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How the relationships between preterm birth and ambient air pollution vary over space: A case study in Georgia, USA using geographically weighted logistic regression

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ABSTRACT

Preterm birth (PTB) is a major cause of infant mortality and morbidity. The relationships between PTB and ambient air pollution have been examined by many previous studies worldwide, but the results vary among different studies, and no general conclusion could be drawn about the relationships. We analyzed 116,112 live and singleton births in year 2000 in Georgia, USA in this cross-sectional study. A spatial statistical method, Geographically Weighted Logistic Regression (GWLR), was employed to model the relationships between PTB and two ambient air pollutants, ozone (O_3) and fine particulate matter ($PM_{2.5}$), with nine individual-level birth and maternal demographic, socioeconomic, behavioral, and lifestyle factors, and three community socioeconomic status (SES) and urbanization variables as covariates. Different from the results calculated from global logistic regression, the results obtained from the GWLR model show that the relationships between PTB and the two pollutants vary over space. Positively significant (a higher risk of PTB is associated with a higher concentration of air pollutant), negatively significant (a lower risk of PTB is associated with a higher concentration of air pollutant), and non-significant relationships between PTB and air pollutants are all discovered in different regions of Georgia, and the varying relationships are strongly related to the varying SES and urbanization level of the communities of the births. PTB is not significantly associated with either O_3 or $PM_{2.5}$ in most of the state, especially in urban communities. The positively significant relationship between PTB and O_3 or $PM_{2.5}$ that indicates either air pollutant might be a significant PTB risk factor is primarily located in rural communities with low SES. These findings suggest that in order to more successfully reduce PTB risk, it is necessary to consider the varying relationships between PTB and air pollution across the communities with different levels of urbanization and SES for making and implementation of local public health policies.

1. Introduction

A preterm birth (PTB) is defined as a birth occurring before 37 completed weeks of gestation. It is a leading cause of infant mortality and morbidity. According to Unites States Centers for Disease Control and Prevention (CDC), there is a higher risk of death or serious disability for PTB babies. In 2013, about 36% of infant deaths were due to preterm-related causes and the PTB babies who survive may have development delay, feeding difficulties, breathing problems, and other health issues (CDC, 2017). PTB is also found to be the primary cause of children death before 5 years of age in a global study. PTB complications were responsible for 0.965 million (15%) of the 6.3 million children who died before 5-year old in 2013 globally (Liu et al., 2015). Therefore, PTB is an important health issue in USA as well as around the world, and it is quite urgent and necessary to make and implement more efficient and effective health policies and preventive initiatives to reduce PTB prevalence rate, which needs a better understanding of its risk factors. The risk factors that have been studied include genetic, maternal illness (e.g. infection and inflammation), maternal socioeconomic and demographic (e.g. education, income, race, and age), maternal behavioral and lifestyle (e.g. smoking, drinking, and exercise), and environmental (e.g. air temperature, pollution) variables (Tu, Tu, & Tedders, 2014; Arroyo, Díaz, Carmona, Ortiz, & Linares, 2016; Frey et al., 2016; Koullali, Oudijk, Nijman, Mol, & Pajkrt, 2016; Mascio, Magro-Malosso, Saccone, Marhefka, & Berghella, 2016; Premkumar, Henry, Moghadassi, Nakagawa, & Norton, 2016; Wallace, Aland, Blatt, Moore, & DeFranco, 2016; Boyle, Rinaldi, Norman, & Stock, 2017; Stayner et al., 2017).

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Air pollution is one of the most frequently studied factors for PTB. An increasing number of studies suggested that PTB might be related to prenatal ambient air pollution exposures, but the findings are not consistent and the causal relationships have not been built (Darrow et al., 2009; Ha et al., 2014). For example, some studies found that higher concentrations of air pollutants were associated with a higher risk of PTB (Kloog, Melly, Ridgway, Coull, & Schwartz, 2012; Ha et al., 2014; Arroyo et al., 2016; Laurent et al., 2016). Ha et al. (2014) examined the effect of maternal trimester-specific exposures to O_3 and $PM_{2.5}$ on PTB in a study of 423,719 singleton births during the period of 2004–2005 in Florida, USA. After the models were adjusted for potential confounders including lifestyle, demographics, and medical variables, they found prenatal exposures to both $PM_{2.5}$ and O_3 in all the three trimesters and the entire pregnancy were significantly positively related to PTB risk (a higher risk of PTB is associated with a higher concentration of air pollutant).

However, many previous studies found non-significant relationships between PTB risk and various air pollutants (Darrow et al., 2009; Gehring et al., 2011; Huang et al., 2015). For example, Darrow et al. (2009) studied over 476 thousand births between 1994 and 2004 in the Atlanta metropolitan area, USA, and did not find significant associations of PTB with air pollutants including $PM_{2.5}$, NO_2, O_3, CO, and SO_2, although some significant positive associations with PTB were found for some pollutants when only the births that were less than 4 miles away from air quality monitoring stations were used in the model.

