) + seasonc	tract	0.987	0.905	1.077
T1	ns(cdate, 4*7)	none	0.985	0.860	1.128
T1	ns(cdate, 4*7)	tract	0.958	0.830	1.106
T2	year+ seasonc	none	1.050	0.976	1.129
T2	year+ seasonc	tract	1.040	0.965	1.121
T2	ns(cdate,7) + seasonc	none	1.064	0.988	1.145
T2	ns(cdate,7)+ seasonc	tract	1.055	0.978	1.139
T2	ns(cdate, 4*7)	none	1.071	0.950	1.209
T2	ns(cdate, 4*7)	tract	1.038	0.909	1.184
T3	year+ seasonc	none	0.991	0.923	1.063
T3	year+ seasonc	tract	0.988	0.925	1.055
T3	ns(cdate,7) + seasonc	none	0.993	0.922	1.070
T3	ns(cdate,7) + seasonc)	tract	0.986	0.920	1.057
T3	ns(cdate, 4*7)	none	1.005	0.915	1.104
T3	ns(cdate, 4*7)	tract	0.995	0.913	1.085
W4	year+ seasonc	none	0.966	0.913	1.022
W4	year+ seasonc	tract	0.961	0.907	1.018
W4	ns(cdate,7) + seasonc	none	0.967	0.915	1.022
W4	ns(cdate,7) + seasonc	tract	0.962	0.909	1.018
W4	ns(cdate, 4*7)	none	0.972	0.916	1.032
W4	ns(cdate, 4*7)	tract	0.967	0.909	1.028
W6	year+ seasonc	none	0.982	0.918	1.050
W6	year+ seasonc	tract	0.976	0.912	1.045
W6	ns(cdate,7) + seasonc	none	0.985	0.922	1.051
W6	ns(cdate,7) + seasonc	tract	0.976	0.913	1.043
W6	ns(cdate, 4*7)	none	0.994	0.923	1.071
W6	ns(cdate, 4*7)	tract	0.984	0.909	1.066
Lag1	year+ seasonc	none	1.005	0.979	1.032
Lag1	year+ seasonc	tract	1.004	0.977	1.031

Lag1	ns(cdate,7) + seasonc	none	1.006	0.979	1.033
Lag1	ns(cdate,7) + seasonc	tract	1.003	0.977	1.03
Lag1	ns(cdate, 4*7)	none	1.006	0.980	1.033
Lag1	ns(cdate, 4*7)	tract	1.004	0.978	1.031
Lag6	year+ seasonc	none	1.008	0.946	1.074
Lag6	year+ seasonc	tract	1.004	0.946	1.066
Lag6	ns(cdate,7) + seasonc	none	1.010	0.942	1.082
Lag6	ns(cdate,7) + seasonc	tract	1.007	0.944	1.075
Lag6	ns(cdate, 4*7)	none	1.029	0.948	1.116
Lag6	ns(cdate, 4*7)	tract	1.019	0.942	1.102

These are statewide average odds ratio estimates and 95% confidence intervals for preterm delivery per interquartile-rage increase in different metrics of exposure to particulate matter <2.5 μm in aerodynamic diameter, Georgia, 1999-2006. Three different temporal control methods are presented for sensitive analysis. And space=tract represents the effect of the tract on the risk of preterm delivery; space=none represents the model does not use spatial factor. Abbreviation: AQS, air quality system. AQS buffer 5: birth to women living within a 5-km radius of an Air Quality System monitor. ns(cdate,7): using natural cubic spline with 7 degree of freedom for the conception date. ns(cdate,4*7): using natural cubic spline with 28 degree of freedom for the conception date. Seasonc: conception season.