Moreover, negatively significant associations of PTB risk with prenatal exposures to air pollutants (a lower risk of PTB is associated with a higher concentration of air pollutant) were found in a few studies (Malmqvist et al., 2011; Wilhelm et al., 2011; Trasande, Wong, Roy, Savitz, & Thurston, 2013; Johnson et al., 2016; Stieb et al., 2016). For example, in a Canadian national study of the relationships between birth outcomes and $PM_{2.5}$ on about 3 million births from 1999 to 2008 adjusted for individual maternal variables and neighborhood socioeconomic status (SES), consistent significant negative relationships were discovered between PTB and $PM_{2.5}$ in most exposure periods (Stieb et al., 2016).

The above literature review suggests that the relationships between PTB risk and prenatal exposures to air pollution actually change over space. An air pollutant that is positively related to an increased PTB risk observed in one location might have no significant effect or even a negative relationship with PTB risk in another location. The spatially varying relationships might be due to the differences in statistical methods and models, susceptible windows, air pollution exposure assessment, covariates selection, and underlying mechanisms (Le et al., 2012; Ritz & Wilhelm, 2008). In addition, the spatially varying relationship might be also due to the spatial variation in the chemical compositions of air pollutants that might be affected by the differences in social and natural environment, including pollution types and sources, pollution control policies and technologies, urbanization level, and climate (Darrow et al., 2009; Laurent et al., 2016). Moreover, spatially varying individual-level and contextual community-level factors, including maternal demographic, lifestyle and behavioral factors, prenatal care, neighborhood SES, may either modify exposures or interact with the effect of air pollution on pregnant women and subsequent birth outcomes (e.g. PTB), and so complicate the relationships between air pollution and birth outcomes (Coker et al., 2015; Le et al., 2012; Hajat et al., 2013; Tu, Tu, & Tedders, 2016).

Thus, we can reasonably hypothesize that the relationships between PTB and ambient air pollution change continuously across space. To the best of our knowledge, no reported researches have analyzed the spatially varying relationships between PTB and air pollution. Only a few have compared the relationships between different subunits (e.g. urban or rural, countries) in their study areas (Bertin et al., 2015; Fleischer et al., 2014). In general, an implicit assumption with the study designs adopted to date is that the association between ambient air pollution exposure and PTB does not vary by location. Furthermore, the results from most national studies or studies that cover multiple states of USA represent only the average situation of the whole study area but not possibly varying relationships across different states or regions with different natural and social characteristics. In addition, many previous studies did consider the neighborhood SES as an effect modifier when analyzing the relationships between PTB and air pollution, but no published research has considered it as a geographically varying effect modifier.

Logistic regression was the most commonly used statistical method to analyze the relationships between PTB and air pollution (Gehring et al., 2011; Ha et al., 2014; Kloog et al., 2012). In the logistic regression models of these studies, PTB (yes or no) as a binary variable was the dependent variable, while the independent variables were air pollutants and other confounders, such as individual-level maternal behavioral and lifestyle, demographic, socioeconomic factors, and community-level SES and environmental factors. Such conventional logistic regression belongs to global statistics, which assumes the relationships do not change across space, and so produces results that represent the whole study area (Fotheringham, Brunsdon, & Charlton, 2002). However, the ample evidence from the previous studies suggests that such assumption is unlikely to hold.

Over the last five years, geographically weighted regression (GWR) has been increasingly used to analyze the spatially varying relationships between health outcomes and associated risk factors (Chan, Chiang, Su, Wang, & Liu, 2014; Goovaerts et al., 2015; Tu, Tu, & Tedders, 2012, 2016; Zhang, Wong, So, & Lin, 2012). Geographically weighted logistic regression (GWLR) is a special form of GWR, designed to predict the value of dependent variables that are binary other than continuous. While a global logistic regression model relies on one regression equation for the entire dataset, GWLR, as a local spatial statistical technique, attempts to capture spatially varying relationships by calculating local regression results for each location of the observed cases (BioMedware, 2014). GWR and GWLR were also used to improve the reliabilities of the relationships among variables by taking into account spatial autocorrelations (Tu & Xia, 2008; Stojanova, Ceci, Appice, Malerba, & Džroski, 2013; Tan et al., 2017). To the best of our knowledge, this technique has never been reported to analyze the relationships between PTB and its risk factors including ambient air pollution.

As such, using the State of Georgia, USA as an example, this cross-sectional study aims to (1) compare the associations of PTB with concentrations of O_3 and $PM_{2.5}$ produced by global logistic regression and GWLR; (2) explore how the association of PTB with each air pollutant generated by GWLR vary spatially; and (3) analyze how the spatially varying association of PTB with each air pollutant is affected by the community SES and urbanization level. Our goal is not to analyze the causal relationship between PTB and air pollutants, nor to quantify the change in the risk of PTB responded to certain critical thresholds of air pollutants, but rather to use GWLR as an exploratory tool to examine the general pattern in the spatially varying relationships between the risk of PTB and the levels of air pollution and how the spatial pattern is affected by the community SES and urbanization levels.

2. Data and methods

2.1. Individual-level birth and maternal variables

The data source of the birth and maternal variables is the electronic birth certificate data provided by the Georgia Vital Records Office in Atlanta, the State of Georgia, USA. The study population is all the live and singleton births in year 2000 in Georgia. The original dataset has 155 individual level variables. Gestational age was calculated from the date of last menstrual period; a birth that had less than 37 weeks of gestation was considered as PTB (Hao et al., 2016). PTB (yes or no), the longitude and latitude of maternal residency (already geocoded from maternal addresses), and nine individual-level variables, including