Adjusted average odds ratio estimates in AQS buffer 10

Exposure	Time	Space	Odds ratio	Lower 95%CI	Upper 95%CI
Total	year+ season	none	1.012	0.948	1.080
Total	year+ seasonc	tract	1.021	0.946	1.102
Total	ns(cdate,7) + seasonc	none	1.034	0.959	1.115
Total	ns(cdate,7) + seasonc)	tract	1.045	0.969	1.128
Total	ns(cdate, 4*7)	none	0.981	0.912	1.056
Total	ns(cdate, 4*7)	tract	0.996	0.908	1.093
T1	year+ seasonc	none	0.990	0.943	1.040
T1	year+ seasonc	tract	0.992	0.945	1.041
T1	ns(cdate,7) + seasonc	none	0.995	0.952	1.041
T1	ns(cdate,7) + seasonc	tract	0.997	0.954	1.043
T1	ns(cdate, 4*7)	none	0.951	0.886	1.022
T1	ns(cdate, 4*7)	tract	0.939	0.863	1.022
T2	year+ seasonc	none	1.027	0.974	1.083
T2	year+ seasonc	tract	1.030	0.975	1.088
T2	ns(cdate,7) + seasonc	none	1.040	0.988	1.095
T2	ns(cdate,7)+ seasonc	tract	1.043	0.993	1.095
T2	ns(cdate, 4*7)	none	1.003	0.928	1.084
T2	ns(cdate, 4*7)	tract	1.005	0.921	1.096
T3	year+ seasonc	none	0.991	0.954	1.030

T3	year+ seasonc	tract	0.992	0.954	1.032
T3	ns(cdate,7) + seasonc	none	0.990	0.946	1.037
T3	ns(cdate,7) + seasonc	tract	0.998	0.955	1.042
T3	ns(cdate, 4*7)	none	1.002	0.955	1.051
T3	ns(cdate, 4*7)	tract	1.005	0.954	1.059
W4	year+ seasonc	none	0.994	0.960	1.029
W4	year+ seasonc	tract	0.995	0.964	1.026
W4	ns(cdate,7) + season	none	0.994	0.959	1.030
W4	ns(cdate,7) + seasonc	tract	0.995	0.964	1.027
W4	ns(cdate, 4*7)	none	0.996	0.963	1.030
W4	ns(cdate, 4*7)	tract	0.998	0.966	1.030
W6	year+ seasonc	none	0.994	0.951	1.039
W6	year+ seasonc	tract	0.995	0.954	1.038
W6	ns(cdate,7) + seasonc	none	0.998	0.957	1.041
W6	ns(cdate,7) + seasonc	tract	0.999	0.961	1.038
W6	ns(cdate, 4*7)	none	0.996	0.948	1.046
W6	ns(cdate, 4*7)	tract	0.994	0.947	1.044
Lag1	year+ seasonc	none	1.003	0.987	1.020
Lag1	year+ seasonc	tract	1.003	0.988	1.019
Lag1	ns(cdate,7) + seasonc	none	1.002	0.986	1.018
Lag1	ns(cdate,7) + seasonc	tract	1.003	0.987	1.018
Lag1	ns(cdate, 4*7)	none	1.005	0.989	1.021
Lag1	ns(cdate, 4*7)	tract	1.005	0.990	1.021
Lag6	year+ seasonc	none	0.992	0.961	1.024
Lag6	year+ seasonc	tract	0.992	0.961	1.025
Lag6	ns(cdate,7) + seasonc	none	0.992	0.956	1.028
Lag6	ns(cdate,7) + seasonc	tract	0.991	0.957	1.027
Lag6	ns(cdate, 4*7)	none	0.995	0.957	1.034
Lag6	ns(cdate, 4*7)	tract	0.996	0.957	1.038

These are statewide average odds ratio estimates and 95% confidence intervals for preterm delivery per interquartile-rage increase in different metrics of exposure to particulate matter <2.5 μm in aerodynamic diameter in AQS buffer 10km, Georgia, 1999-2006. Three different temporal control methods are presented for the sensitive analysis. And spatial=tract represents the effect of the tract on the risk of preterm delivery; spatial=none represents the model does not use spatial factor.

Abbreviation: AQS, air quality system. AQS buffer 10: birth to women living within a 10-km radius of an Air Quality System monitor.